Geodetic deformation monitoring in the dam-reservoir system

H J Al Fatin, M G Mustafin*, H S Ismael
Saint-Petersburg Mining University, 2, 21st Line, St Petersburg 199106, Russia

E-mail: mustafin_m@mail.ru

Abstract. Construction of hydraulic structures is considered to be one of the useful and long-term solutions to most of socio-economic problems that are faced by our societies in the 21st century. With regards to this, it is therefore necessary to constantly monitor the steady state of the dams in order to optimize the operational efficiency and safety measures for both the ecosystem and human beings. Existing methods for monitoring the state of dams are based on observing deformations dams as an independent object. The article discusses the method for estimating dam deformations in the dam-reservoir system. When conducting geodetic monitoring of dam’s displacement, it is necessary to take into account the water level in the reservoir which affects the measurement procedure and makes them more physically reasonable, taking into account the water pressure on the dam. The article shows the method of measuring the water level of the reservoir based on the construction of its 3D model.

Introduction
In accordance with standards of steady-state monitoring of dams horizontal and vertical displacements form the basis of the parameters to be put under monitoring. Their definition is a task of mainly geodetic measurements [1,2,3]. As a result of special geodetic observations, these parameters move from a phenomenological description of the deformation to an analysis of the process that causes the deformation of the object [3].

There is an obvious link between the dam's deformation and the water level in the reservoir. Obviously, observations of the deformation of the dam should be linked to the water level in the reservoir. This opinion is shared by other researchers [2].

This study examines the deformations of the Dukan dam located in northern Iraq. Displacements were estimated using a high-precision total station (angular measurement accuracy 0.5 seconds). Water levels in the reservoir are proposed to be monitored using a three-dimensional digital model created using computer software (Arc GIS 9.2 or 10.4) and special hydrographic or geodetic measurements. Most approaches and computer programs for creating 3D-models are implemented via the software Arc Map or Arc scene [4]. Thus, model is necessary for representation of data, in order to demonstrate the relationship between the water level and the deformation of the dam which its influence on the mechanism of deformation of the dams and tracking, through deformation monitoring.

Relevance
It is necessary to ensure the stability of dams and the possibility of creating an automated technology for constructing three-dimensional digital models of reservoirs based on geodetic data. The risk of
critical deformations or destruction of the dam is related to water level in the reservoir, which determines the pressure on the dam and its deformation.

A common practical example of this is the flooding resulting from dam collapse which occurred in the village of Fujairah in December 1995 after heavy rains and storms continued for three days. This led to rise in water levels in the dam reservoir in the region. The village is located near the mouth of Wadi Safad along the coast of the Indian Ocean, north of the city of Fujairah. At that time of flooding population of the area was about 5,000. A variety of buildings which constituted schools, mosques and residential places were built in the area prior to flooding. After flooding approximately 400 buildings were destroyed due to flooding [10].

Study area
The Dukan Dam is located in the north of Iraq within the following coordinates: (35-57'15") N & (44'57'10") E (Figure 1). The catchment area of the reservoir is 11 690 km² [5]. The dam was built in 1959 on the Small Zab river for flood management during periods of heavy rainfall, irrigation and power generation. The surface area of the reservoir is 270 km² with a normal working level of 511 m above mean sea level, the minimum water level is 469 m above mean sea level [6].

![Figure 1. satellite image of Dukan dam](image)

Methodology and results
Dam deformations are monitored using a geodetic observation system. A diagram of an observation station (control points and deformation marks) is shown in Figure 2. As seen on the dam there are 12 targets (deformation marks). Observations are performed at least once a year (sometimes twice a year). The determination of the value of the horizontal displacement of the dam has been demonstrated. Moreover, at the same time the water level in the reservoir is determined monthly, but independently from the geodetic observations. This will then assist us in knowing the fluctuations of the water levels throughout the seasons of the year (Figure 3).

Based on this research, the water level in the reservoir is a very influential factor in the amount of horizontal displacement of the dam. According to the digital model of the reservoir, it is possible to assess the influence of the water level on the deformation of the dam and further determine the level at which the dam could safely operate.
In order to build a digital model, the spots levels of the bottom of the reservoir can be used. They can be obtained on the basis of the study of topographic maps of the area (before the construction of dam), or by bathymetric survey. Monitoring of water levels or volume can be performed either by creating gauging stations, or based on satellite imagery data. In this regard, GIS can be a powerful tool for building, managing and analyzing spatial data for developing a decision support system [7].

The three-dimensional digital model can be constructed from an elevation matrix. The elevation matrix is extracted from many sources, such as remote sensing data for a dam reservoir, field survey and photogrammetry. There are known cases of using remote sensing data and GIS technology for monitoring water volumes [8]. As an example in this paper, it has been created an elevation matrix according to a topographic map, which in turn is constructed according to aerial photogrammetric survey data [9].

Figure 3 shows the relationship between water level and dam deformations.
The ratios have been observed in Figure 3 it is able to distinguish the water levels in the reservoir and the volumes of water in the reservoir, as well as the water pressure on the dam, however, these data should be linked to dam deformations. To answer this question, the reservoir model should be constructed. In this case study, GIS technology has been used to create a three-dimensional model (Figures 4, 5, 6) of the reservoir.

For GIS modeling, topographic data such as the 3D coordinates of the bottom points or a digital map must be prepared. Firstly, the vector model of TIN (Triangulation Irregular Network, Figure 5) is created using 3D Analyst tool on the basis of which a volume of digital elevation model (DEM, Figure 6) is built.

![Figure 4. 3D model of the Dukan reservoir](image)

![Figure 5. TIN model of the Dukan reservoir, created by GIS.](image)
Summary
Observation data on the deformation of the Dukan dam and its comparison with the values of water levels allow us to see the difference in the values of displacements. Methodology would link these data and could create prerequisites for developing observations taking into account the water levels in the reservoir. In Figure 2 shows 12 deformation marks, which are distributed evenly over the dam. It is possible to determine dam zones where the deformations are maximum (sensitive zones) and to concentrate observations on them. This will require calculations and modeling of deformed state of the dam. These and other studies constitute the stages of further research on this relevant work.

References
[1] Hunter G, Fell R 2003 The Deformation Behaviour of Embankment Dams (University of New South Wales, Sydney).
[2] Bayrak T 2007 Modelling the Relationship Between Water Level and Vertical Displacements on the Yamula Dam (Natural Hazards and Earth System Sciences, Turkey).
[3] Welsh W 2003 Geodesy-the Challenge of the Third Millennium (ISBN 3-540-43160-8, Springer Verlag, Berlin Heidelberg, New York).
[4] Dibs H, AL-Hedny S, Karkoosh H 2018 Extracting Detailed Buildings 3D Model with Using High Resolution Satellite Imagery by Remote Sensing and GIS Analysis (AL-Qasim Green University a Case Study, IJCIET).
[5] Mustafa N F 2017 Statistics and Variability of Darbandikhan and Dukan Dams Inflow Time Series (IZS. 19-2 (part A).
[6] Hassan R, Al-Ansari N, Ali S S, Ali A A, Abdullah T, Knutsson S, Dukan Dam Reservoir Bed Sediment Kurdistan Region (Scientific Research Publishing, Iraq).
[7] Ali A R 2015 GIS Spatial Model Based for Dam Reservoir in Dry Wadis.
[8] Khattab M, Abo R, Al-Muqdadi S, Merkel B 2017 Generate Reservoir Depths Mapping by Using Digital Elevation Model: A Case Study of Mosul Dam Lake (Scientific Research Publishing, Northern Iraq).
[9] Hua W, Hou M, Hu Y 2018 Review of 3D GIS Data Fusion Methods and Progress (ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences) IV-3.
[10] Al- Etihad journal, Information on https://www.alitihad.ae/article/51641/2012/.