CURRENT CONDITIONS OF LARGE DAMS IN BOSNIA AND HERZEGOVINA

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ABSTRACT

Transition of society with all therewith associated problems, as well as the war events in Bosnia and Herzegovina during the 1990s had had significant impact not only on country's economic development, but have directly or indirectly impacted technological systems and complex structures like large dams. In addition, the long existence period of large dam projects provides satisfactory amount of information and data necessary to estimate how successful these projects were, conduct analyses on their current safety, and recommend the measures required to increase the level of their efficiency. With regard to previously mentioned facts and modern approach in the treatment of large dams, detailed expert analyses and studies have been conducted in the last fifteen years in Bosnia and Herzegovina resulting in clear recommendations indicating the necessity for undertaking concrete technical interventions on a large number of dams. Proposed activities have already been carried out on some of them, on few dams interventions are ongoing, whereas future activities on remaining dams are in planning stage.

This paper, created with the aim of sharing recent experiences, provides an overview of the large dams in Bosnia and Herzegovina with the focus on their current conditions, and conducted and planned activities on their rehabilitation.

Key words: seepage, concrete rehabilitation, dam safety, dam foundation stability, grout curtain

1. INTRODUCTION

According to the International Commission on Large Dams (ICOLD) classification, up until now twenty-five large dams have been built in Bosnia and Herzegovina (BiH), including the two dams on the bordering river (Zvornik and Bajina Bašta) whose status is still unclear. The majority of these twenty-five dams have been built in the second half of the 20th century, and their construction and operation have been overseen by the Public Utility Elektroprivreda BiH, water management company Vodoprivreda BiH and a few other socio-economic entities.

Political changes and events in the 1990s caused a cessation in the construction of new dams, thus all current dam-related activities consist of maintenance of existing dams.

Meanwhile there have been significant changes both in jurisdiction and in technical/financial capability. Therefore, it is interesting to point out to the current state of engineering practice and various activities regarding existing dams in BiH.

2. DEVELOPMENT OF ENGINEERING PRACTICE REGARDING LARGE DAMS IN BiH

2.1 The period before the year 1990

The first and only large dam built in BiH in the 19th century is Klinje Dam on river Musnica. It was completed and started operating in 1896 with the main purpose of providing a water supply to nearby Gacko Field. It is a 26 m high and 4.6 m wide arch stone dam with the crest length of 104 m. Reservoir of Klinje Dam is nowadays used for water supply of nearby located thermal power plant Gacko.

Intensive dam construction in BiH essentially began in the second half of the 20th century when between 1950 and 1990, total of twenty-four dams were built. The pioneer dam was Jablanica Dam on the Neretva River, designed and built as a Yugoslavian project which established the human resources and technical capacity for the future design and construction of large dams in BiH. This led to formation of corporations such as “Energoinvest“ and “Hidrogradnja“, which designed and built Jablanica Dam as well as almost all other dams in BiH, and later successfully spread their expertise to foreign hydropower markets.

BiH dam professionals have actively participated in both the Yugoslavian Committee of Large Dams and ICOLD sharing their experience, expertise and achievements with others. They were respected and admired especially in the field of research, design and construction of large dams in karst regions. BiH dam professionals initiated the formation and actively participated in a number of faculties and research institutes where they assumed a leading role in numerous scientific projects.

The last large dam built in BiH is Tribistovo Dam, completed 23 years ago in 1990. Next table presents the list of all large dams in the country with their basic characteristics.

No.	Dam Name	Year Built	River	Type	Height(*) (m)	Intended Use
1	KLINJE	1896	Musnica	PG	26.4	S
2	JABLANICA	1954	Neretva	VA	85.0	H
3	JAJCE II	1954	Vrbas	PG	26.0	H
4	ZVORNIK	1955	Drina	PG	41.0	H
5	SASE	1960	Saska r.	TE	28.0	X
6	ALAGOVAC	1962	Alagovci	TE	22.8	S,I
7	MODRAC	1964	Spreca	MV	33.0	S,R,H

8	GORICA	1965	Trebisnjica	PG	33.5	H
9	BAJINA BASTA	1966	Drina	CB	90.0	H
10	GRANCAREVO	1967	Trebisnjica	VA	123.0	H,C
11	HAZNA	1967	Hazna pot.	TE	23.0	C,R
12	MANDAK	1968	Mandak	PG	30.0	H
13	RAMA	1969	Rama	ER	103.0	H
14	VIDARA	1972	Vidara pot.	TE	15.0	C,R
15	BUŠKO BLATO	1974	Ricina	TE	19.0	H
16	ZUNA TOMASICA	1975	Zuna	TE	47.0	S,R
17	DRENOVA	1978	Drenova	ER	15.0	S,C
18	BOCAC	1981	Vrbas	VA	66.0	H
19	GRABOVICA	1982	Neretva	PG	59.0	H
20	SALAKOVAC	1982	Neretva	PG	69.5	H
21	VRBA	1983	Vrba	TE	31.0	S
22	SNJEZNICA	1985	Rastosnica	TE	58.5	S
23	MOSTAR	1987	Neretva	PG,TE	44.0	H
24	VISEGRAD	1989	Drina	PG	79.5	H
25	TRIBISTOVO	1990	Ruzicki pot.	ER	23.0	S

(*) from the dam foundation

TE	Earth	CB	Buttress	PG	Gravity	F	Fish breeding
ER	Rock Fill	VA	Arch	MV	Multiple Arch	X	Others
H	Hydropower	C	Flood control	N	Navigation		
S	Water Suply	I	Irrigation	R	Recreation		

Before 1950	1950-1960	1960-1970	1970-1980	1980-1990	1990-2013
1	4	8	4	8	0

2.2 The period after the year 1990

The intended use of dams and corresponding reservoirs vary: most of them have been built exclusively for hydropower production and the rest for water supply and other purposes. Out of total dam number 28% are single-purpose dams, whereas 72% of dams have been constructed with the aim of multipurpose utilization. Power utility companies control 64% of these dams, while 36% of them are controlled by water management companies.

After the completion of the Višegrad dam and hydroelectric plant, Elektroprivreda BiH planned to build the hydroelectric plant Foča and other cascades on the upstream part of Drina River and, accordingly, undertook a number of activities around the completion of the main projects and preparatory field works. However, the historical events and war break out that followed not only brought economic development and dam construction to a halt, but also greatly diminished technical and professional resources capable of carrying out such projects. As a result, not a single dam has been built in BiH from 1990 to date.

The main factors contributing to such a situation are as follows:

- Elektroprivreda BiH, which up until the war was the main catalyst in the process of design and construction of large dams, was split into three companies namely Elektroprivreda BiH, Elektroprivreda RS and Elektroprivreda HZ HB.
- Vodoprivreda BiH (Water Management company of BiH) nowadays also exists as three separate entities: Agency for Sava River Water District and Agency for Adriatic Sea Water District both in Federation of Bosnia and Herzegovina, and Public Institution “Vode Srpske“ in Republika Srpska.
- Energoinvest and Hidrogradnja, companies which have emerged from the experts working on the earlier mentioned Jablanica Dam project, and by the 1990s gained

wide international recognition, are currently struggling for survival without a clear vision and future prospects similar to all other state-owned enterprises in BiH.

- Typical of a country in transition, BiH exists with all negative effects that come with that process: disrupted system of values and competences, undefined relations between private and government ownership, unfair competition process, lack of clear development strategy, etc.
- Issues such as complex political inner structure, conflicting national and ethnic interests, uncoordinated legislation, and dependence on foreign factors make BiH an overly complex and ineffective country. Because of that, professional associations are either non-functional or function with many difficulties, technical symposia and workshops are not held and consequently, technical professionals experience a kind of total scientific blockade.
- Amid the total collapse of economic and manufacturing capacity and poverty of the general population, the excess of energy generated has emerged that is currently being exported in significant quantities. It is not clear for how long such a situation could last, nor is there a state-level strategy for what is to come afterwards.

However, during this period some activities related to the existing dams in BiH have been conducted including the reconstruction and modernization of the dam safety related equipment, rehabilitation and repair of various defects stemming either from war-related damages or malconstruction, modernizing dam monitoring systems, improvements in general dam safety as well as organizing professional associations. The above mentioned activities were initiated due to different events like:

- War-related damages (Snjeznica, Salakovac and Mostar dams),
- Floods (Grabovica and Jablanica dams),
- Occurrences endangering the stability of dam foundations (Višegrad Dam),
- Necessary safety improvements for safe flood passage (Bočac Dam),
- Necessary rehabilitation of dams with compromised structural stability (Modrac, Hazna and Vidara dams).

Initial organized activities had begun during the 90s war when the dam professionals, who were present in the Sarajevo region, got together, prepared the necessary documentation and applied for BiH membership to ICOLD. After the positive response from ICOLD, a Statutory Meeting was called and BHCOLD was established as a legal entity with all necessary legislative acts.

During the first few years of existence, BHCOLD was working normally and maintained contact and fulfilled its obligations towards ICOLD. However, all BHCOLD's activities have stopped shortly thereafter due to the following reasons:

- BHCOLD was formed during a period of deep divisions and disagreements in the country without knowledge and participation from parties who at that time were independently creating their political status. After the war ended, these parties did not participate at the BHCOLD activities due to different reasons.
- Paying of fees and expenses ended up being the responsibility of a few companies based in Sarajevo and after several years even those companies ceased their participation in such payments.
- Eventually, due to the enthusiasm of a few individuals, dam professionals from the entire BiH territory agreed to participate in BHCOLD. However, it was impossible

to organize an Electoral Convention which would verify legislative acts and elect different BHCOLD bodies.

- The mandate of the BHCOLD membershas long expired, some have passed away, some have retired and ceased professional participation, while some have moved on to other enterprises.

Currently, BHCOLD exists only on paper. Contacts with ICOLD are discontinued and government entities that own and operate the existing large dams in BiH do not show any intent of re-establishing the workings of BHCOLD as an association of BiH dam professionals.

Besides all above mentioned facts, it is also important to note that several activities have been conducted recently related to preparing of technical documentation as well as actualization of projects developed, but not constructed prior to the 90s war.

3. CHARACTERISTIC EXAMPLES OF REHABILITATION OR RECONSTRUCTION OF DAMS IN BiH

This chapter brings few characteristic examples of rehabilitation or reconstruction of dams in Bosnia and Herzegovina in recent years.

3.1 HPP Bočac dam

HPP Bočac is located adjacent to the toe of a 66-meter high concrete arch dam on the River Vrbas. The power plant was commissioned in 1981 and, apart from a short stoppage during the 90s war, it has been in regular operation ever since. The two-unit powerhouse has installed capacity of 110 MW and average annual generation of 307.5 GWh.

Flood discharge facilities consist of a 2-bay side spillway equipped with radial gates and a discharge tunnel, which was used as a diversion tunnel during the construction (Fig.1). Flood discharge facilities have been designed for the 1000-year return period and their combined capacity, including the low level outlet, at maximum flood surcharge reservoir elevation (which is 1 m higher than the maximum normal elevation) is Q0.1 = 1490 m^3/s.

Hydrological analyses, carried out in year 2000 within a framework of the conceptual design phase of the downstream located projects HPP Krupa and HPP Banja Luka, resulted in design flood values for various return periods that were significantly different from the original estimates. According to these hydrological analyses, the 1000-year flood for Bočac Dam was estimated to be 2073 m^3/s, which is about 40% higher than the 1000-year flood of 1490 m^3/s derived during the original design. It was concluded that the new design flood exceeds capacity of the existing discharge facilities, which would lead to the dam overtopping with unknown consequences in a case of such flood occurrence.

Based on field investigations, research and analyses that followed, the potential risks were quantified and possible solutions for safe passage of the new design flood were identified. All potential solutions have been thoroughly analyzed and verified using numerical and hydraulic models. The four options for increasing capacity of discharge facilities were identified as feasible:

1) Construction of an additional spillway bay in the left side with similar geometric characteristics to the two existing spillway bays. In addition, the flood discharge would pass through a new 5.5 m diameter tunnel also located in the left side;
2) Construction of a 80 m long free crest spillway with its sill elevation equal to the maximum flood surcharge reservoir elevation, and a 6.0 m diameter discharge tunnel approximately parallel to the existing tunnel;

3) Construction of facilities as in option (2) above but located on a left river bank, with small modifications in the design of a 5.0 m diameter discharge tunnel;
4) Raising of the dam at a particular location on the arch so that powerhouse and switchgear are protected, and overtopping of the dam is allowed at the 50 m long portion of the arc adjacent to the right side.

Eventually, the option (3) has been selected and is currently being implemented.

As a consequence, an 80 m long free crest side spillway on the left side is being constructed (Fig. 2). The spillway is activated as soon as the reservoir rises to the maximum flood surcharge elevation. A 5.0 m diameter discharge tunnel curves and transitions into a chute located on the right abutment, then crosses the access road and ends with a jump. At the 2.5 m head (which is 0.5 m lower than the dam crest elevation) the side spillway and discharge tunnel can pass 580 m^3/s, which is equal to the capacity deficit of the existing discharge facilities.

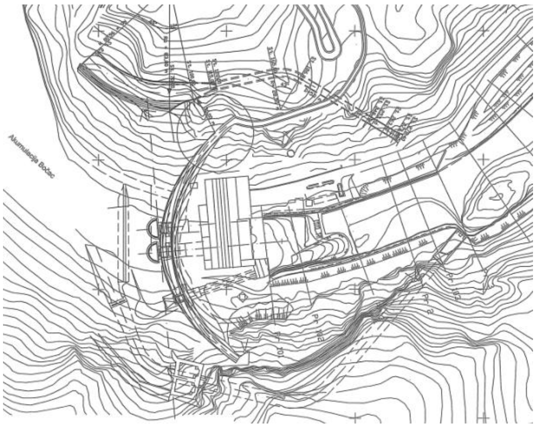


Fig. 1:HE Bočac layout

Fig. 2:Additional discharge facilities – construction site

3.2 HPP Višegrad dam

HPP Višegrad is located on the River Drina, adjacent to the toe of a 79.50-meter high concrete gravity dam with the 280 m long dam crest.Installed flow value of 800 m^3/s, and flood discharge facility capacity of 11000 m^3/s classify Višegrad as the largest hydro power plant in Bosnia and Herzegovina.

The construction of Visegrad Dam on the Drina River was finished in the late 1989. The three-unit powerhouse has installed capacity of 315 MW and average annual generation of 1010 GWh.

During the reservoir test-filling, while the grout curtain was being completed, the occurrence of boils was noticed in the river bed downstream of the dam. Water coming from these boils was turbid indicating the connection of boils to the seepage from the reservoir. The design team developed and undertook monitoring program to analyze these phenomena and simultaneously enhanced the grout curtain with additional grout holes in order to ensure stability of the dam. The results of monitoring program indicated that the seepage zone was located under the grout curtain (i.e. its segment #5), and the seepage amount was 1.40 m^3/s. All further activities were stopped in 1992 due to the commencement of war in BiH.

The monitoring and research program resumed after the war in 1996, and it was revealed that both the number and yield of boils have significantly increased. Measurements carried out in 2008 indicated that the seepage amount have increased tenfold to 14 m^3/s (Fig. 3).

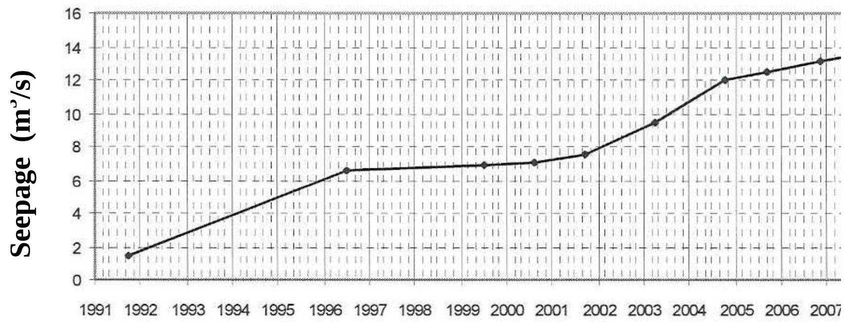


Fig. 3: Change in seepage with time

During 2009, comprehensive geological, hydrogeological and geophysical investigations were carried out including detail geological mapping; deep drill holes from the upstream face of the dam; detailed land survey of the dam location including bathymetric survey of the reservoir and downstream area where the boils have occurred; borehole geophysics; geo-electric and seismic 2D tomography; equipotential tracing including the "mise a la masse" method; and numerical modelling of surface and groundwater hydraulics.

These investigations revealed fairly large underwater hole located in the central part of the reservoir about 140 m upstream of the dam. This hole and its geometry was analyzed using underwater cameras, and it was estimated that the water loss to this hole was approximately 8-9 m^3/s. Considering rather large capacity of the hole and its connection to the boils downstream of the dam, it was decided to start conceptual design of the rehabilitation.

The conceptual design solution assumes backfilling the underwater hole in the reservoir with granular backfill in order to fill caverns and karst channels under the body of the dam as much as possible. After that, the additional backfilling of caverns will be done through the large drill holes (∅ 200-600 mm) drilled from the upstream face of the dam. Once the caverns and karst channels were completely filled, the special mixture will be injected to further compact existing backfill material, following which the drill holes will be closed.

Following preparatory works have been completed to date:

- Improvement of access roads, set up and preparation of construction, building of the dock for storage of the backfill material; building of the system for transport of the backfill material from the dock to the underwater hole in the reservoir, drilling of the preliminary drill holes adjacent to the upstream face of the dam (10 drill holes with depth ranging from 180-195 m below the bottom of the reservoir), drilling of the additional piezometric wells within the grout curtain gallery located in the body of the dam (3 piezometric wells 110-145 m deep)
- Various monitoring equipment was installed in the preliminary drill holes, piezometric wells and downstream boils. The preliminary drill holes were equipped with piezometers, sensors measuring salt (NaCl) concentration, equipment for the geo-electric 2D tomography between the drill holes. The boils in the river bed downstream of the dam were equipped with underwater video cameras, flow velocity meters and sensors measuring salt concentration. All monitoring equipment was wired to data-loggers which are wired to the central computer where all results are stored and could be accessed at any time.

It is planned that the project progresses in three phases:

1) The first phase consists of testing the granular stone backfill material (0-4 mm, 4-8 mm, 8-16 mm, 16-32 mm i 32-64 mm). The reservoir hole will be test-filled with 200 m3 of

each of the three fractions of the granular stone backfill. After the test-fill and checking the stability of individual fractions through underground channels as well as analyzing monitoring results, the optimal mixture of the granular material will be determined and used for the permanent backfilling. The first phase will end when the reservoir hole is completely backfilled. After that, the entrance to the hole will be plugged by a concrete plug.

2) The second phase consists of widening of the existing preliminary drill holes on the upstream face of the dam and, if necessary, drilling new larger drill holes (∅ 200-600 mm). The wider drill holes will be used for direct injection of the backfill into the existing caverns with the aim to fill the cavern areas that have not been filled by backfilling the reservoir underwater hole.
3) In the third and final phase of the project, once the caverns and karst channels were completely filled, a cement or concrete mixture will be injected to further compact existing backfill material.

The project works commenced in October 2012 and preparatory works are currently in their final phase (Fig. 4). The main contractor is renowned European company.

Fig. 4: Preparatory works

Fig. 5: Boils in the river bed downstream of the dam

3.3 HPP Jablanica dam

The Jablanica power plant was commissioned in 1955. The arch-gravity dam located on the Neretva River is 85 m high. The powerhouse revitalization, completed in 2008, resulted in increase in the installed capacity from 150 to 180 MW. The average annual generation is 770 GWh.

Flood discharge is passed through an 8-bay spillway equipped with fish-belly flap gates. The flap gates originally had only two positions, open and closed, which prevented precise control of the reservoir level. The flap gate reconstruction resulted in enabling partial gate opening and better control of the reservoir level.

Spillway discharge jet energy dissipation was solved by allowing spontaneous formation of the scour hole over several years of operation. In the meantime waste-rock from the quarry located just downstream of the dam had been entering the river, which resulted in formation of the almost-impermeable barrier behind which a pond of significant depth was formed. This benefited the spillway energy dissipation since spillway discharges could now plunge to greater depths thereby dissipating more energy. However, the created pond also resulted in submergence of the low level outlet as well as some equipment for its operation (that has subsequently been relocated on higher ground).

No analyses of the possibility of the overtopping of Jablanica Dam from the downstream side have been conducted to date.

3.4 HPP Grabovica dam

The Grabovica project is located on the Neretva River, about 12 km downstream of Jablanica. The project consists of a power plant adjacent to a 60 m high concrete gravity dam. The two-unit powerhouse has installed capacity of 114 MW and average annual generation of 334 GWh.

This project is located in a very narrow canyon along which major traffic routes pass (road and railroad), which greatly limited project layout options and also made construction activities more difficult.

Flood discharge is passed through a 2-bay spillway equipped with radial gates and a discharge tunnel, which was used as a diversion tunnel during the construction. During operation of the power plant has been noticed that, for discharges greater than 1300 m^3/s, the jet from the tunnel outlet reaches the opposite bank since the river at that location is rather narrow. This could lead to flooding of some power plant equipment, which actually happened in December of 1995. At that time, the left abutment wall was also damaged but was later repaired.

It has been also noticed that there was water seepage as well as calcium leaching of concrete in grout injection gallery and on dilatation joints between some concrete blocks of the dam. Since these phenomena have intensified in recent years, the research activities were undertaken and the rehabilitation plan was developed. The rehabilitation project is currently in its final phase. The rehabilitation works utilize cement and chemical masses with certain additives. Microfine cements are being used with Blaine fineness of at least 7500 cm^2/gr.

3.5 HPP Salakovac dam

The Salakovac project is located just at the exit of the Neretva River from its canyon, about 17 km upstream of the city of Mostar. The project consists of a power plant adjacent to a 70 m high gravity dam. The three-unit powerhouse has installed capacity of 210 MW and average annual generation of 590 GWh.

The power plant was out of operation for two years during the 90s war, and the body of the dam was experiencing stresses that have not been envisioned during the initial dam design. The drainage pumps lost their power supply which caused increase in the tailwater level and subsequent flooding of the powerhouse equipment and drainage gallery in the body of the dam. The reservoir level was controlled by the low level outlet only since spillway gates were closed and not functioning due to their power sources being damaged by war activities. Therefore, the dam was under increased risk from overtopping which fortunately did not happen.

Similar to the Grabovica Dam case, it has also been noticed that there was some water seepage as well as calcium leaching of concrete in Salakovac Dam but at much smaller scale. The rehabilitation was carried out the same way it is currently being performed on the Grabovica Dam.

3.6 HPP Rama dam

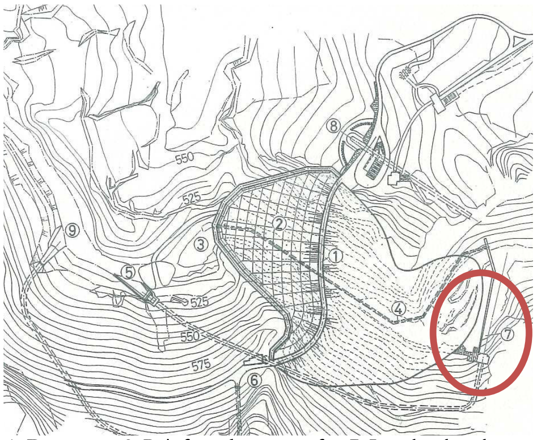
Rama Dam is a rockfill dam with a reinforced concrete face. It was built and commissioned in 1969. Rama Dam is 103 m high with the 230 m long dam crest. HPP Rama project has the installed capacity of 160 MW and average annual generation of 650 GWh.

Rama Dam has a fairly unusual layout of its low level outlet. The direction of the outflow jet from the low level outlet is parallel to the downstream toe of the dam. Therefore, when the low level outlet operates, the outflow jet either lands parallel to the toe of the dam, or hits the opposite river bank. Since HPP Rama power plant was not operating for a significant amount of time during the 90s war, the reservoir level was controlled by low level outlet only. This means that the low level outlet was operating almost permanently during that period, which resulted in some soil degradation in the vicinity of the toe of the dam and consequent danger to the dam stability.

Considering the HPP Rama project importance within the power system, following the war the equipment was modernized and following activities related to the dam and its facilities were undertaken:

- Improvements and repairs on penstock and surge tank;
- Reinforced concrete jet deflectors were built to direct high pressure low level outflow discharges;
- River bed between low level outlet and the dam left abutment was lined with concrete;
- Both the left abutment foundation and the dam concrete face were repaired;
- The grout curtain was repaired.

Fig.6: Low level outlet in operation



1. Dam crest 2. Reinforced concrete face7. Low level outlet

Fig 7:Rama dam layout

3.7 Modrac dam

Modrac Dam was built in 1964 on the Spreca River with the purpose of supplying necessary water for the industrial production needs of Tuzla and Lukavac municipalities. Today the primary purpose of the Modrac reservoir is the municipal drinking water supply.

This is a reinforced concrete multiple-arch buttress dam with 9 buttresses and 10 arches. The dam crest is 205 m long, maximum dam height is 205 m, and the thickness of the arches ranges from 0.40 to 0.50 m. Due to various stresses and climatic influences, the reinforced concrete arches experienced damages, especially at locations of their contact with buttresses. Due to this fact, it was decided in 2000 to start research activities and preparation of technical documentation with the aim to find the best solution for rehabilitation of the dam. During the first phase of the rehabilitation works the arches 1, 2 and 3 were repaired, and in the second phase the dam foundation and the arches 8, 9 and 10 were repaired.

Fig. 8: Modrac Dam

Fig. 9: Repairs of the arches

4. CONCLUSIONS

Political events and the war outbreak in early 1990s of the last century have significantly impacted economic development of Bosnia and Herzegovina in the last two decades. As a consequence, a total stagnation in construction of new dams has occurred limiting all dams-related activities to undertaking necessary and urgent measures on maintenance of existing facilities. One of the outcomes of such sectorial development is that currently BHCOLD exists only in theory with no regular day-to-day activities and completely frozen contacts with ICOLD.

Above described activities on rehabilitation and reconstruction of existing dams in Bosnia and Herzegovina are essential for their safety and extension of their project lives. However, these activities are financed mainly through foreign investments (mostly credit lines and occasional grants), and the foreign financiers have significant influence on both the tender process and final selection of consultants, contractors and equipment suppliers, leading to a very limited participation by local professionals and companies in these projects. This approach additionally limits full involvement of domestic experts and dam specialists in these projects having as a consequence additional stagnation in the development of the sector with tradition of more than a century in BiH.

Bosnia and Herzegovina is well known for its abundant water resources which are only partially exploited in terms of hydroelectric energy and drinking water supply, both of which are closely related to the building of dams. Considering that future demand for both clean water reserves and renewable energy resources will increase significantly, it is reasonable to expect that dam building activities in BiH will be again seriously considered. The design and construction of new dams only could lead to the consolidation of engineering practice and construction capabilities for such complex projects. Therefore, involvement of the state and other interested stakeholders in preparation and development of large dam projects is necessary with full engagement of domestic, acknowledged experts from the subject area. Urgent reactivation of the BHCOLD activities, with support of ICOLD and other national committees, represents one of the steps on the path of full-fledged sectoral development in Bosnia and Herzegovina.