HYDROGRAPHIC SURVEY OF THE STILLING BASIN OF THE HYDROPOWER PLANT DUBRAVA

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Summary: *The paper describes hydrographic survey of cross sections of the stilling basin of the hydroelectric power plant Dubrava which is situated on the river Drava near the city of Varaždin in the Republic of Croatia. The survey was conducted by application of both satellite and echo sound methods, i.e. by integrating GPS_RTK with echo sounder. In the data post processing various software was applied. The primary result of the survey was production of seven cross sections of the stilling basin in scale 1:300/90. The contour plan in scale 1:600 and the 3D model of the stilling basin were also produced. The final result is calculation of the volume of material in the stilling basin of the hydroelectric power plant Dubrava which was eroded downstream between two surveying epochs in years 2015 and 2016.*

Keywords: *Hydrographic survey, stilling basin, hydropower plant Dubrava, contour plan, 3D model*

1. INTRODUCTION

First traces of hydro power usage were found in the region of Mesopotamia and Egypt dating 6000 years B.C. From then water power was used only for powering the irrigation systems until water was used for running the mills that were used to grind wheat grain into flour. The revolution of hydropower usage began in the middle of the 18th century when the French engineer Bernard Forest de Bélidor (1698–1761) published the book *L*'a*rchitecture Hydraulique* where he described hydraulic machines. The first hydropower plant was built in Bavaria in 1876 for the purpose of lighting the cave next to the Linderhof castle, and the first public hydropower plant was built in Switzerland in 1883. Tesla's invention of alternating current and the construction of Niagara Falls Power Plant in the year 1881 are marked as a beginning of a boom of power plant construction whose number

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in 1889 in North America has grown up to two hundred. First hydropower plant in the Republic of Croatia was Jaruga on the river Krka which was put into operation in 1895 and since then in our state that is rich with water resources, vast number of hydropower plants was constructed [1]. In order to keep all the hydropower plants functioning properly there is a need not just for regular mechanical check and service, but also for monitoring of built objects and its environment, in which main role has geodesy, or precisely, engineering geodesy for external objects monitoring and maritime (hydro) geodesy for underwater objects and environment monitoring. This paper describes the survey procedure of seven cross section of stilling basin of the hydropower plant (HP) Dubrava for the purpose of determining the changes of the bottom caused by the water flow in the period of one year, which is determined by the annual surveying plan [2].

2. DAMS

Dam is an integral part of every hydropower plant and one of its most important parts (Figure 1).

Figure 1. Hydropower plant Dubrava dam [3]

Primary purpose of a dam like all the other water barriers, before everything else, is to retain natural flow of rapid or river and enable water flow into the channel which supplies hydropower plant [4]. Dams generally serve for creating reservoirs or retentions aimed to regulate water flow in purpose of flood control, as well as water supply, irrigation, electricity generation, etc. Main parts of a dam are [5]:

- dam body – it accepts water pressure and other forces acting on the dam, and passes them through the core to the bottom and the sides of river valley or riverbed, and it finishes with the crest which usually serves as a maintenance road or a hiking trail,
- spillways – they are placed on the highest point of reservoir and it serves for evacuation of flood water from the reservoir to the riverbed,
- penstocks – they serve for reservoir discharge, water exploitation from the reservoir or rinsing of deposited sediment, and usually are embedded in dam body or side part of a dam,

- stilling basin – part of hydraulic structure in which dissipation of energy is done, when upper and lower levels of water join.

3. STILLING BASIN

All the energy which was accumulated along the slow flow in the river and the reservoir must be consumed in a small area beneath the dam. Stilling basin (Figure 2) is a basin which is by a spillway or a steep slopped canal connected to the natural riverbed, and it serves for dissipating the kinetic energy of exiting water, which prevents erosion and scouring of the riverbed and undermining the dam [5].

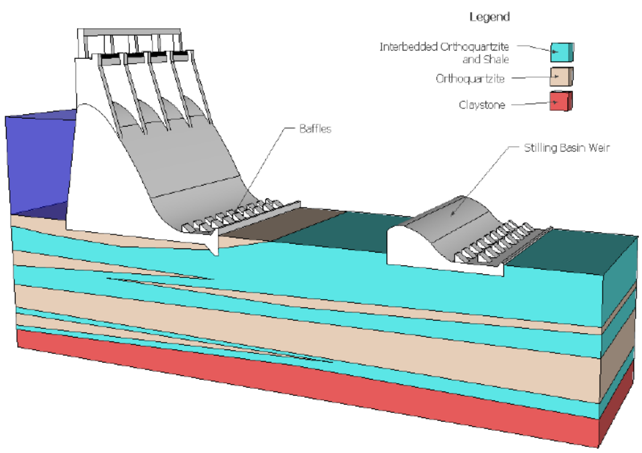

Figure 2. Example of a stilling basin [6]

In a stilling basin, hydraulic jump occurs, or more precisely change of a form of free water surface in form of a jump during transition from rapid to tranquil flow. Biggest part of the accumulated energy is dissipated in vortices which occur during transition from rapid to tranquil flow, while the rest dissipates on friction along the steep slope and on squeezing bubbles of entrained air at impact of the flow in water surface of the downstream flow. There are three different cases of hydraulic jump depending on its position: undular hydraulic jump, strong hydraulic jump and the unstable hydraulic jump when two previously listed types exchange [5]. In praxis engineers strive to undular hydraulic jump. The length of the stilling basin should be equal to the length of a hydraulic jump, but if there are energy dissipaters in the bottom (chute blocks, baffle blocks or similar concrete objects) it may be shorter. In the stilling basin dynamic loads may occur because of the dynamic lift, cavitation or vibrations. Cavitation and vibration occur in the stilling basin as a result of speed and pressure fluctuation in pressure jets and vortices. If the water flow is faster than 25 meters per second prominences in the stilling basin should be avoided. In stilling basins there is a big chance of appearance of the abrasion along the erosion, caused by the sediment which came through the spillways, and exactly because of that there is a need for periodical hydrographic survey of the bottom of the stilling basin with the main objective of calculating amount of the material which was eroded downstream [5].

4. METHODS OF HYDROGRAPHIC SURVEY

Depth measurement or bathymetry is a process of determining the vertical distance between water surface (sea, lake, river, etc.) and bottom in the given moment [7]. Because of the tides, measured depths in different period will have different values, so it is necessary to correct measured depths to a referent surface which is geoid surface or main sea level surface. In that way depths will be in the same referent coordinate system. Depths are measured by classical methods like measuring with pole and manual depth meter, sounding methods (different types of echo sounding) and laser methods in which include LIDAR (LIght Detection And Ranging) and SHOALS (type of LIDAR) [7]. Depth measuring is not goal by itself, but it is carried out in order to product bathymetry maps. For that purpose it is necessary to determine spatial or planar coordinates of the discrete point in which the depth has been measured. First precise positioning of depth meter was made by forward intersection with two theodolites on the shore, and later with the development of optical, and especially electro-optical distance meters, simple tachymetric method was used. Development of Global Positioning System (GPS) led to the start of combining depth meter instruments with GPS instruments. Combination of depth meter and GPS receiver provides simultaneous depth measurement and determination of spatial coordinates of discrete points in World Geodetic System 1984 (WGS84) which are in post-processing most often transformed into the national planar projection coordinate system. Most commonly used combination of surveying instruments in praxis is combination of GPS receiver and echo-sounder. It is constructed in the way that the rod with the GPS antenna on the top, and the echo-sounder probe in the bottom is attached on the side of a vessel. Distance between phase centre of GPS antenna and echo-sounder probe is defined before the start of survey, and its value is constant for which all the measurements should be corrected [7].

5. HYDROPOWER PLANT (HE) DUBRAVA

Hydropower plant (HE) Dubrava with another two plants on the river Drava makes Production Area Sjever (North) [2]. The construction of it started in September of 1984, and it became fully operational in March of 1990. HE Dubrava is the last plant on Drava all the way to river Mura estuary. In comparison with other two plants, its dam is highest, reservoir biggest and derivation canal shortest. Many solutions implemented in the construction of upstream plants during the construction of HE Dubrava dam were additionally improved which gave the flow of almost 6000 cubic meters per second [1].

6. HYDROGRAPHIC SURVEY OF CROSS-SECTIONS OF STILLING BASIN OF HE DUBRAVA

Hydrographic survey of the cross-sections was carried away by the combination of GPS receiver Topcon Hiper V and dual frequency echo-sounder Simrad EA 400 with 1 centimetre resolution and dual frequency probe 38/200 kHz. Dual frequency echo-sounder was chosen because of several advantages:

- 38 kHz signal penetrates the ground enabling insight into the type of soil,
- it can measure depth even in case of overgrown bottom,

- combination of two frequencies enables elimination of errors,
- it measures depths of only 20 centimetres.

Mounting of measuring instruments was implemented by mounting of GPS antenna and echo-sounder probe on a rod which was attached on the side of the boat. Also, inside of the boat have been set up GPS receiver, field computer, walkie-talkie, thermometer and a battery system that powers all the previously listed devices (Figure 3).

Figure 3. Boat with mounted hydrographic equipment [3]

For positioning GPS kinematic method with two base receivers was used. Base was set up on a permanent point of the hydropower plant micro network with known coordinates in the 6th zone of Croatian State Coordinate System. For keeping the boat in the direction of cross-section theodolite was used, and measurements were made only on a tranquil water surface without waves at 2 meter intervals. To calculate the final value of geodetic height of the point measured on the cross-section of the stilling basin, we used next expression:

$$h_T = h_1 - k - d_1 \tag{1}$$

where are:

h_1 – geodetic height of the phase centre of the GPS antenna,

d_1 – depth measured with echo-sounder,

k – constant height difference between phase centre of the antenna and the echo-sounder probe $(k = h_2 + d_2)$,

h_2 – height of the antenna above the water surface,

d_2 – depth of echo-sounder probe submersion.

Measuring on every point implied registration of position obtained by GPS, depth of echo-sounder probe submersion and measured depth.

7. SURVEY DATA POST-PROCESSING

Conducted hydrographic survey covered about 500 points in seven cross-sections of the stilling basin, and all raw data was uploaded into the computer application Profil 32. Application Program 32 was developed specially for work with longitudinal profiles and cross-sections with the possibility of tracking by years, projects and objects inside the projects. By overlapping the cross-sections surveyed several times it is possible to quickly recognize errors, correct them and calculate the differences. Data input can be direct or from the other software or data registers. Also, it is possible to export data in different formats for other software.
Project specifications determine that measuring points on cross-sections must be every 2 meters, but that is impossible to achieve on the water surfaces. To solve that problem, a special algorithm was developed which interpolates data from the raw data in a way that creates new points with measurements at 2 meters intervals. During the survey it is not possible to start from the same point, so the start and end points of cross-sections are permanently stabilized and then it is possible to precisely overlap and compare measurement of surveyed cross-sections. Parts of cross-sections which are in shallow parts along the shore are measured manually and afterwards also manually imported into Profil 32. When that part of the job is done it is possible do draw the cross-section and compare it with the same cross-section surveyed in different epoch.
Drawn profile can be exported in a .dxf file and additionally processed in some other special computer application like AutoCAD Civil 3D which was used in this project. Considering that the points are interpolated in 2 meters intervals, survey marks are also set in 2 meters intervals, cross-section lines are smoothed and closed so it is possible to calculate their areas and later volumes to see if the material is depositing in the stilling basin or erodes.

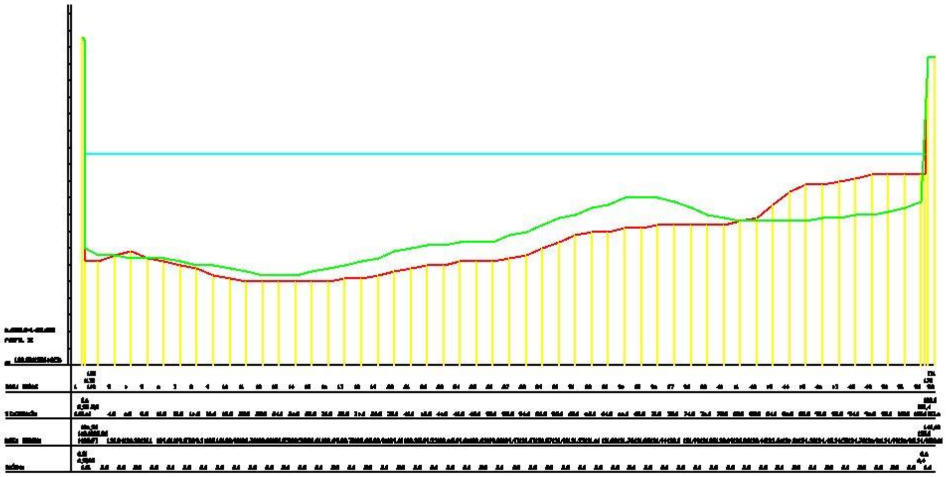

Figure 4. Cross-section surveyed in years 2015 and 2016 [3]

In Figure 4 there is shown one of the surveyed cross-sections. The red line represents cross-section surveyed in 2016, while the green line represents the same cross-section surveyed in 2015. For every profile positive and negative area differences are measured. Areas where the red line is above the green one are considered positive because amount of the material in 2016 is bigger than in 2015, while areas where the red line is under the green one are considered negative because amount of the material in 2016 is lower than in 2015. From measured areas of cross-section and distances between them, difference of material volume between two epochs has been analytically calculated (Table 1). Volumes of the material between a pair of cross-sections was calculated by the expression:

$$\Delta V_n = \left(P_n + P_{n+1}\right)/\left(2 \cdot d_n\right), \tag{2}$$

where are:

- ΔV_n – difference of volume of the material between pair of cross-sections surveyed in two epochs,
- P_n, P_{n+1} – differences of areas in each of pair of cross-sections surveyed in two epochs,
- d_n – distance between two cross-sections.

By summing all the differences of volume of the material between pairs of cross-sections we get the overall volume difference of material which was eroded from the stilling basin in amount of 1080.06 m^3, or on the surveyed area of 7930 m^2 water has eroded on average 14.0 centimetres of material in a period between 2015 and 2016.

Table 1. Analytical calculation of volume of the eroded material [3]

Profile	**Area (m^2)**	**Area (m^2)**	**Distance (m)**
P1	98.25	–225.19	16.10
P2	75.65	–13.20	
Volume (m^3)	1399.90	–1919.04	
P2	75.65	–13.20	11.57
P3	88.20	–48.50	
Volume (m^3)	947.87	–356.93	
P3	88.20	–48.50	11.96
P4	33.98	–60.93	
Volume (m^3)	730.64	–654.39	
P4	33.98	–60.93	15.78
P5	14.38	–51.52	
Volume (m^3)	381.56	–887.23	
P5	14.38	–51.52	15.44
P6	7.72	–40.77	
Volume (m^3)	170.61	–712.48	
P6	7.72	–40.77	5.82
P7	8.33	–37.33	
Volume (m^3)	46.71	–227.27	
Sum (m^3)	3677.28	–4757.35	**–1080.06** (m^3)

Survey data from the years 2015 and 2016 was also processed in a software Surfer 13 in which an interpolation was made by application of kriging method. From the given results the contour map of surveyed area was produced (Figure 5).

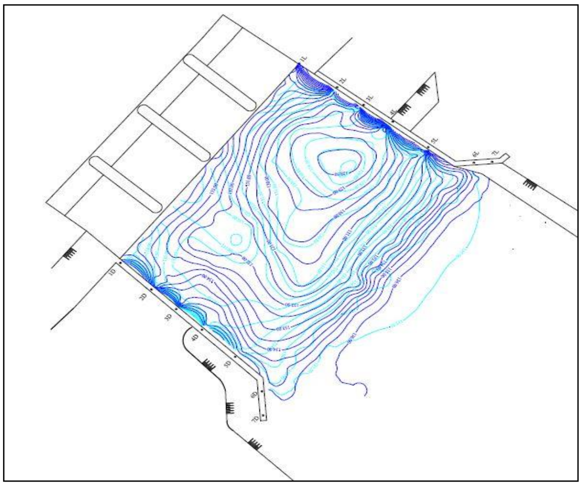

Figure 5. Contour map produced in Surfer 13 (light blue – 2015, dark blue – 2016) [3]

In the same software there were also made 3D models of the area surveyed in 2015 and 2016 (Figure 6).

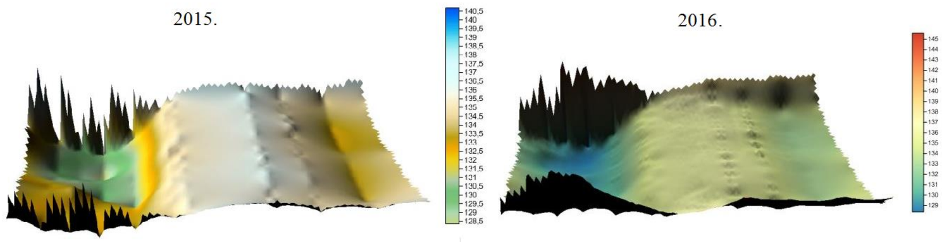

Figure 6. 3D models of stilling basin from the surveying data in 2015 and 2016 [3]

By overlapping two 3D models and starting required tool the software automatically calculates the difference of their volumes. In this concrete project the final result was deficit of the material in amount of 1176.26 m^3 in area of 7930 m^2, which gives us an average of 14.8 centimetres lower bottom of the stilling basin in one year, from 2015 to 2016.

8. CONCLUSION

From overlapping 3D models of the stilling basin from 2015 and 2016, difference of volume is 1176.26 m^3, from which is visible that the height of the material in 2016 is in average 14.8 centimetres lower than in 2015. By calculating the volume difference between pair of cross-sections, surplus and deficit of material for every pair of cross-sections was determined, and in the end by summing all of the volume differences, the overall volume difference was calculated. Analytical method gave us a result of 14.0 centimetres of material in average which was eroded downstream from the stilling basin from 2015 to 2016. By post-processing data survey with two different methods, respectively analytical calculation of volume and automatic calculation from the 3D models, two obtained results were very similar. If the survey was conducted in the bigger area, results between two methods would be even more dissimilar, which means a lot more material. For the projects which demand higher accuracy, distance between cross-sections should be a lot shorter, from 3 to 5 meters, with discrete point distance 2 meters or less. In that way the number of discrete points would be increased, interpolation would be more accurate, and because of that map of the bottom of the stilling basin would be more precise, which would make 3D model a fair view of the bottom, and consequently it would make calculating of eroded material more precise.

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ХИДРОГРАФСКА ИЗМЕРА СЛАПИШТА ХИДРОЕЛЕКТРАНЕ ДУБРАВА

Резиме: *У раду је описан поступак хидрографске измере попречних профила на слапишту хидроелектране Дубрава, на реци Драви у близини Вараждина, у Републици Хрватској. Измера је обављена применом сателитске и ултразвучне методе, тј. интегрисаним системом ГПС_РТК + дубиномер. У поступку обраде* *података примењено је више различитих софтвера. Примарни резултат измере је израда 7 попречних профила слапишта у размери 1:300/90. Израђен је слојни план слапишта у размери 1:600 те 3Д модел слапишта. Коначан резултат је израчунавање волумена материјала на подручју слапишта хидроелектране Дубрава, којег је снага воде однела низводно између две епоха мерења 2015. и 2016. године.*

Кључне речи: *Хидрографска измера, слапиште, хидроелектрана Дубрава, слојни план, 3Д модел*