INVESTIGATION OF POSSIBILITIES TO USE FEM MODELLING IN THE PROCESS OF MODERNISATION OF CONTROL NETWORKS FOR CONCRETE DAMS

Janina Zaczek-Peplinska[1], Paweł Popielski[2]
[1])Institute of Applied Geodesy, e-mail: j.peplinska@gik.pw.edu.pl
[2])Institute of Water Supply and Hydraulic Engineering
e-mail: pawel.popielski@is.pw.edu.pl

Warsaw University of Technology
pl. Politechniki 1, 00-661 Warsaw

ABSTRACT

The paper presents analysis of possibilities to utilise results of modelling the work of concrete dam construction elements, obtained by means of the finite elements method (FEM), for the needs of modernisation of a control network. Such analysis should answer the question, whether – basing on the results of modelling with the use of currently controlled points of the object, as the network nodes, and pointing to zones (locations) of threats – it will be possible to formulate recommendations concerning the improvement of a set of controlled points and to perform related modifications of the existing control network.

1. INTRODUCTION

Modernisation of geodetic control networks used for investigations of displacements of engineering structures is an important issue with respect to safety of users of a given object. Following the development of surveying and computational technologies, possibilities of more reliable and accurate monitoring of changes of engineering structures have been increased.
In the course of planning modernisation of the control network, we may use historical information, which describes in details the conditions and work of the structure in various circumstances, among others: results of control surveys, determined short- and long-term trends of changes, observed relations between particular phenomena, analysis of observed dislocations of particular elements.
Such a knowledge is missing in the case of designing the network for a new structure; therefore it may occur during the process of modernisation that the geodetic control network must be enlarged/amended with points located in places of the highest dislocations, which have not been controlled yet. Those locations may be specified by means of analysis of the work of the particular structure basing on the data already acquired in the phase of prior control measurements. Development of the digital model of the structure as early as at the design stage may allow for the optimum planning of location of geodetic control points.

2. BESKO DAM

The concrete dam in Besko on the Wisłok River, located at 172.8 km, the exploitation of which was commenced in 1978, is the hydrotechnical structure for which the analysis described in this paper has been performed.
The dam consists of 12 contraction joints of 12 m width and 2 spillways of 15 m width. The maximum height of the section equals to 38.2 m, and the maximum height of the reservoir in the area of overflow sections equals to 29 m. Seasonal variations of the water levels equal to 3 to 5 m, having the maximum value of 12.3 m.
Control measurements performed for Besko Dam include: 24-hour measurements of the air temperature within the vicinities of the Dam, weekly measurements of temperature in galleries, surveys of vertical dislocations of benchmarks fixed on the dam crest, on the downstream face and in the bottom gallery of the Dam, surveys of displacements of geometric targets in upper and bottom parts of the downstream face of the dam, surveys of the fixed reference line on the dam crest, surveys of relative displacements: feeler gauges, slope gauges and pendulums, measurements of pressure in piezometers, measurements of water levels in the reservoir (WG), measurements of the tailwater levels.
The digital model of the structure's operation has been developed for 6 sections of the dam.

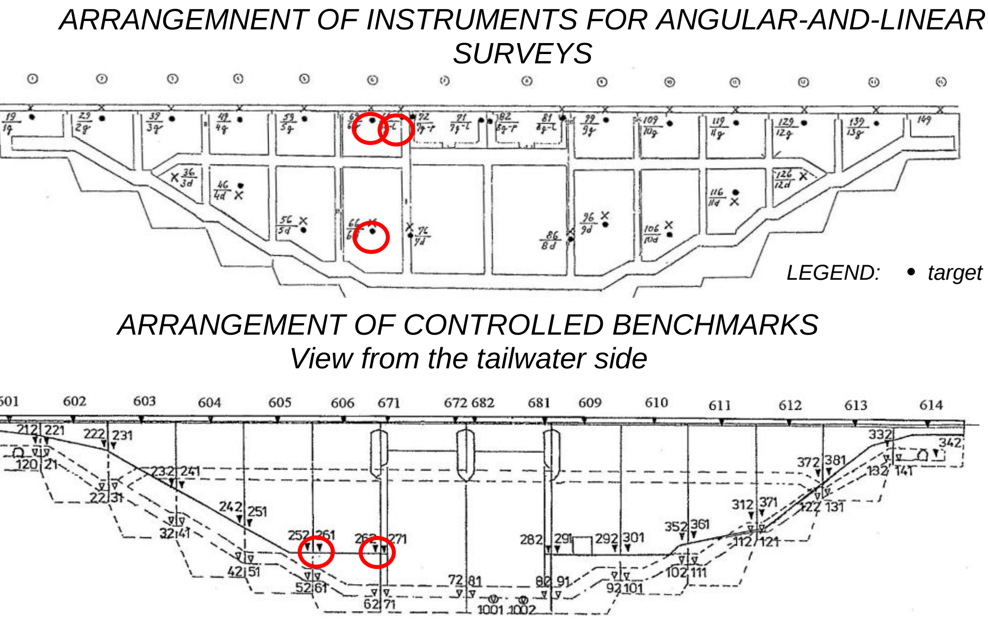


Fig. 1. Besko Dam – Arrangement of controlled points; points of the section 6 are marked in red.

3. COMPLETION OF THE LOCATION OF CONTROLLED POINTS BASING ON THE FEM MODELLING OF THE DAM'S BEHAVIOUR

The method of verification of the design of placing the targets on the dam's construction elements, utilising the measurement data of the geodetic control network which describe the dam's behaviour with the use of the finite elements method, has been proposed. Basing on the results of control surveys, performed for many years in the past, models of the construction's behaviour for variable loads may be developed; such loads are not only connected with changes of the headwater level (WG) in the reservoir, but also with the changes of soil substratum resulting from long-term ground loading by the structure itself, as well as by accompanying structures.

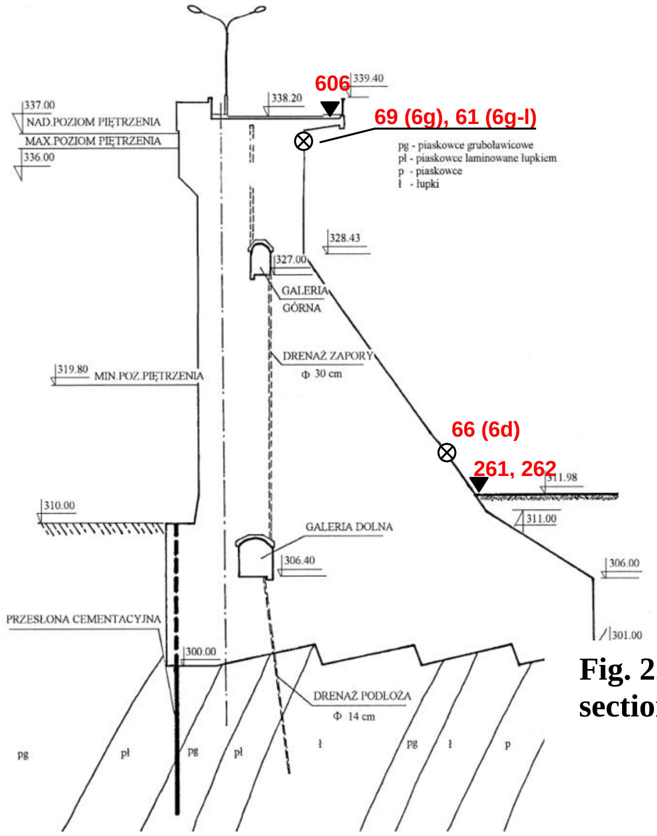
The finite elements modelling (FEM) is an appropriate tool used for forecasting the work of a concrete dam. The present analysis is to answer the question, whether – basing on the results of modelling, including, among others, the controlled points of a structure – it is possible, by pointing hazarded places, to formulate recommendations concerning the completion of a set of the controlled points and related modification of the existing control network.

4. THE MODEL OF THE STRUCTURE'S WORK

Numerical computations of interaction between the concrete dam and the soil substratum have been performed with the use of the finite elements method. Calculations were performed by means of the HYDRO-GEO software package (Dłużewski, 1997).

HYDRO-GEO is the Polish software package which applies the finite elements method for the analysis of issues related to geotechnics, hydraulic engineering and environmental engineering. This package has been developed since the late seventies at the Warsaw University of Technology, in co-operation with the Silesia Technical University and the Water Dams Control Centre of the Institute of Meteorology and Water Management.

The software in question uses the finite elements method in displacement approach.



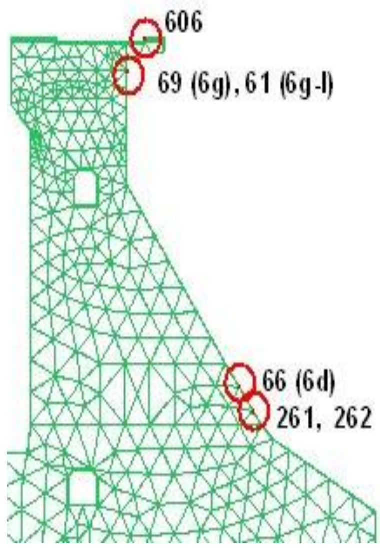


Fig. 2. The drawing of the Besko Dam section 6 and corresponding fragment of the FEM nodes.

Calculations were performed in the plane state of strain. The elastic-plastic models of the soil environment, based on the Coulomb-Mohr plasticity condition, have been adopted for simulation of the substratum operation. The non-associated flow law, assuming the non-compressibility of materials in the plastic range of their operation, i.e. the dilatation angle equal to zero, has been used. The six-node, triangular iso-parametric elements with the functions of shape of second-degree, have been applied for numerical analysis. In order to discretise the area adopted for calculations, the tools contained in the

HYDROGEO package have been taken advantage of. Having determined the geometry of the areas describing the material zones and structures and objects found within the cross-section under analysis, the grids of finite elements were generated following which the data regarding the material parameters, boundary conditions, levels of groundwater, inception stresses were introduced.

In the numerical model, reconnaissance of the soil substratum described in geological-and-engineering documentation and discussed in (Dłużewski et al., 1995), (Dłużewski et al., 1996) was utilised. The configuration and inclinations of particular material layers were restored. Values of material parameters of the substratum were acquired from (Dłużewski et al., 1995). The backward analysis was performed, which verified material parameters of the layer which is located directly under the toe of the dam.

Cross-sections of analysed sections of the structure were used for the needs of developing the model of the concrete dam. Particular elements of the structure, such as offsets in a wall to the headwater side, the shape of the dam's crest, the cut off trench of the toe of the dam, as well as the configuration of inspection-and-measurement galleries and internal rooms of the dam, were modelled in details. At the stage of preparation of the model geometry, locations of particular targets and benchmarks, installed in the structure, were considered. The FEM grid was generated in such a way that the FEM grid node is assigned to each point of the control network on the dam (i.e. targets, benchmarks and points of the fixed reference line). The grid consisted of 2566 nodes and 1213 elements.

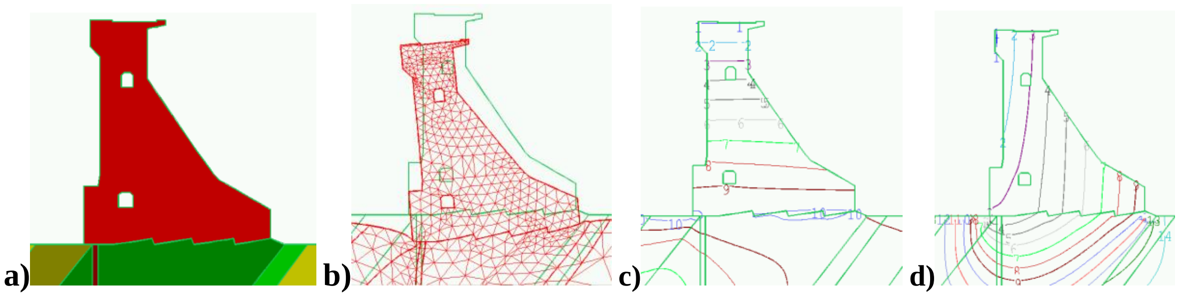


Fig. 3. Besko Dam – the model of section 6 (stage II.):
a) diagram of the structure and substratum layers, b) displacements resulting from the construction weight (the reservoir without water), c) iso-lines of horizontal displacements, d) iso-lines of vertical displacements.

<u>The calculations have been made in three stages:</u>

I. In the first stage, the initial stresses and porous pressures arising from the configuration of the layers of soil and level of groundwater occurring within the cross-section under analysis, were generated. The configuration of layers and the level of groundwater used have been adopted in accordance with the hydro-geological cross-sections (discussed in (Dłużewski et al., 1995), (Dłużewski et al., 1996)). At this stage, only the substratum area under the dam occurred in the model (full analogy with (Dłużewski et al., 1995), (Dłużewski et al., 1996)).

II. At the second stage the reservoir without water was modelled (Fig. 3). Elements presenting the dam's construction were added to the model. As the load the weight of implemented constructions was assumed (according to (Dłużewski et al., 1995), (Dłużewski et al., 1996)).

III. At the third stage the loads resulting from filling the reservoir were modelled. Loads were applied to the upstream face of the dam, to the bottom of the reservoir – load values resulted from the ordinate of the water level (Fig. 4). The load was applied to the filtering curtain and to the toe of the dam. The water level in the open PO6d piezometer, located opposite to the analysed section, was considered as the water level on the downstream face. The load value on the toe of the dam reflected the real distribution of pressure, measured in piezometers closed under the toe of the dam.

After completion of calculations the coherence of obtained dislocations of nodes – targets with the displacements obtained as a result of control surveys was checked, assuming surveys performed in March, 1997 as the initial surveys, and the surveys in April 1998, as the successive surveys.

		WG	WD	DX 69 (6g)	DX 66 (6d)
	03-1997	332,75	309,79	0,00000	0,00000
Model:	03-1997 04-1998	331,59	310,00	0,00009	0,00050
Geodetic survey:	03-1997 04-1998	331,59	310,00	0,00010	0,00050

Table 1. Comparison of displacements obtained from FEM and geodetic surveys.

5. SIMULATION OF CHANGES IN WORK OF THE STRUCTURE

After checking the correctness of the model, two cases of work of the structure were simulated:

1. Constructional modification of the concrete structure – introduction of an empty room in the section.
2. Breakdown of the grout curtain – increase of uplift forces acting on the toe of the dam.

DISPLACEMENTS OF NODES /TARGETS MODEL - SIMULATED CASE

Model		04/1998 WG - 331,59			Model		03/1997 WG - 332,75			
Stage	dX 69 (6g)	dH 69 (6g)	dX 66 (6d)	dH 66 (6d)	Etap	dX 69 (6g)	dH 69 (6g)	dX 66 (6d)	dH 66 (6d)	
2	-0,00325	-0,00673	-0,00057	-0,00547	2	-0,00325	-0,00673	-0,00057	-0,00547	Reservoir without water
3	-0,00059	-0,00663	0,00211	-0,00533	3	0,00040	-0,00661	0,00261	-0,00547	Filled reservoir
Displacement 2-3	0,00266	0,00010	0,00268	0,00014	Displacement 2-3	0,00366	0,00012	0,00318	0,00001	

Constructional modification of section		04/1998 WG - 331,59			Constructional modification of section		03/1997 WG - 332,75			
Stage	dX 69 (6g)	dH 69 (6g)	dX 66 (6d)	dH 66 (6d)	Stage	dX 69 (6g)	dH 69 (6g)	dX 66 (6d)	dH 66 (6d)	
2	-0,00284	-0,00634	-0,00049	-0,00516	2	-0,00284	-0,00634	-0,00049	-0,00516	Reservoir without water
3	-0,00014	-0,00623	0,00223	-0,00503	3	0,00086	-0,00621	0,00274	-0,00517	Filled reservoir
Displacement 2-3	0,00270	0,00010	0,00271	0,00013	Displacement 2-3	0,00370	0,00012	0,00323	0,00000	
Model - Change	0,00045	0,00040	0,00011	0,00030	Model - Change	0,00046	0,00040	0,00012	0,00030	

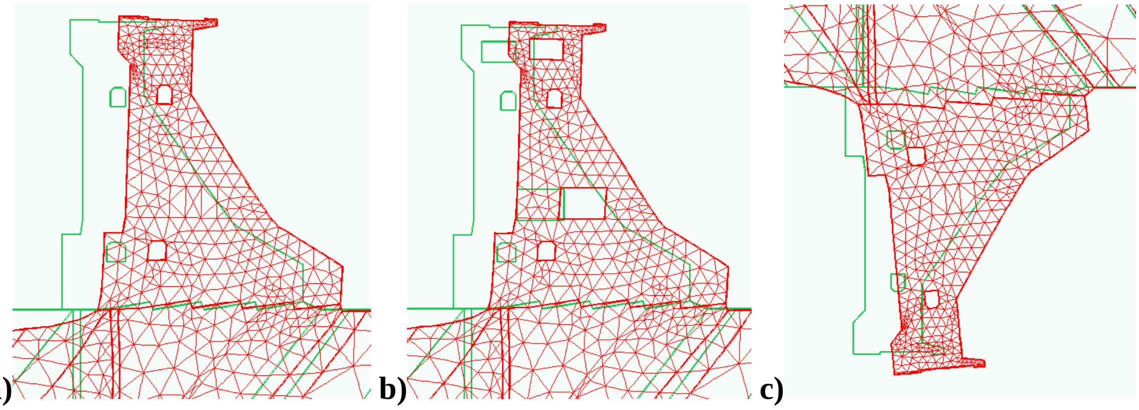
Breakdown of the curtain		03/1997 WG - 332,75			
Stage	dX 69 (6g)	dH 69 (6g)	dX 66 (6d)	dH 66 (6d)	
2	-0,00325	-0,00673	-0,00057	-0,00547	Reservoir without water
3	0,00092	-0,00518	0,00209	-0,00449	Filled reservoir
Displacement 2-3	0,00417	0,00155	0,00265	0,00098	
Model - Breakdown	0,00052	0,00143	-0,00053	0,00098	

Table 2. Comparison of displacements obtained for the normal work of the structure and for emergency cases.

Forecasted displacements of the grid nodes for the normal operations and for simulated cases were compared.

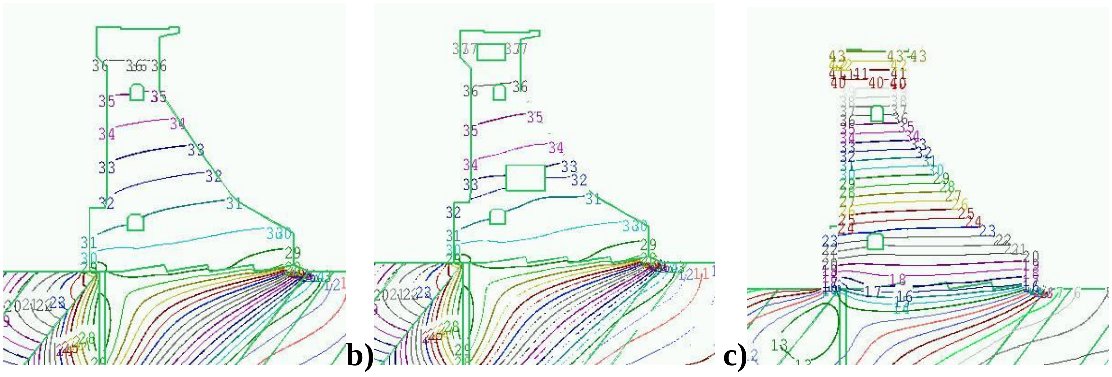
In the simulated case of <u>the constructional change of the dam's section</u> there is no difference between values of calculated displacements of targets in both models. The drawings of iso-lines (Table 2, Fig. 5, 6, 7) of displacements indicated that the area of the maximum changes occurred above the line of observed points, at the altitude of „empty spaces" in the structure. This justifies the inspection of additional points located between the lines of currently observed targets. Selection of a detailed location of points requires that more calculation variants should be performed.

In the second analysed case – <u>the breakdown of the grout curtain</u> – due to the direction of the uplift force, applied to the toe of the dam, vertical components of displacements of the grid nodes are bigger and the entire structure displaces in a coherent way. Areas, which are characterised by various values of expected displacements cannot be located. The number and location of the currently observed targets are correct.



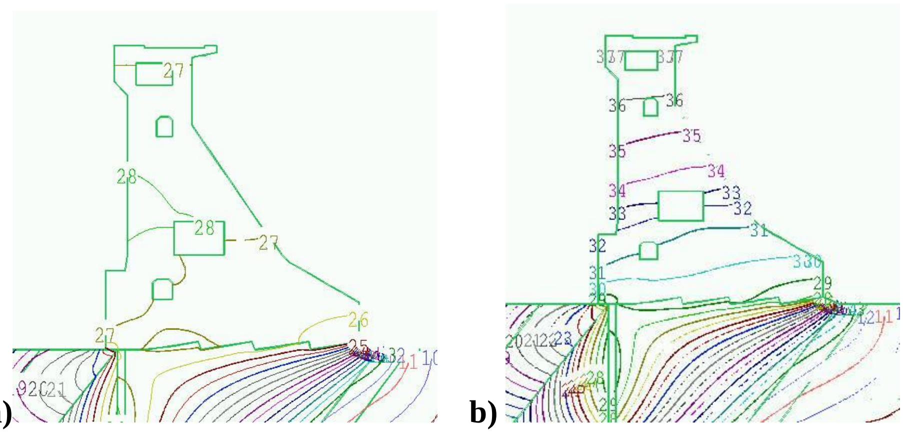
a) b) c)

Fig. 4. Besko Dam – the model of section 6 (stage III, WG=332m above the sea): a) displacement of the structure for the reservoir filled with water, b) displacement of the modified structure, c) displacements of the structure – breakdown of the grout curtain.



a) b) c)

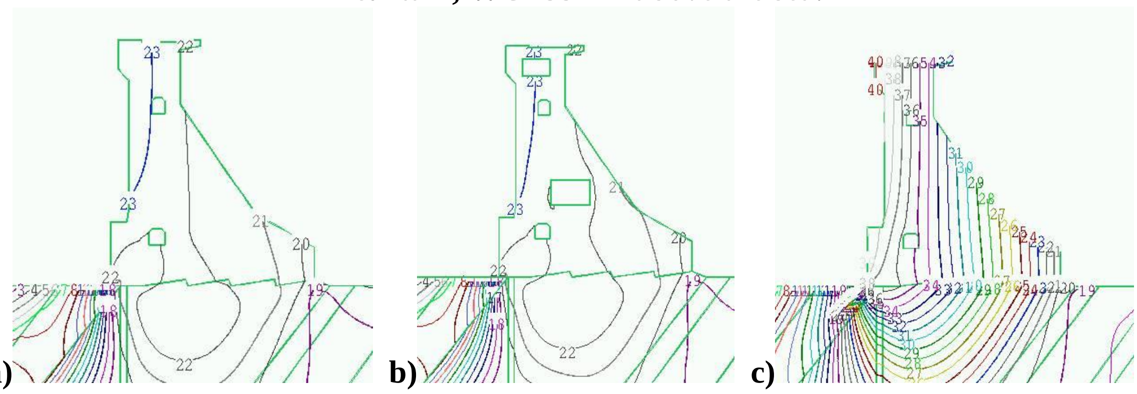
Fig. 5. Besko Dam – the model of section 6 (stage III, WG=332m above the sea), iso-lines of horizontal displacements with 0,0001 m interval: a) displacement of the structure for the reservoir filled with water, b) displacement of the modified structure, c) displacements of the structure – breakdown of the grout curtain.



a) b)

Fig. 6. Besko Dam – the model of section 6 (stage III), iso-lines of horizontal displacements with 0,0001 m interval: a) displacement of the modified structure,

WG=331 m above the sea, c) displacements of the structure – breakdown of the grout curtain, WG=332 m above the sea.



a) b) c)

Fig. 7. Besko Dam – the model of section 6 (stage III, WG=332m above the sea), iso-lines of horizontal displacements with 0,0001 m interval: a) displacement of the structure for the reservoir filled with water, b) displacement of the modified structure, c) displacements of the structure – breakdown of the grout curtain.

6. SUMMARY

The results of analysis described above are consistent with expectations and they point to the possibility to use the FEM modelling in the process of modernisation of the geodetic control network. It should be noticed that calculations discussed in this paper create the beginning of works aiming at description of the algorithm, which utilises the FEM modelling in order to specify location of additional targets, which improve the existing control network.

The successive stage of analysis should include the analysis of the structure's stresses – which considers the temperature changes within the structure and possible changes within the substratum caused by filtration phenomena. All calculations should be based on surveys performed for the real structure in order to locate successive targets (control points) in places where the maximum stresses occur.

REFERENCES

Beynar-Czeczott E., Reszka T. Interpretacja bieżących wyników badań i pomiarów kontorolnych oraz ocena stanu technicznego zapory w Besku. IMGW, Zakład Inżynierii Wodnej, Warszawa 1981.

Boros-Meinike D. Analiza i interpretacja wyników pomiarów kontrolnych oraz ocena stanu technicznego i bezpieczeństwa zapory Besko za okres X 2002 do VII 2004 roku. IMGW OTKZ, Warszawa 2004.

Dłużewski J., Gajewski T., Tomaszewicz A., Boros-Meinike D. Analiza wytrzymałościowa sekcji betonowej celem wcześniejszego wykrycia ewentualnych uszkodzeń i potwierdzenia prognozy przemieszczeń na przykładzie sekcji 8 zapory w Besku. IMGW OTKZ, Warszawa 1995.

Dłużewski J., Gajewski T., Tomaszewicz A., Boros-Meinike D. Analiza przemieszczeniowo-wytrzymałościowasekcji 8 zapory betonowej w Besku w celu interpretacji pomierzonych przemieszczeń. IMGW OTKZ, Warszawa 1996

Dłużewski J. HYDRO-GEO - program metody elementów skończonych dla geotechniki, hydrotechniki i inżynierii środowiska. Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa, 1997.

Prószyński W., Zaczek-Peplinska J. Kompleksowa modernizacja geodezyjnej sieci kontrolnej środkiem do podniesienia wiarygodności wyników pomiarów przemieszczeń. XI Konferencja TKZ, Zakopane, 8-11 maja 2005.