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COMPARISON IN SITU MEASURED VERTICAL DISPLACEMENTS IN THE SUBSOIL OF THE HYDROPOWER PLANT IN GABČÍKOVO WITH NUMERICAL RESULTS

Ľuboš HRUŠTINEC, Jozef SUMEC, Jozef KUZMA
Slovak University of Technology, Bratislava, Slovakia

1. Introduction

In 1977, the construction of Water Works Gabčíkovo on Danube in the vicinity of Bratislava began. Water Works Gabčíkovo was originally designed and constructed as a part of Water Works System "Gabčíkovo – Nagymaros". Among the main works of Gabčíkovo stage belong two lock chambers and hydropower plant (HPP). The hydropower plant consists of four blocks onto which is installed 8 hydro-aggregates with total output 720 MW. Hydropower plant was founded in foundation pit located in the sealing tank. Sealing tank for founding the HPP was made of:

- clay-cement underground sealing walls 0,6 m thick,
- pre-injected gravel subsoil making of bottom of sealing tank 7,0 m thick.

At solving problems of calculation of HPP subsoil deformation calculation and definition of geotechnical model we used information in archives [1,2]. The deformation measurements continued in the respective stages of construction. Deformation measurements for the selected objects and structures of HPP continue until now.

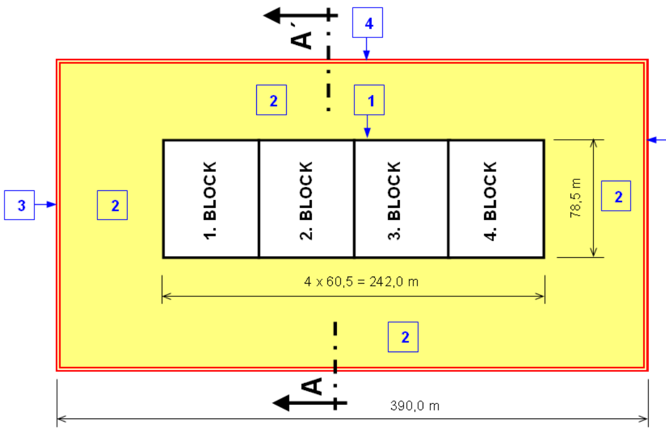
During the respective stages of construction and during operation complicated loading states were implemented onto the subsoil and HPP. Size of final and uneven settlement of foundation construction has also an influence on the reliable HPP operation. For calculation of vertical subsoil deformations and HPP foundation construction had been used mathematical modelling (Finite Elements Method - FEM). Numerical calculation results are compared with the actually measured vertical displacement on construction and HPP objects.

2. Boundary conditions of the calculation model

Basic data on HPP Gabčíkovo that served as a prerequisite for the geotechnical model preparation were taken from the project documentation and archive materials listed in the bibliography. Basic geometric parameters of the calculation model of the sealing tank and HPP object are indicated in the Fig. 1 (plan view) and Fig. 2 (cross section). The prepared geo-technical model involves some simplifications with respect to the project documentation. These simplifications lie in the adequate adjustment of the respective constructions in a manner not allowing for the significant modification with respect to the project and in order to comply with the requirements necessary for the calculation model preparation. Real non-homogeneous geological environment was replaced with engineering-geological model of the subsoil. Hydropower plant is based on medium dens to dens gravel-sand fluvial deposits of Danube that reaches thickness up to 300 m. Groundwater level (GWL) is situated approximately 1.0 m deep under the terrain. Deformation and volume properties were determined by the laboratory tests and in-situ loading tests. Geotechnical surveys [1] for the gravel soil in the area in question recommended two alternative values of deformation modules (E_i), which size is functionally dependent on deep (z_i) in accordance to relations:

1. Alternative: $E_i = 21{,}090 + 2{,}460 * z_i$,
2. Alternative: $E_i = 34{,}745 + 3{,}413 * z_i$.

Due to the aforementioned reason two alternative subsoil models were taken into consideration when making geotechnical calculation. Graphic interpretation of the functional dependency of the deformation modules on depth under the terrain is indicated in Fig. 3. Calculations took into a consideration groundwater level in the terrain level and deformation depth zone 90.0 m under the footing bottom of the hydropower plant. Material properties of soils and sealing tank construction used in the geotechnical calculations for the 1st and 2nd alternative subsoil model are listed in Tab. 1.

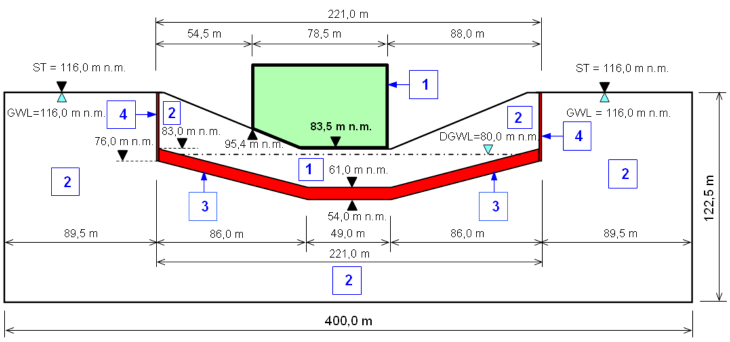


1 – Blocks of hydropower plant (1st to 4th block of hydropower plant),

2 – Pre-grouting sealing tank bottom,

3 – Sealing underground wall

Fig. 1 Basic geometric parameters of computational model (sealing tank and hydropower plant) – Plan View.



1 – Hydropower plant,

2 – Graveled subsoil,

3 – Pre-grouting sealing tank bottom,

4 – Sealing underground wall

Fig. 2 Basic geometric parameters of computational model (cross section A–A´).

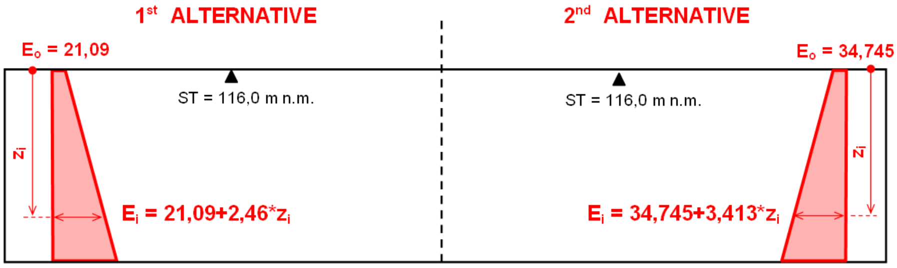


Fig. 3 Alternative models of subsoil : ST – Surface terrain, E_o – Module of deformation on the surface terrain, E_i – Module of deformation in depth z_i.

Table 1 Material properties of soils and sealing tank structure used in geotechnical calculations for the 1st and 2nd alternative of subsoil model.

Alternative of subsoil model	Description of material (structure)	Depth (from surface terrain)	Deformation modulus	Poisson´s ratio	Density		
					with natural humidity	effective (under water)	total (saturated)
			E	ν	γ	γ_{su}	γ_{sat}
		/ m /	/ MPa /	/ - /	/ kN.m^{-3} /		
1. a 2.	Pre-grouting gravel (sealig tank bottom)	-	7500,0	0,20	21,0	-	-
	Clay-cement material (underground sealing wall)	-	36,0	0,45	13,0	-	-
1.	Gravel medium-dense till dense (subsoil)	0,0 až 20,6	46,4	0,25	20,0	11,0	21,0
		20,6 až 32,5	86,4				
		32,5 až 62,0	137,3				
		62,0 až 122,5	251,7				
2.	Gravel medium-dense till dense (subsoil)	0,0 až 20,6	69,9	0,25	20,0	11,0	21,0
		20,6 až 32,5	125,4				
		32,5 až 62,0	196,0				
		62,0 až 122,5	354,7				

3. Loading state of the solving problem

In this article we are dealing with loading state after load on the subsoil exercised by HPP object before puncture of the sealing tank and normal HPP operation at designed water levels in inflow and outflow canals. The following loading states are defined:

1. Loading state (1 LS): excavation of HPP foundation pit.
2. Loading state (2 LS): completion of HPP construction in the sealed foundation pit.
3. Loading state (3 LS): puncture of sealing underground wall on the side of outflow canal and filling the outflow canal with water onto ground elevation 109.0 m above sea level, i.e. water surface level before the start of production of excellent electrical energy.
4. Loading state (4 LS): filling the inflow canal with water onto level of maximum hydrostatic level i.e. ground elevation 131.0 m above sea level.

The aforementioned loading states reflect all significant changes in subsoil strains caused by modification of effective strains in the gravel subsoil, load on subsoil exercised by the engineering structures and pressure (uplift) effects of water onto the sealing tank and HPP.

4. Solving method and numerical calculation results

Method of mathematic modeling with utilization of mathematical apparatus of numerical method of finite elements was used at problem solving. The task was solved as planar in accordance with the assumption of the linear flexible theory. Geotechnical calculations were executed with GEO 5 (MKP Module) program [3]. Geotechnical calculations yielded quantitative and qualitative information on deformation of subsoil and foundation of hydropower plant (HPP). Calculation results (vertical deformations of HPP subsoil) for defined alternative models of subsoil (1st and 2nd Alternative) and loading states (1 to 4 LS) were assessed in the representative points of calculation model.

Final values are assessed in its relation to modification of vertical deformations as against 1 LS, which is considered to be basic (referential). Graphic representation of the vertical deformation calculated in forms of iso-planes is listed in Fig. 4 (1st Alternative) and Fig. 5 (2nd Alternative).

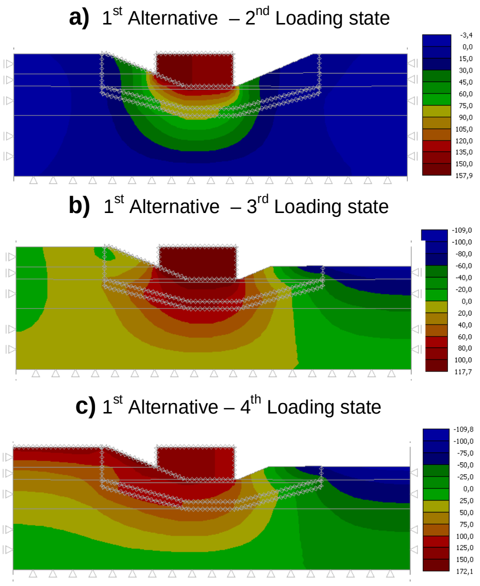


Fig. 4. Calculation results for the 1st alternative: iso-surfaces of vertical deformations for the 2nd to 4th Loading state.

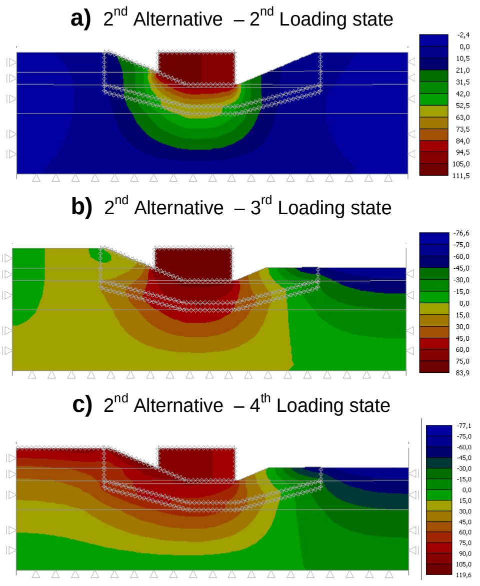


Fig. 5. Calculation results for the 2nd alternative: iso-surfaces of vertical deformations for the 2nd to 4th Loading state.

The aforementioned calculation results reveal vertical deformation sizes:

- Due to the HPP construction additional load to the subsoil was added at the level of foundation construction (2 LS). Maximal settlement values were calculated in the area of the foundation joint sized 147.0 to 157.9 mm (1st Alternative) or 99.9 to 111.5 mm (2nd Alternative)
- Due to the underground wall puncture on the side of outflow canal and filling the canal with water to the elevation 109.0 m above sea level (3 LS) sealing tank was flooded

with water what caused hydrostatic uplift and pressure onto HPP. Due to the uplifting effects the maximal settlement values of HPP decreased. Maximal settlement values were calculated in the area of foundation joint sized 112.7 to 117.7 mm (the 1st Alternative), or 80.6 to 83.9 mm (2nd alternative).

- Due to the filling of inflow canal with water onto the level of maximal hydrostatic level, i.e. ground elevation 131.0 m above sea level (4 LS) caused by hydrostatic prssure, occurred additional load to impervious (asphalt-concrete) inflow canal bottom and HPP object. Maximal settlement values were calculated in the area of foundation joint sized from 118.9 to 149.9 mm (the 1st alternative) or 85.0 to 106.1 mm (the 2nd alternative).

Measured calculation results provided us rather complex information on vertical deformations, which are occurring in the HPP subsoil for the defined loading states. Accuracy of the calculated deformations is verified in the following chapter with measured settlements for HPP.

5. The measured settlements and they comparison with numerical results

Severity of HPP Gabčíkovo required also systematic measurements of subsoil deformation and structures. From the perspective of reliability assessment of HPP operation, the most significant are deformations at the level of foundation, or foundation joint. Vertical deformations (settlements) measurements of foundation were executed using geodetic method of very precise levelling on the mounted measuring points at the ground elevation level 86.6 m above sea level. Hydropower plant settlement measurement began only after the foundation structure was built and measuring points mounted. Schematic representation of the selected measuring points mounted on the foundation is indicated in Fig. 6. Maximal settlement values were measured from 120.4 up to 139.5 mm. From the timelines of settlement it is obvious that also water level in inflow and outflow canal influences the settlement size, i.e. Water Work Gabčíkovo also has an impact on the size of deformations.

Mutual comparison of maximal and minimal values of HPP settlement for subsoil models defined in the 1st and 2nd Alternative taking into consideration real operation (4 LS) is indicated in Fig. 7. From comparison of results it is obvious that relatively very good congruence of calculated and measured of vertical deformations is reached for subsoil model defined in 1st alternative. For the 1st alternative theoretically calculated (prognoses) values of vertical deformations differs from the measured values up to 10.0 mm at the most. The most significant result is the fact that for the congruence of design physical model with real measured deformation was reached, which confirms proper representation of physical essence at problem solving.

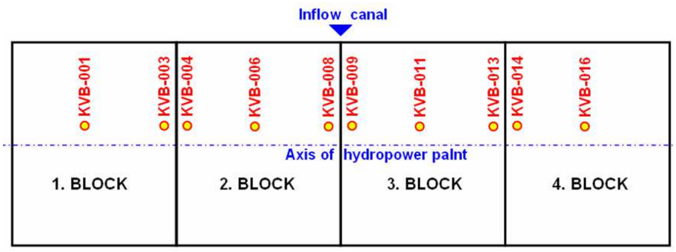


Fig. 6. Schematic illustration of a position of the selected measuring points mounted onto the foundation structure of HPP Gabčíkovo (on ground elevation 86.6 m above sea level).

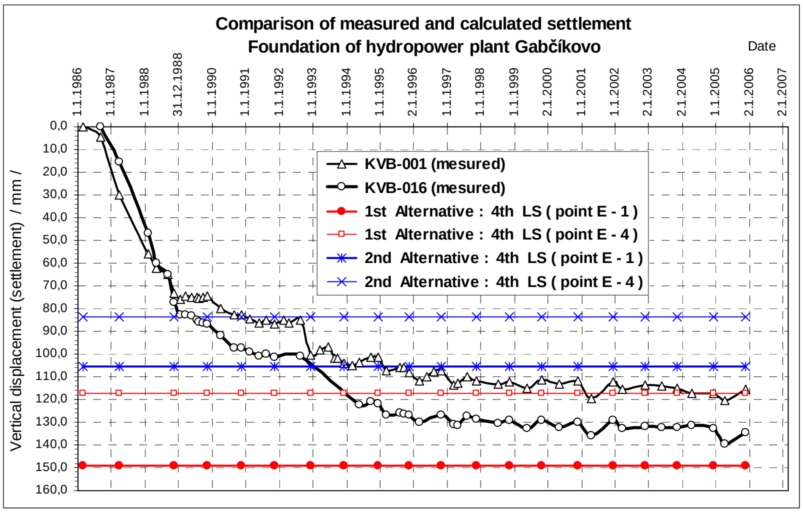


Fig. 7. Measured values of timelines of settlement of measuring points mounted onto foundation of HPP Gabčíkovo (on the ground elevation 86.6 m above sea level).

6. Conclusion

The qualitative and quantitative congruence of the geotechnical prognosis with real structure behavior in interaction with subsoil is an important criterion of theoretical approach accuracy in the problem solution. This prognosis method was also used for the problem solution of a complex issue related to the HPP Gabčíkovo construction. Model calculations yielded complex (quantitative and qualitative) information, which might be used at increase of hydropower plant reliability and other prognosis of interactions of executed structures with subsoil.

References

[1] Kuzma, J. a kol. (1987): Expert assessment and evolution of deformations on Water Work Gabčíkovo – Nagymaros. Phase 1 and Phase 2. Bratislava 1987, (In Slovak).

[2] Strähle, G. (1978): Water Works Gabčíkovo – Nagymaros. Water management construction, PRAVDA, Bratislava 1978, (In Slovak).

[3] Computing program GEO5 (Module FEM), FINE Ltd. © , www.fine.cz.

Acknowledgement

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POROVNANIE IN SITU NAMERANÝCH ZVISLÝCH DEFORMÁCIÍ PODLOŽIA VODNEJ ELEKTRÁRNE V GABČÍKOVE S NUMERICKÝMI VÝSLEDKAMI

Zhrnutie

Príspevok podrobnejšie analyzuje veľkosť zvislých deformácií (sadnutia) pre rôzne zaťažovacie stavy, ktoré môžu nastať počas výstavby a prevádzky vodnej elektrárne v Gabčíkove. Na riešenie problému bola použitá MKP. Vypočítané hodnoty sú porovnané so skutočne nameranými hodnotami zvislých deformácií podložia vodnej elektrárne.