DAM ENGINEERING IN REPUBLIC OF MACEDONIA: RECENT PRACTICE AND PLANS

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ABSTRACT

The construction of dams in the Republic of Macedonia dates from 1938, and until now 27 large dams have been constructed which enclose impounding reservoirs, with total storage capacity of 2.4 km^3. The dams are mostly multipurpose, serving for irrigation, electricity production, flood control and water supply. The highest dams among them are the embankment dams *Kozyak* with structural height of 130 m, *Tikvesh* (113.5 m) and *Shpilje* (112.0 m). The potential of rivers in Republic of Macedonia is utilized to 27%, and still there is a permanent shortage of water for various purposes. Due to this fact, as well as due to strongly expressed uneven distribution of water, it is indispensably necessary to construct new large dams with impounding reservoirs. According to the national planning documents Water Master Plan and Spatial Plan, more large dams have been planned, the major of them are being: Boshkov Most (river Jadovska), H = 45 m, 70 MW, 127 GWh/year; Chebren (river Crna), H = 192 m, 150 MW, 286 GWh/year; Galishte (river Crna) H = 140 m, 195 MW, 257 GWh/year; Lukovo Pole, 103 GWh/year; Gradec (river Vardar), H = 42 m, 55 MW, 252 GWh/year; Konjsko (river Konjska), irrigation; Rechani (river Orizarska), multipurpose.

There are four active tailings dams in Republic of Macedonia, very important for our copper, lead and zinc mines. After a period of stagnation, in the last 10 years the mines have been restarted and tailings dams in their composition have been activated and raised.

Use of advanced methods for structural two- and three-dimensional analysis of dams was successfully applied in scientific and practical tasks. The obtained results were compared with monitoring data, thus leading to verification and calibration of the model and monitoring instruments and assessment of dam stability during construction and service period.

Most of the dams were constructed up to 1982 and a need of some reparations and replacement of the monitoring equipment is necessary. A project for rehabilitation of monitoring systems of some important dams in ownership of the public utility Macedonian Power Plants ELEM, financed by KFW bank from Germany, have been recently realized.

1. Introduction

Republic of Macedonia is located in the central part of the Balkan Peninsula, in the area between $20^0$27' and $23^0$01' longitude East (East from Greenwich) and $40^0$51' and $42^0$21' latitude North. It covers an area of 25,713 km^2 with a population of about 2.1 million inhabitants. Its mountain relief, vast valleys and numerous long and narrow ravines distinguish the topography of the Republic of Macedonia.

The rivers in Republic of Macedonia belong to three main river basins: (a) The Aegean basin, in which they flow out through the rivers Vardar and Strumica; (b) The Adriatic basin, to which they are taken away through the river Crn Drim (Black Drim); and, (c) The Black Sea basin, through the river Binachka Morava, which extends over a quite insignificant part. The biggest is the catchments basin of the River Vardar, which extends to some 20,525 km^2 or 80% of the territory of the Republic of Macedonia. Total available surface water resources in the Republic of Macedonia are assessed as about 3,300 m^3 per capita annually.

The annual average precipitation in the entire state is approximately 730 mm/year, but it ranges from 380 mm in some parts of Eastern and Central Macedonia, up to 2000 mm in some mounting regions of Western Macedonia. The distribution of the rainfall is very unfavourable in space and time and relatively small in quantity, as a result of the Continental climate and the Mediterranean influence. The uneven distribution of the precipitation in time and space results in long dry periods (summer-autumn and shorter winter periods). On the other hand, there is abundant rainfall between October and December, and limited rainfall between March and May. Such a distribution of the precipitations, together with the other meteorological phenomena categorizes Republic of Macedonia as a semi-arid area.

Total water demands in the country are 2,030 million m^3 annually. Dominant user of the water is the irrigation with 900 million m^3 (46%), then minimum accepted flows with 635 million m^3 (28%), follows industry with 275 million m^3 (14%) and drinking water supply of the population and tourists with 220 million m^3 (12%).

The use of water for electricity production, which is closely connected with the dams and reservoirs, is also very important, taking into account that it is a renewable and adaptable energy resource. Total hydropower potential of Republic of Macedonia is estimated on 5,500 GWh/year and currently is used only 27% or 1,500 GWh/year, with installed power of 530 MW. Depending on the hydrological conditions, the hydropower covers mainly from 10 to 20% of the total energy demands in the country. For illustration, the annual production in 2000 was 1,170 GWh, in 2002, 755.4 GWh, in 2005, 1,344.7 GWh, in 2007, 910.6 GWh, in 2009, 1,097.6 GWh and in 2010, 2,184.8 GWh. Among 11 existing hydropower plants (HPP) on the large reservoirs, the most important are: Vrutok (27% of total production in average), Shpilje (24%), Tikvesh (17%), Globochica (15%), small HPPs (11%), Vrben (3%) and Raven (3%). The HPP Vrutok, Raven and Vrben are units of one cascade system – *Mavrovo*.

2. Dams in Republic of Macedonia

The construction of dams with reservoirs in the Republic of Macedonia dates from 1938, when the *Matka* arch dam was constructed, located on the River Treska, in the vicinity of Skopje, still in service, since 2008 with double capacity, after the construction of a new power plant. Until now 27 large dams have been constructed which enclose impounding reservoirs with total volume of about 2.4 $\times 10^9$ m^3, Figure 1 and Table 1. The golden period for dams construction was 1952-1972, when 13 important reservoirs were formed by large dams: *Mavrovo* (dam height 54 m), *Globochica* (82.5 m), *Vodocha* (42 m), *Tikvesh* (104 m), *Kalimanci* (85 m), *Shpilje* (101 m), *Turiya* (77.5 m), *Lipkovo* (29.5 m), *Gratche* (29 m), *Mladost* (27 m), *Prilep* (35 m), *Ratevska Reka* (49 m), and *Glazhnja* (71.5 m) [1, 2]. Up to 1982 five new large dams were commissioned, the largest and most important between them being *Strezhevo*

(76 m), especially important for the region of the city of Bitola. During the last 15 years the reservoir construction was again intensified, resulting to the finishing of the projects *Kozyak* (114 m, highest dam in Macedonia), *Loshana (*41 m, our first rock-fill dam with geomembrane facing, [3, 4]), *Markova Reka* (26 m),*Lisiche* (66 m), *Knezhevo* (75 m) and *Saint Petka (64.0 m)*. The dams *Kozyak, Tikvesh,* and *Shpilje* are largest projects of this type, enclosing reservoirs with volume range of a half billion m^3 [5, 6, 7].

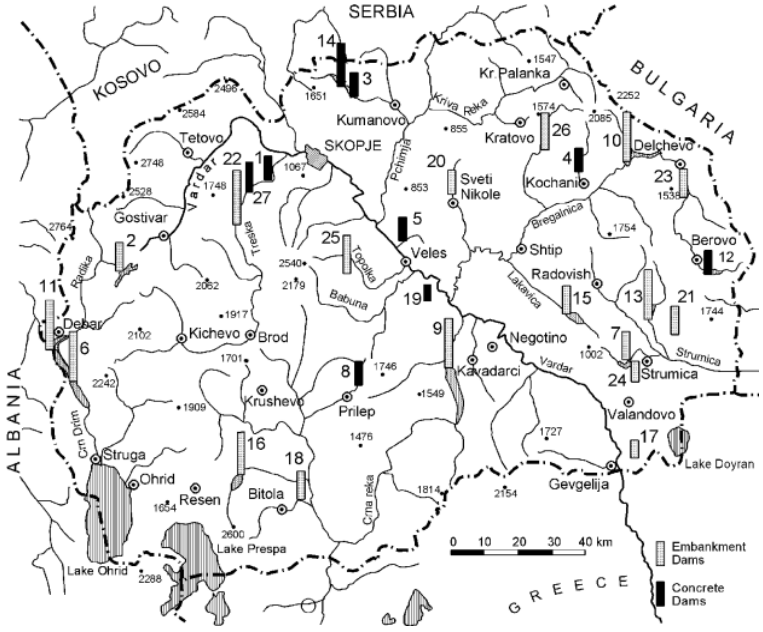

Figure 1. Large dams in Republic of Macedonia

Table 1. Large Dams in Republic of Macedonia

Name	River	Year completed	Type	H [m]	H_S [m]	L [m]	V_D [m^3×10^3]	V_R [m^3×10^6]	Purpose
1. Matka	Treska	1938	AR	29.5	38	64	3	3.55	HEP
2. Mavrovo	Mavrovska	1952	EAR	54	62	210	777	357	HEP, IR
3. Lipkovo	Lipkovska	1958	AR	29.5	40	203	13	2.25	IR, WS
4. Gratche	Kochanska	1959	AR	29	43	150	12	2.4	WS, IR
5. Mladost	Otovica	1962	AR	27	34	73	2.56	8	IR
6. Globochica	CrnDrim	1965	E-R	82.5	90	196	998	58	HEP
7. Vodocha	Vodocha	1965	E-R	4	48.7	185	316.8	26.7	IR, WS
8. Prilep	Oreovechka	1966	MA	35	38.5	408.5	25.5	6	IR
9. Tikvesh	Crna Reka	1968	E-R	104	113.5	338	2722	475	IR, HEP
10. Kalimanci	Bregalnica	1969	E-R	85	92	240	1389	127	IR, HEP
11. Shpilje	Crn Drim	1969	E-R	101	112	330	2699	520	HEP
12. Ratevska	Ratevska	1972	AR	49	53	194	21.7	10.5	WS, IR
13. Turiya	Turiya	1972	E-R	77.5	93	417.3	1978	48	IR, WS, HP
14. Glazhnja	Lipkovska	1972	AR	71.5	80	344	168	22	IR, HEP
15. Mantovo	Lakavica	1975	E-R	37.5	49	138	261	47.5	IR, WS
16. Strezhevo	Shemnica	1982	E-R	76	84.6	632	4300	112	IR, WS, HEP
17. Paljurci	Luda Mara	1982	EAR	21.1	21.5	310	185	2.9	IR
18. Suvodol	Suvodolska	1982	EAR	33.9	38.3	941	1740	7.88	R, WS
19. Podles	Vodnik	1985	AR	18	22.5	92	6.7	0.31	IR
20. Mavrovica	Mavrovica	1999	EAR	24	29	360	400	2.8	WS, IR
21. Ilovica	Ilovichka	2004	E-R	27.8	29.8	274	131	0.5	WS, IR
22. Kozyak	Treska	2005	E-R	114	126	300	3340	550	R, HEP, WS
23. Loshana	Loshana	2006	R-F	41	45.2	165	260	1.08	WS
24. Markova R.	Markova R.	2006	E-R	26	30	72.5	64.6	0.66	WS
25. Lisiche	Topolka	2008	ERT	66	76.9	579.6	3295	23	WS, IR
26. Knezhevo	Zletovska	2011	E-R	75	83	290	1550	23.5	WS, IR, HEP
27. Saint Petka	Treska	2012	AR	41	66	115	32.5	9.1	HEP

Table key: H–height above ground; Hs–structural height; L–length of dam crest; V_D–dam volume; V_R–maximum reservoir capacity; EAR–earth-fill dam; E-R–earth-rock dam; R-F–rock-fill dam; AR–arch dam; MA–multiarch; WS–water supply; IR–irrigation; HEP–hydroelectric power; R–retention.

Various kinds of dam sites are presented in Republic of Macedonia concerning the geological, topographical and hydrological conditions. That is why between the constructed dams there are both concrete and embankment dams. Most of the large dams – 18, were constructed of local materials: clay, sand, gravel and rock, while 8 dams were constructed as concrete arch dams, and only one as concrete multiple arch dam.

The most important reservoirs formed by large dams in Republic of Macedonia are:

Matka (St. Andrea) – the first artificial lake in Macedonia (1938), 3.55×10^6 m^3 reservoir volume, formed by an arch concrete dam (29.5 m high), located in the exit of the river Treska from a picturesque narrow gorge (Fig. 2). All structures, together with the reservoir, are very well adapted to the terrain and to the nature. The purpose of the reservoir is electricity production, with the installed capacity of the power plant of 3.2 MW, not small for the period just before the Word War II. After the refurbishment recently done, the installed capacity was doubled.

Figure 2. The new penstocks and power plant of Matka dam; behind is the old power plant, now a museum (view from the dam crest).

Mavrovo – very important lake, at altitude of 1200 m.a.s.l., formed with the first Macedonian embankment dam (also one of two first dams of this type in former Yugoslavia), constructed in the period 1947-53. The reservoir capacity is more than 300 million m^3, while the maximum depth is around 50 m. It gains water not only from the own catchments area, but also from the adjacent catchments area of the river Radika, through a specially constructed water supplying tunnel. It serves mainly for electricity production by means of three power plants (more than 400 million kWh per year), but also for recreation, tourism, and fishing. The mountainous environment surrounding the lake is extremely nice.

Vodocha – constructed on the river having the same name (1965), with reservoir volume of 26.7 million m^3, formed by an earth-rock dam, 44 m high. The purpose of the reservoir is irrigation, but it serves also for fishing and recreation.

Prilep – a reservoir with volume of 6 million m^3, formed by a unique multi-arch buttress dam, 35 m high. The main aim of the reservoir is irrigation of the famous tobacco fields surrounding the town of Prilep.

Tikvesh – one of the largest Macedonian reservoirs (total volume 475 million m^3, length 22 km), formed by an earth-rock dam, 104 m high, constructed in 1968 on the River Crna, the largest tributary of Vardar. This reservoir, aimed for electricity production and irrigation of the agricultural fields in the central part of Macedonia, is of the great importance for the state

economy. The lake is rich with different kinds of fish – examples of carps and spearfish up to 100 kg have been caught. Tikvesh Dam was the highest embankment dam constructed in former Yugoslavia [8].

Kalimanci – the largest reservoir in the Eastern Macedonia, with volume of 127 million m^3, formed by an earth-rock dam 85 m high, on the river Bregalnica, the largest left tributary of Vardar. This reservoir has a key-role in the agriculture of this dry region, irrigating the fertile fields near the towns of Kochani, Shtip and Sveti Nikole. A small power plant also is in operation.

Shpilje – one of the three largest Macedonian artificial lakes (1969), reservoir volume 520 million m^3, located on the river Crn Drim, near the Albanian border, formed by an embankment dam, 101 m high. The river Crn Drim flows out from large natural Ohrid Lake. By means of a simple regulating structure Ohrid Lake is an excellent compensation basin for the two downstream power plants with artificial reservoirs: Globochica (V=58 million m^3) and Shpilje. The mean annual electricity production of Shpilje plants is around 300 million kWh. With the high dams Globochica and Shpilje, as well as with the three dams on the river Drim in Albania, the migration path of the eels from Ohrid Lake to Sargasso Sea has been broken.

Ratevska Reka – located in the mountainous eastern region, formed with a double curvature arch concrete dam 49 m high, near the town of Berovo, at elevation of around 1000 m.a.s.l. It serves for water supply, irrigation, and recreation.

Turiya – with volume of 48 million m^3, closed by means of an earth-rock dam 77.5 m high, enables the water supply of town of Strumica, as well as irrigation of the rich surrounding fields. Secondary purposes of the reservoir are electricity production in a small power plant, and fishing.

Glaznja – located on the Lipkovska River (the nearest city Kumanovo), formed by the highest concrete dam in Republic of Macedonia (71.5 m). The reservoir volume is 22 million m^3. Commissioned in 1972, has served for water supply, irrigation and electricity production (in a small power plant).

Mantovo – a key structure in the frame of the eponymous irrigation system. The reservoir volume is 47.5 million m^3, formed by an earth-rock dam 37.5 m high, very important for the agriculture of the region of Radovish.

Strezevo – a large reservoir (109 million m^3), formed by damming the river Shemnica with an earth-rock dam, 76 m high. The reservoir is a part of a modern hydro system, aimed for: irrigation of more than 20,000 ha agricultural field in the plain Pelagonia, water supply of the city of Bitola and the adjacent large thermo power plant, and for electricity production in two small power plants.

Kozyak – located on river Treska, some 16 km upstream from dam Matka, in a narrow dam site. Commissioned in 2004, this reservoir is a key-structure of the multipurpose hydraulic scheme with the main task flood control, with retention storage of 100×10^6 m^3. Also, it serves for electricity production (152×10^6 kWh per year), as well as for water-supply (in future). The total reservoir volume is 550 million m^3, formed by the earth-rock Kozyak dam, (Fig. 3), the highest in Republic of Macedonia (114 m above the terrain, 130 m above the foundation). The dam body is constructed from rockfill (limestone), taken from the quarry near the dam, while the waterproof element is in the form of slightly inclined clay core. Due to rather unfavourable geological conditions in the zone of the reservoir, as well as in the dam site (presences of carstified limestone, faults, and so on), extensive grouting works have been performed to reduce the seepage. In order to define the stress-strain state of the dam body following the loading history of the structure, Kozyak Dam was analyzed by means of both two- and three-dimensional numerical models (Fig. 4), with application of two different software packages. Very complex three-dimensional model (time consuming and requires much more effort than two-dimensional one), was necessary because the dam site sides are very steep: the left 1:1.5 (Ver:Hor), and the right even 1:1. In such cases appreciable influence of the three dimensional effects is to be expected. The analysis was conveyed taking into account: (a) the constructed geometry of the dam body, (b) geotechnical

parameters of the materials gained from control tests in the construction period, (c) the real loads during the dam construction, and (d) the regime of the first reservoir filling and water level fluctuation at the beginning of the service period [9]. The results from the analysis served for comparison with the measured results and their verification. The comparison showed that calculated displacements in the body of Kozyak dam, at different stages of construction and reservoir fluctuation, are in the frame of expected ones for an earth-rock dam with structural height of 130 m. Also, the calculated values of the displacements are in a good accordance with measured ones. For illustration of some results, in Figure 5 the lines of equal horizontal displacements parallel to the longitudinal dam axis (y-axis) are shown (a). The direction of the displacements is from abutments towards the middle part of the dam, where a zero displacement line is formed. Maximum values are below 20 cm, and appear approximately at the middle of the dam height. The appropriate lines of equal vertical displacements are shown in Figure 5b. Maximum value of 113.4 cm appears in the middle.

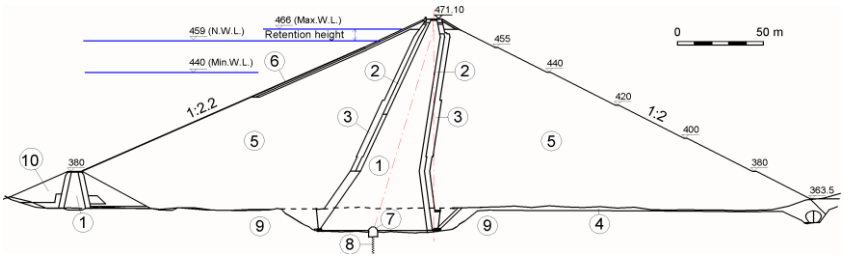

Figure 3. Main cross section of Kozyak Dam. (1) Clay core; (2) first transition zone; (3) second transition zone; (4) river deposit; (5) rockfill shells (limestone); (6) arranged slope protective stones; (7) grouting gallery; (8) grout curtain; (9) rock foundation (limestone); (10) gravel in the upstream cofferdam.

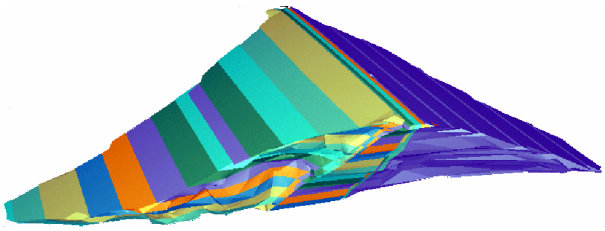

Figure 4. Kozyak dam, general view of the dam body, generated by the 3D FEM model.

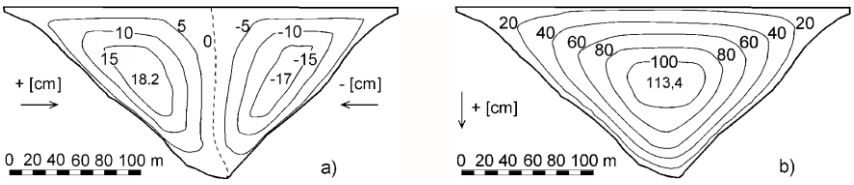

Figure 5. Kozyak dam, longitudinal section trough the inclined central clay core plane: a) lines of equal horizontal displacements parallel to the longitudinal dam axis (y), b) lines of equal vertical displacements, i.e. settlements (z).

Lisiche – with volume of 23 million m^3, closed by means of an earth dam 66 m high, in the first stage enables the water supply of town of Veles. In the second stage irrigation of the surrounding fields is planned.

Knezhevo – with volume of 23.5 million m^3, formed by our first rockfill dam with asphaltic core, 80 m in height, commissioned in 2011 (see the cross section in Figure 6). This is a multi-purpose scheme, very important for the eastern parts of Republic of Macedonia [10]. The dam is a key structure in the frame of the hydro-system Zletovica, planned to fulfill

following purposes: water supply of the population and the industry in several municipalities, irrigation of 3000 ha of agricultural land, electricity production, and retention of the flood waters. The dam body construction started in September 2008 and it was completed at the end of December 2009, (Fig. 7), with a break of three month during the winter 2008/2009. The construction of the dam body was accomplished by domestic construction companies Beton and Granit, while for the asphalt core, constructed by special contemporary machinery, was employed specialized company Kolo Veidekke from Norway.

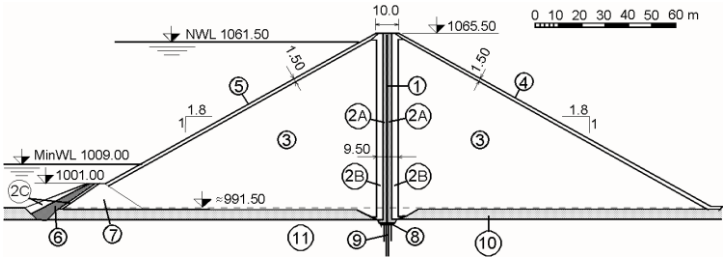

Figure 6. Typical cross-section of the Knezhevo dam. (1) Asphaltic concrete core; (2A) fine transition zones, crushed andezite, 0-60 mm; (2B)coarse transition zones, crushed andezite, 0-250 mm; (2C) filter in the cofferdam; (3) rockfill - schist, stones up to 650 mm; (4) downstream protection, large blocks; (5) rip rap, andezite, blocks up to 800 mm; (6) clay core in the cofferdam; (7) rockfill in the upstream cofferdam; (8) reinforced concrete plinth; (9) grout curtain; (10) river alluvium; (11) rock foundation..

Figure 7. Knezhevo dam, placement of the top asphalt layer on 29 of December 2009(left), and completed dam with reservoir space prepared for first filling (right, 2010).

The monitoring system of Knezhevo dam includes various instruments, installed for measurement of displacements, pressure in the foundation, seepage discharge through the dam body and foundation, etc. First time in a dam in Macedonia was installed so called DSM system (displacement system of measurement), containing devices installed in two dam cross-sections, placed in two different elevations, allowing measurement of the internal settlements of the rockfill in the dam body. Also for the first time in Macedonia, in Knezhevo dam was installed optical fiber cable, just downstream of the waterproof element, with an aim to register any change in the temperature, which is more or less constant inside the dam body. Therefore, any sudden change of the temperature means a leakage. The temperature reading allows indirectly detecting leakage through the core, but this method enables not only detecting a leakage, but also to determine its location.

For the purpose of as-built design, the dam was analyzed in 2010 by means of both two- and three-dimensional model (ratio Length:Height=280:80=3.5<4). Analyzes were performed using the software packages SOFiSTiK (Germany) and Geo-Slope (Canada). All different material zones of the dam body were included in the analyses, the dam construction process was simulated in 10 increments, while the reservoir impounding in 3 increments. To enable differential movements in the contacts between materials with different deformation

properties, the whole contact dam body – rigid foundation, as well as the contact asphaltic core – fine transitions, was modeled by special plane contact elements. Knezhevo dam body and foundation (with the irregularities in the shape) were discretized practically without any modifications. The consequence was very large number of finite elements and nodes. Despite the dam was completed during the first half of 2010, it was commissioned at the end of 2012, due to some unsolved problems in the hydro-system as a whole. Therefore, the first reservoir filling is not yet completed, thus the measured values can not be compared with calculated ones. Especially interesting would be to see how would fit the real horizontal displacements of the asphaltic core after the first reservoir filling with gained ones by FEM. In the early 1980s one of the authors of this paper has analyzed a hypothetical rockfill dam with an inclined asphaltic concrete core using two-dimensional FEM with hyperbolic constitutive relation. The dam material properties were similar with those of Finstertal dam. Very good agreement with measured values at Finstertal dam was gained, Figure 8 and B, of course, taking into account the difference in the dam's height. Expected horizontal displacements of the asphaltic concrete core, calculated by the described three-dimensional FEM model in the first half of 2010, are shown in Figure 8C.

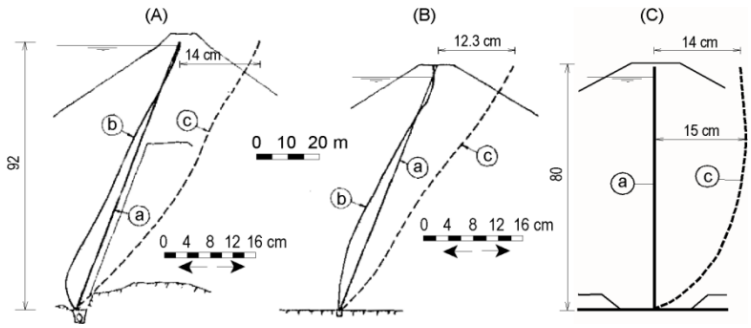

Figure 8. Horizontal displacements of the core after first reservoir filling at Finstertal dam, Austria (A, measured values), at a hypothetical dam 80 m high (B, calculated by 2D FEM), and at Knezhevo dam (C, calculated by 3D FEM). (a) Designed position of the core axis; (b) position of the core axis after the dam construction; (c) position of the core axis after the first reservoir filling.

Saint Petka – located between existing dams Matka and Kozyak, commissioned in 2012, with main purpose energy production (36.4 MW, 53 GWh/year). Saint Petka dam is 64 m high double curvature arch dam (Fig. 9), forming reservoir with volume of 9.1 million m3. Saint Petka HPP enables optimal use of the hydro potential of river Treska, i.e. with its construction the cascade system composed of HPP Kozyak, HPP Saint Petka and HPP Matka is completed.

Figure 9. Dam and power plant Saint Petka (October, 2012)

2.1 Small dams

In the Republic of Macedonia there are around 110 small dams. All of them are earthfill type, built mainly in the period from 1960 to 1980, and some of them after 1980. Our small dams create reservoirs with the volume less than 500,000 m^3, aimed mainly for irrigation of surrounding agricultural land. Most of them are with height from 8 to 15 m, but there are also some higher then that – up to 18 m and more. In Republic of Macedonia is not applied the ICOLD classification, by which all dams higher then 15 m belong to the group of large dams. The Ministry of Environment and Spatial Planning, decides whether the dam will be treated as large or it will be counted as small dam. In the process of decision making not only the height of the dam is taken into consideration, but also the volume of the reservoir, menace of the people and goods at eventual breakdown and etc. [11].

2.2 Tailings dams

The tailings dams belong to hydraulic structures; however, according to their type of construction and materials used, they cannot be equalized with the classical dams due to their purpose – deposition of waste materials, instead for water storage, necessary for man survival. However, the similarities between tailings dams and embankment dams have contributed many procedures and techniques, developed for designing, construction and maintenance of embankment dams to be applied at tailings dams. Yet, numerous reports on hazards at tailings dams in the last few decades worldwide and also in Republic of Macedonia, point on conclusion that technical safety was not verified at same level as in case of embankment dams. This fact arises primarily from the long lasting construction of tailings dams (as construction material is used sand obtained by process of hydro cycling during service stage of the tailings dams), amplified with the solutions on capacity increase of the deposit lake, thus additionally prolonging the service period.

There are four active flotation tailings dams at mines in R. Macedonia: Buchim (Radovish), Sasa (M. Kamenica), Zletovo (Probishtip) and Toranica (Kriva Palanka). The importance of the mining industry in Republic of Macedonia can be seen from the official data from the State Statistics Institution. According to the data on the gross-domestic product (GDP) for 2011, the industry participated with 18% in the total structure of the GDP, and mining sector participates with 1.5%. According to the data on added value from 2010, the participation of the department "Metals production" is 9.34% in the total industrial production. Therefore, the tailings dams, although they are civil engineering structures with highest potential hazard on the environment, in future will also be current structures in Macedonia. In the following will be given sublime of our largest tailings dams Topolnica and Sasa.

Topolnica – in the frame of copper mine Buchim, Radovish, created by deposit of flotation pulp. By method of pulp hydro cycling from the sand is created downstream dam and the spillway from the hydro cyclones is released in the upstream deposit lake. In that way, in the deposit lake is performed mechanical deposit of the coarsest particles and chemical treatment of the used reagents, present in the tailings. The construction of the sand dam, up to elevation 610.0 m.a.s.l., was done in skew layers, by progressing in downstream direction of the initial dam. Afterwards, the construction of the sand dam up to elevation 630.0 m.a.s.l., due to the proximity of village Topolnica (directly to the downstream toe of the dam), was done by filling in upstream direction. In the final stage is adopted crest heightening of the sand dam, up to elevation 654.0 m.a.s.l., by progressing in upstream direction, Figure 10. The tailings dam Topolnica, with height above foundation at the initial dam of around 120 m (upon completion will rich 134.0 m), is one of the highest tailings dams in Europe. Up to 2011 in some 105×10^6 tons of tailings have been deposited, and current crest of the sand dam is at elevation 642.0 m.a.s.l.

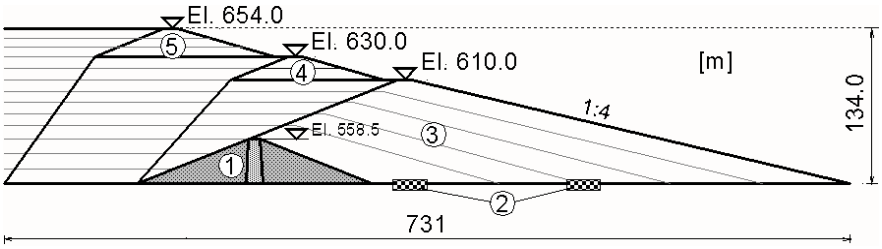

Figure 10. The cross section of Topolnica tailings dam. (1) Starter dam; (2) longitudinal base drainages; (3) first phase sand dam, constructed using downstream method; (4) second phase sand dam, constructed using upstream method; (5) third phase sand dam, constructed using upstream method.

Sasa –in composition of mine Sasa, Makedonska Kamenica (Fig. 11), serves for deposit of floatation pulp (tailings), obtained by technological process on flotation of zinc and lead. The flotation tailings is transported by gravity pulp-line, and before depositing by hydro cycling is classified in two products: (a) sand, by which repose deposit downstream tailings dam shell is constructed, and (b) silt, which fills the deposit lake of the tailings dam. Along the valley of Saska River up to now four tailings dams (no. 1, 2 and 3-1) are constructed, currently active tailings dam no. 3-2, and for deposition of the tailings after 2015 construction of tailings dam no. 4 is planned. The structures for creation of tailings dam no. 3-2 are: an initial dam, water conveyor, diversion tunnel and drainage system. These structures, for lake level at 960 m.a.s.l. and crest level at 962 m.a.s.l., are constructed in the period 2006-2007. To increase the capacity of the tailings dam no. 3-2 heightening is adopted from elevation 960 m.a.s.l. up to maximal possible level of the deposit lake, established at 972 m.a.s.l, for annual production of 900.000 tons of mine. The full height of the tailings dam no. 3-2 above the rock foundation (dam, tailings and foundation with river deposit) is around 100 m.

Figure 11. Tailings dams Sasa, upstream slope of dam no. 3-1 and deposit lake no. 3-2 (2011).

As it was already mentioned, a common practice in our country is the application of modern methods of dam analysis [12]. Advanced numerical methods for evaluation of static and dynamic stability of both Buchim and Sasa tailings dams have been widely used. In this way, the complex questions like rate of deformations, pore pressure, liquefaction etc., were analyzed and the stability of these responsible structures for different construction phases was confirmed.

3. Maintenance and operation

The large dams and their reservoirs are operated by different operators depending of the main use of the stored water. The public utility Macedonian Power Plants ELEM is responsible for operation of the reservoirs which main purpose is energy production, while other dams are mainly operated by the public Water Economy Enterprises, Agro-combine or

private Water Organizations. According to the new law, the waters are under responsibility of the Ministry of environment and spatial planning.

During the whole period of 75 years construction and service of dams and large reservoirs in Republic of Macedonia, there was no serious incident, despite of the chronic lack of funds for maintenance and reparation. Monitoring and surveillance have been performed continually, but a lot of devices are out of use and have to be repaired, or replaced. A project for rehabilitation of monitoring systems of some important dams in ownership of the public utility Macedonian Power Plants ELEM, financed by KFW bank from Germany, have been recently realized in cooperation with SISGEO from Italy. The project consists of installation of probes at dam monitoring instruments, automation of the measurements, bar-coding of each instrument and creation of web-server with data base in monitoring station in the administrative building of HEC "Crn Drim" in Struga.

4. Environmental impact

The major number of dams and reservoirs were constructed more than 40 years ago, which presents sufficient period of time for assessment of the environmental impact. The analyses and the assessment are rather positive due to the location of dams and applied technical solutions. The dams are mainly located in the mountains where there were no populated areas, or significant industrial or economic facilities. With small exceptions, there was no need for large resettlement of the population or facilities. The situation is similar with the new planned dams. All of them should be constructed in non-populated areas, no significant size of irrigable lands, facilities or cultural and historical monuments should be flooded, and no specific or protected species would be endangered (with rare exceptions). The Environmental Impact Assessment Study is a legal obligation as part of the Feasibility Study documentation [13].

5. Future plans

According to the national planning documents Water Master Plan and Spatial Plan, more hydropower projects have been planned (all with large dams and reservoirs), the major of them are being: *Boshkov Most,* river Jadovska, H = 45 m, 70 MW, 127 GWh/year; *Chebren,* river Crna, H = 192 m, 150 MW, 286 GWh/year; *Galishte,* river Crna H = 140 m, 195 MW, 257 GWh/year, *Gradec,* river Vardar, H = 42 m, 55 MW, 252 GWh/year, *Veles*, river Vardar, H=61 m, 93 MW, 300 GWh/year. Two of these reservoirs, *Chebren* and *Galishte*, will serve also for irrigation.

The *Lukovo Pole* project will be extended to increase electricity generation for 103 GWh/year of the three existing plants in the frame of the hydro-system Mavrovo: Vrben, Vrutok and Raven. It will include a 71 m high embankment dam with a reservoir of 39×10^6 m^3.

To meet the increased demands for different purposes, another large dams with reservoirs are planned, as: *Rechani,* river Orizarska, near the town of Kochani, H = 80 m (multipurpose, with main aim water supply, recently the base project was finished), *Konjsko,* river Konjska, near the town of Gevgelija, H = 75 m (also the base project recently finished), *Vakuf,* river Kriva Reka, (multipurpose); *Razlovci,* river Bregalnica, irrigation; *Plavaja,* river Plavaja, irrigation; *Buchin*, (multipurpose); *Paligrad*, river Kadina Reka, (multipurpose) [7].

6. Summary

Concerning the number of citizens and the area of territory, it can be concluded that Republic of Macedonia has a rich practice of dam construction. From the first finished dam

in 1938 up to now 27 large dams and, about 110 small ones, have been constructed. The total volume of the reservoirs is around 2.4 $\times 10^9 m^3$.

With two-three exceptions, the large dams in Macedonia have been constructed on rock foundations and in relatively favorable topographical conditions. The most of dams are of embankment type, but, also one multiple arch dam and eight arch concrete dams have been constructed. Among embankment dams three are higher than 100 m and they are appreciable achievements not only for Macedonian conditions. Embankment dams are mainly of earth-rock type, but, in the latest time a geomembrane facing, as well an asphaltic concrete core, have been applied as a waterproof element at two rockfill dams. The geomembrane facing and asphalt core were proposed recently for the waterproof element of recently designed Rechani and Konjsko dam, respectively.

Most of the dams were constructed up to 1982 and a need of some reparations and replacement of the monitoring equipment is necessary. Several such projects were realized last ten years.

After a period of stagnation, in the last 10 years some mines have been restarted. Consequently, tailings dams in their composition have been activated and raised. The tailings dams as hydraulic structures require safety verification at same level as in case of embankment dams in order to prevent potential hazards.

Use of advanced methods for structural two- and three-dimensional analysis of dams was successfully applied in scientific and practical tasks. The obtained results were compared with monitoring data, thus leading to verification and calibration of the model and monitoring instruments and assessment of dam stability during construction and service period.

The need of water for different purposes increases from year to year. On the other hands, an appreciable part of the river potential in Macedonia is still unused. That means we have to build new dams in order to create more reservoir space for water supply, irrigation, electricity production, flood control, and so on. The development must respect the principle of sustainability, and the environment has to be protected.

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