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THE ANALYSIS OF WATER RELEASE FROM THE HYDRO ACCUMULATION LAKE MODRAC WITH SPILLWAY CURVE AND VOLUME CURVES

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SUMMARY

Dam Modrac is multiple arched reinforced concrete buttress dam, with nine buttresses and ten arches, which by its technical characteristics and volume of the accumulation is considered as one of the high dams. Crown level of spillway is 200.00 m a.s.l. Crest length is 205.00 m, while the maximum height is 27.50 m. To control the water level in the reservoir, under normal hydrological conditions, there are four basic discharges with maximum capacity around Q = 77 m^3/s for the projected state. The paper gives an analytical expression of the spillway curve and analytical expressions of amounts of water discharge separately for each bottom outlet, which are obtained by conducted measurings. Special significance of this paper gives volume curves for hydro accumulation Lake Modrac for projected state and the period of use of the system.

Keywords: *hydro accumulation, dam, bottom outlet, spillway curve, volume curve*

INTRODUCTION

During the design and construction of dams and hydro accumulation Lake Modrac, it was planned for it to serve as a multi-purpose water management system. It was planned to provide continuous and safe supply of industrial capacity Tuzla basin with water, to partially supply the population of Tuzla and Lukavac with water, to lessen big waves of water and prevent flooding of agricultural land in Sprecko Field areas downstream from the dam profile, to protect against other destructive effects of water disarray and allow land reclamation of Sprecko irrigation fields and enable solution of industrial wastewater and municipal sewage as well as to contribute to the reduction of water pollution by dilution of waste water through the discharge portion of the accumulated water.

Currently the system only meets the demands for water supply for industry and party for population with drinking water and reduces large water waves. Also, to a lesser extent and ensures the production of electricity.

Dam Modrac with its basic outlets and spillways are part of the system which with the amount of discharged water directly affects the accumulation, its volume and the water level.

The established minimum operating level at an altitude of 195.00 m a.s.l., with useful storage capacity of $64x10^6$ m^3, in which it is still possible to supply consumers with water. Since in this area critical drought periods occurs between June and November, it is necessary at the beginning of this period, if this hydrological conditions allow, to achieve and maintain the water accumulation level at an altitude of 199.50 m a.s.l.

BOTTOM OUTLETS

The dam Modrac has four bottom outlets, used to manage the water accumulation. The bottom outlets are located on the buttresses number 2, 6, 7 and 8 measured from the left coast. The bottom outlets 6, 7 and 8 are at an altitude of 187.00 m a.s.l., while the bottom outlet number 2 at level 190.00 m a.s.l. The amount of water discharged with the bottom outlets is regulated with floodgates and directly depends on the floodgate openness. During designing the theoretical value of the shape function and hydraulic characteristics of the discharge and the coefficient α was determined. Actual value of the coefficient α was determined by tare of the outlets. The measurements were taken at the level of the hydro accumulation at an altitude of 198.96 m a.s.l. and 199.26 m a.s.l. [1].

According to performed measurements the analytical expression was determined, which is defined by the equation:

$$Q = \alpha \cdot \sqrt{\Delta H} \tag{1}$$

The preceding formula is derived from Bernoulli's equation for the section upstream of the dam and the output, and a control section of discharges. The value of the coefficient α for certain bottom outlet is determined on the basis of water flow amount which is measured on the dam with known difference ΔH which represents the height difference between the water level and the level of axis of discharge shaft on the outlet. The value α depends on the degree of openness of the shutter on the bottom outlet. Based on the data on the degree of openness as well as of data on elevations of hydro accumulation Modrac, it is possible to calculate daily flow values of certain bottom outlets according to the formula number 2.

$$Q = \alpha_i \cdot \sqrt{H - K} \tag{2}$$

where is:
α_i – coefficient dependent on the openness of the shutter (S)
H – level of the water level in the hydro accumulation
K – level of axis of shutter at the exit of the bottom outlet.

The results of processing of the experimental data, and functional dependency of the coefficient α from the size of the shutter S, are given in Table 1.

Table 1. A functional dependency of coefficient α form S

Outlet number	K (m a.s.l)	S									
		1	2	3	4	5	6	7	8	9	10
		$\alpha_i (m^{5/2} s^{-1})$									
2	190.00	0.391	1.199	1.972	2.680	3.375	3.976	4.436	4.830	5.159	5.192
6	186.55	0.294	1.235	2.065	2.732	3.460	4.120	4.650	5.185	5.625	5.690
7	186.51	0.246	1.088	1.870	2.590	3.210	3.780	4.225	4.650	4.980	5.040
8	186.55	0.485	1.372	2.468	3.296	3.997	4.628	5.105	5.525	5.834	5.850

For each of the four bottom outlets there are determined formulas for the amount of discharged water for the maximum level of opening the shutter, as follows:

Bottom outlet number 2:

$$Q = 5{,}192 \cdot \sqrt{(H - 190{,}00)}$$

Bottom outlet number 6:

$$Q = 5{,}690 \cdot \sqrt{(H - 186{,}55)}$$

Bottom outlet number 7:

$$Q = 5{,}040 \cdot \sqrt{(H - 186{,}51)}$$

Bottom outlet number 8:

$$Q = 5{,}850 \cdot \sqrt{(H - 186{,}55)}$$

The following diagram shows the dependence of the coefficient α in relation to the openness of the shutter S for each of the four bottom outlets on the dam Modrac [1].

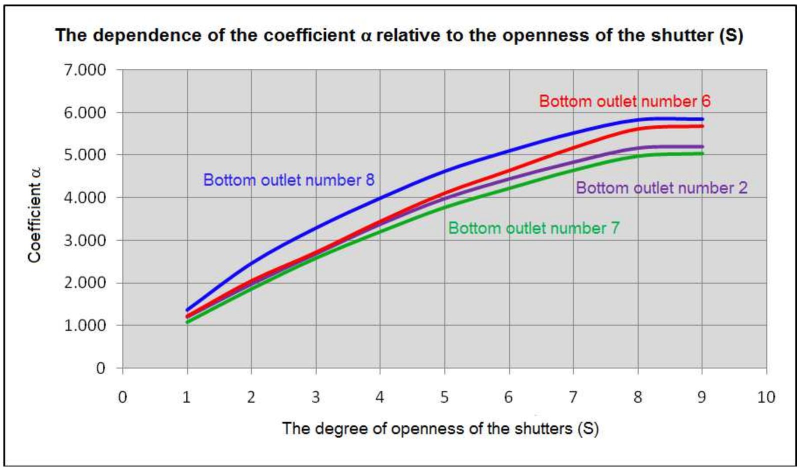

Figure 1. The dependence of the coefficient α to the openness of the shutter S

It should be noted that on the bottom outlet number 2 was built small hydropower plant 2 MW in 1998, which uses the excess amount of water available for production of electricity. The management capacity of the hydro accumulation Modrac in the function of certain flows, can be done manually and is reduced to the manipulation of shutters on three bottom outlets (6,7 and 8).

SPILLWAY BAYS AND SPILLWAY CURVE

For the evacuation of high water, in addition to the bottom outlets, there were predicted three spillway bays, with the maximum amount of spill of about Q = 1000 m^3/s, thus providing the evacuation of high water of river Spreča with the occurrence rank 1/1000. Spillway bays are structures that represent the adaptation of the basic custom arches for the free flow of water above level of spillway (level of 200.00 m a.s.l.). Spillway bays are designed in the form of a ski jump and thus "destroy" part of the energy before it falls downstream from the dam, in the flow of the river Spreča.

The presence of a high water flow of water in the hydro accumulation is larger than the capacity of bottom outlets of the dam, which for an elevation of the normal slowdown of the hydro accumulation (200.00 m a.s.l.) is about Q = 77 m^3/s. The difference in flow between influx and efflux from the hydro accumulation is spilled over the spillway bays of the dam Modrac. Spillway level increases until such time as it equals the amount of water flowing into the hydro accumulation and the amount of water that flows out of the hydro accumulation (bottom outlets, consumers and spillage over the spillways) [2].

The elevation of the water level above the spillway bays, so to speak, temporarily increases the total volume of the hydro accumulation. This practically means reducing the size of the maximum axis of flood wave downstream from the hydro accumulation, and the hydro accumulation Modrac, respectively, with is its retention effect that influences significantly on reduction of the flooding in the area downstream of the dam Modrac [3].

Analytical expression of functions of spillway is depending on the water level in the hydro accumulation Modrac and is provided by a method of the smallest quadratic deviations. This function is used when calculating the maximum water flow, or when the water level is above the level of 200.00 meters above sea level. It is then that the water supply is so large that it cannot be released only through the bottom outlets, so the level in the hydro accumulation rises and when it reaches the level of the spillways (200, 00 m a.s.l.), water starts to overflow over the spillway bays number 6, 7 and 8.

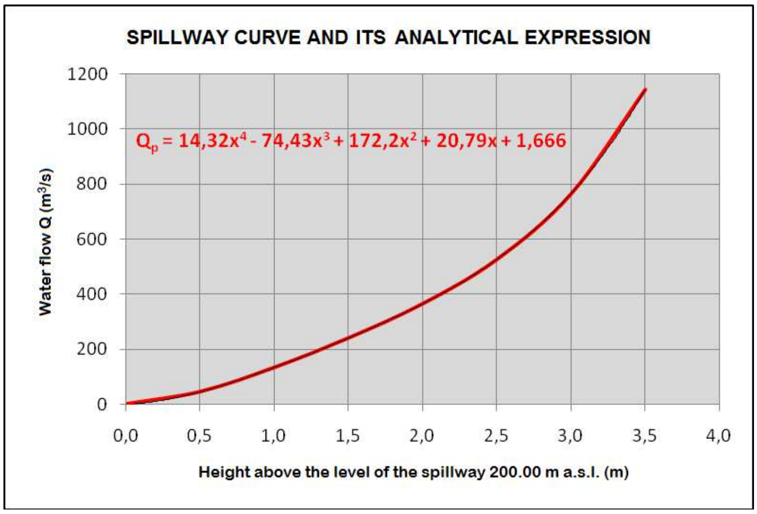

Figure 2. The spillway curve with its analytical expression

The inflow of water into the hydro accumulation Modrac is not defined directly, or by measuring the flow in the main watercourses Spreča and Turija, but indirectly through the level and the volume of the hydro accumulation as well as from the data on the release of water from the hydro accumulation. In this way it was obtained a series of medium daily inflow values in the hydro accumulation, for the period from 1980 to 2012. The interpretation of these data was performed in the form of variations of the annual inflows in the specified period and the average inflow duration curves [4].

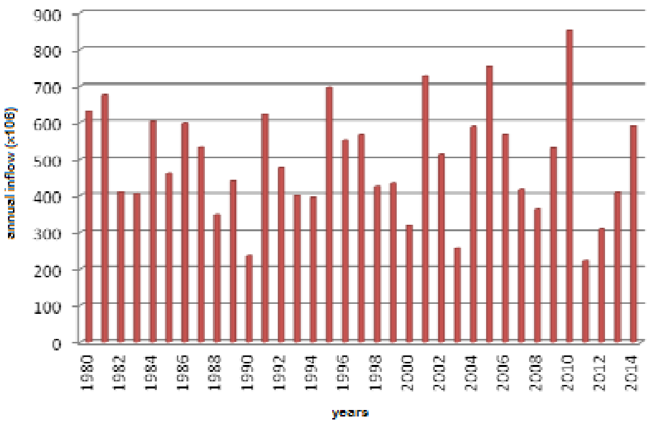

Figure 3. Variation of the annual inflow of water into the hydro accumulation for the period 1980-2014

From the diagram of variation of the annual inflow into the hydro accumulation, shown in Figure 3, it can be concluded that the water inflow into the hydro accumulation was in the range of 220 to 860 million m3. During this period, the minimum value of water inflow into the hydro accumulation Modrac was in 2011, while the highest value was in 2010 [4].

Inflow duration curve in the hydro accumulation Modrac is an important factor that affects the operation of the dam spillway bays. This curve shows the torrential hydrological regime of watercourses in the basin of hydro accumulation.

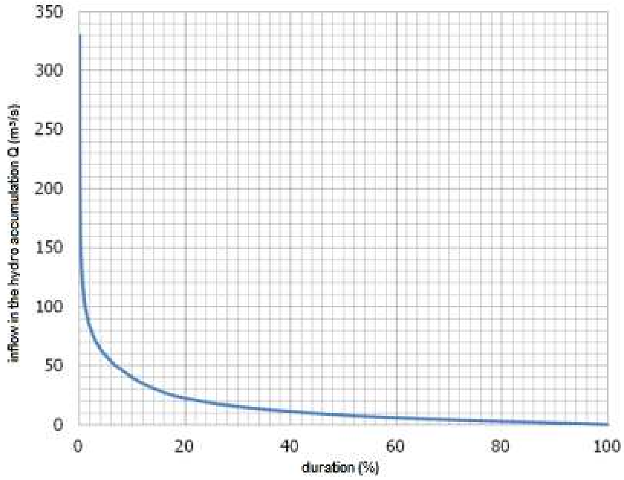

Figure 4. The inflow duration curve in the hydro accumulation Modrac

VOLUME CURVES

The volume of each of hydro accumulation is essentially divided into the dead space volume and the usable volume [5].

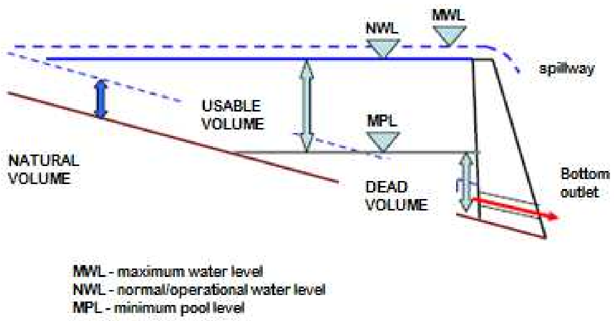

Figure 5. Basic volumes of hydro accumulation

The volume of so-called dead space is used for the placement of the deposits in front of the dam and represents an area of water that is not used, while the usable volume of the hydro accumulation represents the volume of water for ensuring the needs of the consumers which are water supply, power generation, etc. Volume of hydro accumulation Modrac was eventually reduced because of the considerable amount of sediment, mainly coal dust from the mine Banovići. In order to properly determine the natural flows in different periods of time, it is necessary to know the volume curve. Therefore, at certain time intervals geodetic surveys are carried out at the bottom of the hydro accumulation and consequently a volume curve can be constructed [6].

The first geodetic survey of the planned hydro accumulation was carried out in 1953, by recording the cross sections at a distance of 200 m, and the first volume curve was formed for the level of normal backflow (level 200.00 m a.s.l.) of 100 x 10^6 m^3 [7,8].

Because of the tracking intensity of the backfilling of deposits on the hydro accumulation from river Spreča, Turija and Oskova and as well as backfilling of deposits coal dust from coal separation Banovići and Đurđevik, a recording was carried out of sections of the hydro accumulation at different intervals of time, form 6 ot 7 years. Based on these measurements the volume curves were formed with its analytical expressions, as shown in Figure 6.

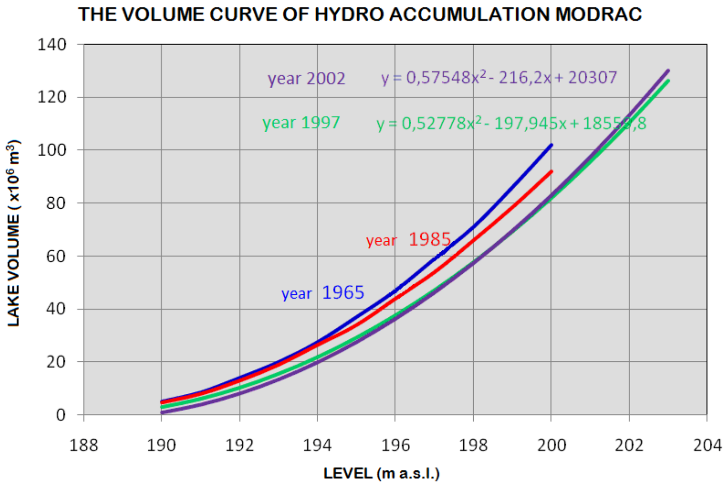

Figure 6. The volume curves of hydro accumulation Modrac for 1965, 1985, 1997, 2002

CONCLUSIONS

Maximum throughput of the dam Modrac through evacuation organs is 1200 m^3/s at the level 203.00 m a.s.l. and this is the level of the dam crown, and the level of the dam arches. The amount of discharged water is regulated with the bottom outlets and spillway organs and depends on currant water level in the hydro accumulation Modrac. Since the amount of discharge of water is limited by the level of large water waves, there is an increase of water level in the hydro accumulation and thus it accepts a fraction of the volume of the water wave, and makes reduction of the maximum flow rate. Reduction of the maximum flow downstream of the dam Modrac ranges from 17% to 47% depending on the size of water wave as well as of the water level in the hydro accumulation.

The volume of hydro accumulation Modrac was decreased by 9% until 1985. The sediment that comes from the zone of the mine as a loss on mining facilities has fine granulometric structure and is transported in the form of suspended sediment, so it does not participate in the formation of reefs in the riverbed of Spreča. These reefs were created by stopped and deposited bed load, which comes from the river basin. Hydrographical network of torrential streams in the basin is highly developed with a large number of watercourses. Torrent streams take erosion deposits in Speča and Turija, with which it comes to the hydro accumulation Modrac. The torrential hydrological regime in the observed basin is characterized by short duration of high waters and very long duration of low waters and a wide range of flows (Q_{max} /Q_{min}).

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