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APPLICATION OF EROSION-CONTROL MATERIALS AND SPONTANEOUS VEGETATION IN THE PROTECTION OF RESERVOIRS IN SOUTHERN AND EASTERN SERBIA

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Abstract — The quality and stability of erosion-control materials in protection of reservoirs in Southern and Eastern Serbia have been examined both in the field and in accredited laboratories in our country. Field investigations have been carried out over a period of 15 years in Eastern Serbia and for up to 30 years in Southern Serbia, and they are still being conducted by monitoring the state and possible damage of consolidation-retention check dams, walls, and other erosion-control structures. The materials used in protection of the Selova and Grlište Reservoirs are typical construction materials, such as resistant natural stone, concrete of the BI group, i.e., MB 20, aggregate, synthetic elements, etc. Long-term monitoring of their state and minor deformations has shown that the materials were well-chosen and stable, and that there has been no significant damage, except for some minor crumbling and smaller cracks due to negligible scouring. This is all the result of prior thorough empirical and laboratory testing of applied materials, which helped to achieve stability and functionality of structures erected to prevent silting-up of the reservoir. Such a state has contributed to stabilization of erosion processes and reduction of sediment quantities, improvement of water quality, and advancement of the autochthonous vegetation (*Salix* L., *Cornus* L., *Quercus* L.). Vegetation has further mitigated erosion, decreased floods, and consolidated the structures, thereby improving the ecological quality of the catchments as well as the entire study area.

Key words: Reservoirs, catchments, erosion-control materials, stone, concrete, vegetation, examination, ecological quality, water

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INTRODUCTION

Long-term monitoring of the behavior of check dams made of stone masonry and of concrete in the examined catchments of the Selova and Grlište Reservoirs has produced exceptional results.

In the catchment of the Selova Reservoir, erosion-control works were performed over a period longer than 30 years. During that period, about 20 check dams were built up to 1990. They are still performing their function and are almost completely filled up with erosion sediment. They are made of limestone from the local Trećak Quarry and to a smaller extent of limestone from a quarry owned by the Brzeće Road Enterprise. This stone is sufficiently resistant for the purpose, and all check dams are still in an excellent state. Only some minor crumbling of debris was observed, due to scouring, but it is within tolerance limits and can be considered as a normal and unavoidable phenomenon that does not affect efficiency of the structures. Built of stone masonry, check dams will continue to function efficiently as a debris basin for erosion material and to stabilize erosion processes in the catchment, which will conserve the quality of water and prevent silting-up of the reservoir.

MATERIAL AND METHODS

Since 1990, another 10 stone masonry check dams have been built of the same material. They are back-filled and perform their function, especially on the river Kačaruška Reka, where the check dam was visibly back-filled even during its construction.

In the Grlište Reservoir's catchment during the period from 1990 to 1991, seven concrete check dams were built of MB 20 concrete. They have been in an excellent state for 17 years and are still efficient.

The check dams are 1.5-5 m high.

They were made of mortarless limestone walls, which then became covered with vegetation, thereby performing their protective role, which has contributed to erosion control and water protection against the suspended sediment and bed load. In this way, they have prevented silting-up, which has always been a strategic ecological concern of both individual states and civilization as a whole, since the conservation of water resources on the planet is a matter of both local and global importance.

According to Dr. S. Gavrilović, in the catchment of the Grlište Reservoir, the erosion coefficient calculated by the method of mean values amounts to z = 0.45, while the coefficient calculated by the analytic-quantitative method is z = 0.51.

The volumetric concentration of sediment in the water is s = 0.128.

The mean bulk density of torrential water is γbv = 1.102, and the coefficient of torrentiality is k = 0.91.

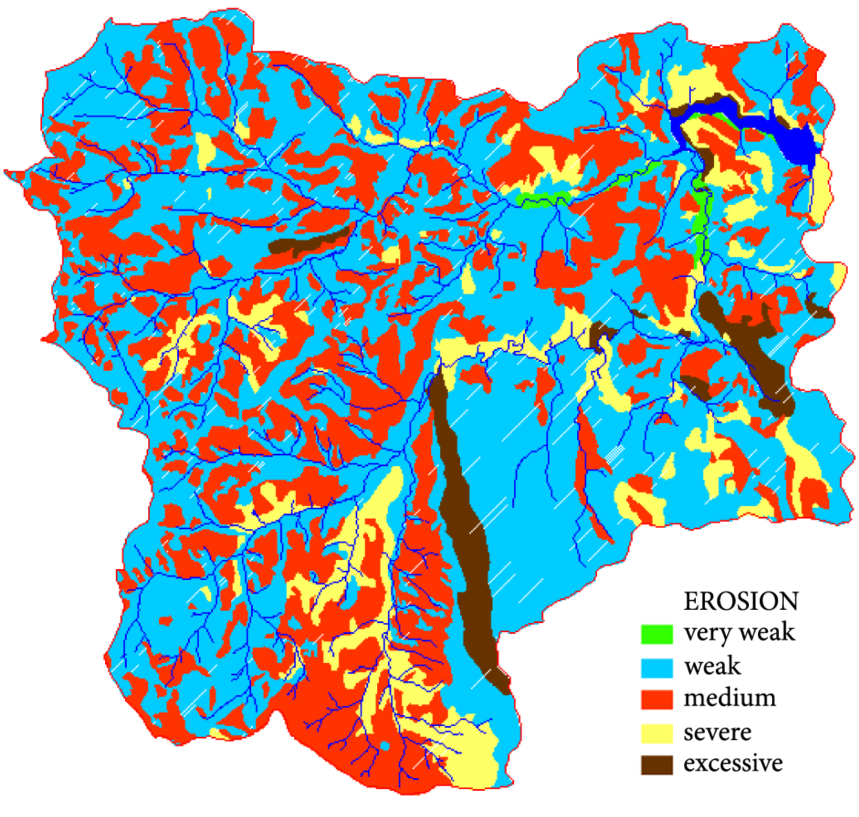
The substratum is made of volcano-clasite andesites and rudistic limestone in the form of spikes with an average width of 2 m.

The soils are skeletal soil, smonitza, acid brown soils on limestone, acid brown soils on eruptives, alluvium, and skeleton.

The climate is temperate-continental, with Hyear = 713 mm.

The absolute annual minimum of precipitation is 535 mm, the maximum 920 mm.

The average daily maximum for a period of several years is L = 33 mm.



Map of erosion in the catchment of the Grlište Reservoir.

Average annual air temperature (according to the Zaječar weather center) is t = 10.4°C.

The warmest month is July, the coldest January.

The absolute maximum is 41.6°C.

The absolute minimum in February 1956 was -27.9°C, so resistance of the material to high and low temperatures should be maximal.

The Grlište is a left-hand tributary of the Beli Timok. The catchment area lies on the slopes of the mountains Tupižnica and Lisovača. The catchment includes the streams Lasovačka Reka, Grabovac, Negalica, Lenovačka Reka, Bačevička Reka, Vrbovčić, and Lupoglav. It belongs to the municipalities of Zaječar, Boljevac, and Knjaževac.

The relief is hilly, with transition to typical mountainous (the Tupižnica massif), with elevation of 1,143 m. The terrain is dissected. The slope is 15-40% (dominant slope), up to 100% on the western side of Mt. Tupižnica.

The catchment has almost circular form, which leads to rapid concentration of slope water and the formation of flood waves. The coefficient of hydrographic network density is 1.28-1.35 km/km^2.

Total length of the hydrographic network is Lh = 54.20 km.

The prevailing parent rocks are volcano-clastites, limestones, flysch formations, sandstones, Senonian marls, claystones, latites, and conglomerates. There are copper and manganese mines in the region.

The soils are:

- skeletal soil, 35%;
- eroded smonitza, 25%;
- acid brown soils on limestone, 15%;
- acid brown soils on eruptives, 20%;
- alluvium, 4%; and
- skeleton, 1%.

The most erodible soil types are skeletoid and acid brown soils on eruptives.

The applied materials are natural and ecological, so the balance and harmony of the environment are not disturbed, while the soil and climate conditions are improved for the development of plant and animal life. The water supply of settlements is also improved, as are conditions for irrigation of the surrounding areas and crops.

The state of these structures has been monitored for more than 30 years in the catchment of the Selova Reservoir and 20 years in that of the Grlište Reservoir. Although they are made of different materials, all of them are stable and ecologically justified. There is no significant damage or structural deformation, so their role has been completely maintained with the best forecasts of longevity.

RESULTS AND DISCUSSION

Stone has been the oldest building material in all civilizations. Longevity of the Egyptian pyramids or the Great Wall of China and similar structures is well-known.

The best-quality rocks are magmatic, followed by metamorphic and (finally) sedimentary rocks. The rocks of poorest quality are sandstones, claystones, weathered or soft rocks, and those that soften with time. Based on our results from the reference laboratories, it is confirmed that the better class includes broken and bedded rocks of the first two classes, sandstones with siliceous cement, and dense massive limestones. Granite, syenite, schists without mica, greywacke, and quartzite have good characteristics. The best-quality stone is that made of basalt, diabase, diorite, gabbro, melaphyre, porphyry, quartz schists, etc. These rocks are also the most expensive because they are more difficult to exploit and process. They are characterized by high physical-mechanical, chemical, rheological and other properties. Modern civil engineering requires prior research of all materials. Stone is no exception.

The limestone used in the catchments of the Selova and Grlište Reservoirs is massive dense limestone with exceptional physical-mechanical parameters, which have contributed to quality and durability of the structures, now more than 30 years old.

Table 1. Characteristics of the applied limestone.

Characteristics	Density kg/m^3	Porosity (%)	Water absorption (%)	Shrinkage -swelling (%)	Compressive strength MPa	Resistance to wearing cm^3/50 cm^2	Resistance to frost	Resistance to atmospheric effects	Resistance to acids	Resistance to temperature changes
Limestone	2500	0.9	2	0.1	150	35	good	good	good	good

The research shows that bulk density of the stone is above 2,500kg/m^3, porosity 0.9%, water absorption 2%, shrinkage and swelling below 0.1%, compressive strength 150 Mpa, and resistance to wearing up to 35 cm^3/50 cm^2.

The above-enumerated good characteristics guarantee durability (of consolidation-retention check dams, mortarless stone walls, etc.). Some minor scouring is expected and negligible.

The stability and functionality of the structures has contributed to the stabilization of erosion processes, thereby preventing silting-up of the reservoir.

In the catchment of the Grlište Reservoir during 1990, seven check dams were built of concrete, which also has good characteristics. They became covered with vegetation, as intended.

The applied concrete was of the MB 20 type and during the last 17 years there has been no damage, except on check dam number 4, on the river Bačevička Reka, where a crack was formed from the sluice towards the check dam foundation due to minor scouring and slope instability.

The minimal quantity of PC 40 and PC 45 is 250 kg/m^3 of concrete, and 150 l of technologically good water is required, i.e., m_V/m_c = 0.4-0.6.

The shoring-up is wooden, double and single. Between the shore wall and the concrete, there is a layer of gravel, 3-5 cm thick.

The aggregate's compressive strength is 15 Mpa, maximal wearing is 10 cm^3/50 cm^2, γ = 1800 kg/m^3, and the aggregate is composed of granite, syenite, porphyrite, diabase, basalt, etc.

The concrete was treated 3-5 times daily over a period of seven days.

A stone riprap was made on the upstream side of check dams to provide filtration and higher stability of the structures in case of hydrodynamic loading, since check dams are dimensioned to hydrostatic and earth pressure. The riprap consists of broken stone, the size of which is 20 x 25 x 30 cm. The pile

Fig. 1. Check dam on the river Bačevička Reka (V. Matić).

Fig. 2. Vrbovčić check dam (V. Matić).

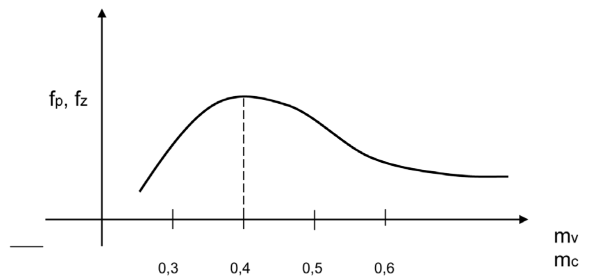


Diagram 1. Dependence of physical-mechanical characteristics on the water-cement ratio (mv/mc ratio).

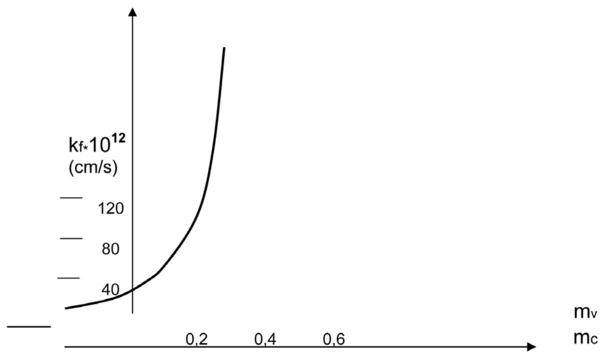


Diagram 2. Dependence of coefficient of impermeability on the water-cement ratio.

is stable and contains less than 20% of cavities.

Calculation shows that 211,320 m^3 of sediment is delivered to the storage valley in the guise of 171,069 m^3 of suspended sediment and 40,251 m^3 of bed load. Total retention capacity of the designed structures is W_{vn} = 150,848.70 m^3. A technical solution is justified if the ratio of structure volume to retention capacity is at least 1: 10, which is satisfied in this case.

From the aspect of erosion in the catchment, there is very little or no silting-up behind the structures, so aggradations are insignificant, which is explained by lower human activity and by advancement of the autochthonous vegetation.

The check dam in the stream Vrbovčić is in an exceptionally good state and is densely covered with vegetation. There is no erosion, and no traces of soil loss.

Two coal mine spoils and one copper mine spoil remain in this catchement. These mines were closed long ago, but their waste tips remained untouched and are covered with vegetation, which means that there were no major erosion processes and soil loss in the catchment during the study period, so the streams are not loaded with sediment.

They are covered with vegetation generally consisting of *Salix* sp. trees and shrubs, which is reflected in the name Vrbovčić (willow stream).

The check dam concrete belongs to the medium category (γ = 1900-2500 kg/m^3), and regarding technology to class BI. It can be prepared at the site, which requires stricter control testing, especially for the minimal allowed quantity of cement in light of the rule that finer aggregate fractions increase the quantity of cement. Concrete exposed to atmospheric effects or water should have a water-cement ratio (m_v/m_c ratio) of $m_v/m_c \approx 0.4$, because this ratio gives the best physical-mechanical and other characteristics, as well as impermeability.

In the same way, the type of concrete also depends on the water-cement ratio.

The aggregate mixture consists of the following fractions, per weight:

Ø mm	0-4	30%
	4-8	15%
	8-16	15%
	16-31.5	40%

Portland cements PC 40 and 45 were applied in a minimal quantity of 250 kg/m^3 of concrete. Concrete was incorporated in the double shoring in layers of 30 cm. Stone anchors were made of solid rock, which was washed and cleaned to ensure safe cementing of the following layer.

The maximal wearing after Bohme is 10 cm^3/50 cm^2. The aggregate density is about 1,800 kg/m^3. Extension joints of the check dams and bank wall are covered with bitumen or lined with tarpaper. Pipes 200-250 mm in diameter are placed at the joint of bank wall and log sills, so that the lower edge of the pipe is at the height of the upper surface of the water cushion. The pipes are made of asbestos-cement or PVC.

A riprap was built on the upstream side to filter the sediment-containing water and increase stability of the structures against hydrodynamic loading, since they were dimensioned only for hydrostatic and earth pressure. The stone sizes were 20 x 25 x 30 cm. This stone was piled to produce maximal stability and contains 20% of cavities at most. A drainage ditch was formed in the riprap for easier evacuation of water released from sediment through check dams.

The catchment vegetation belongs to the alliances *Fagetum submontanum* Rud., *Querceto-fraxinetum*, and *Querceto-carpinetum-serbicum* Rud**.**

Land use in the catchment is as follows:

- forests, 20% of the catchment;

- pastures, 12.6%;

- meadows, 8.4%;

- farmland, 45.92%; and

- bareland, 0.58%.

The rest consists of settlements, roads, and watercourses.

The coefficient of catchment protection with vegetation is $S_z = 0.84$.

CONCLUSIONS

Testing of characteristics and durability of materials used in erosion control works are imperative for both professional and scientific reasons because the structures are exposed to unfavorable effects of atmosphere, seismics, excessive forces, torrents, geodynamic forces, uncontrolled human impacts, and other adverse factors.

Prior research is mandatory, both for construction materials and in regard to introduced and native vegetation. This involves both study of previous experience and acquisition of new knowledge based on laboratory experiments and monitoring in the field. In our country, data on vegetation are insufficient (only some studies of *Salix* L., *Robinia* L., *Pinus* L. have been conducted to date). The research should be focused on biological characteristics, strength of the roots, resistance to extreme conditions, etc., for many available and potentially usable plant species, ones that have not yet been employed here or elsewhere for erosion-control technical protection.

It is well-known that errors in this field can be catastrophic for humans, animals, plants, material goods, and harmony and prosperity of the environment, i.e., its ecological values.

The herein discussed long-term monitoring of structures in the examined catchments and their function over a period of 15-30 years was performed within several previous and current projects financed by the Ministry of Science and by water management organizations in Eastern and Southern Serbia.

Vegetation has not been specially employed in technical protection against erosion, but it has developed spontaneously thanks to stabilization of erosion processes after the building of structures made of MB 20 and stone masonry, as well as mortarless stone walls. Autochthonous vegetation stabilized the structures by spontaneous development, and erosion processes existing in the catchments were mitigated and new ones prevented. Species of the genus *Salix* L. appeared along the watercourses and at the wetter sites. In the higher areas, there are characteristic species of the Balkan beech alliance *Fagion moesiacae* Bleč. et Lakš., suballiance *Fagenion moeesiacae submontanum* Jov., 1976, where mesophilic and sciophilic beech is accompanied by numerous deciduous and not so often coniferous woody species, which in floral, geographical, and ecological respects are similar to beech species, such as *Acer pseudoplatanus*, *Acer platanoides*, *Acer heldreichii*, *Abies alba*, *Fraxinus excelsior*, *Tilia platyphyllos*, *Tilia cordata*, *Ulmus montana*, *Prunus avium*, *Sambucus nigra*, *Sambucus racemosa*, *Daphne mezereum*, *Daphne laureola*, *Lonicera xylosteum*, *Lonicera nigra*, *Lonicera alpigena*, *Euonimus latifolius*, and many others. Among herbaceous plants, the most numerous are geophytes, which bloom before beech trees put forth their leaves. They are sciophilic mesophylls and ferns. This area is inhabited by white oak and flowering ash of the *Orno-Quercetum virgilianae* Gaj. (synonym: *Quercus pubescens-Fraxinus ornus* Gaj.) community. The most common species are *Quercus virgiliana*, *Quercus cerris*, *Fraxinus ornus*, *Tilia argentea*, *Acer tataricum*, *Cornus mas*, *Evonimus verucosus*, *Viburnum lantana*, *Ligustrum vulgare*, *Crataegus monogyna*, *Hedera helix*, *Rosa arvensis*, *Helleborus odorus*, *Galium album*, *Ruscus aculeatus*, *Viola alba*, *Dactylis glomerata*, and others. Forests of the *Querceto-carpinenetum serbicum* Rud. and *Carpino orientalis-Quercetum cerris* Jov., 1979 communities are characteristic of the xerothermic areas of Eastern and Southeast Serbia.

The establishment of vegetation was an objective of all technical works because it prevents the delivery of sediment to the Selova and Grlište Reservoirs and reduces the retention of material in the aggradations of consolidation-retention check dams and protection structures.

The structures have remained undamaged, except for some minor and expected debris and scouring and a minor surface crack on check dam No. 4 on the river Bačevička Reka. This good condition can be attributed to prior testing of the MB 20 concrete used in the catchment of the Grlište Reservoir and the dense limestone from known quarries in that of the Selova Reservoir. The testing was performed in accredited laboratories according to valid international standards. Long-term monitoring of materials in the field confirmed their quality and durability, as well as the optimal and justified selection of ways to oppose destructive forces in the studied catchments.

The durability of structures and reduction of sediment quantities, especially in the catchment of the Grlište Reservoir, have also resulted from a decline in the area's population. Some undesirable human activities causing degradation of land and vegetation and new erosion foci have been reduced to a minimum. This has resulted in the prevention of silting-up and in improvement of water quality, both in the reservoir and in the watercourses. It has also led to a better ecological potential for the development of all organisms and improvement of living conditions for the remaining human population.

The involvement of ecology and ecological engineering in protection of land and water resources (the title of a department of the Faculty of Forestry in Belgrade) is now both a local and a global imperative. It can be concluded that the herein discussed research activity represents a significant contribution to quality of the environment and life in general.

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ПРИМЕНА ПРОТИВЕРОЗИОНИХ МАТЕРИЈАЛА И СПОНТАНЕ ВЕГЕТАЦИЈЕ ПРИ ЗАШТИТИ АКУМУЛАЦИЈА У ЈУЖНОЈ И ИСТОЧНОЈ СРБИЈИ

ВЈАЧЕСЛАВА МАТИЋ и ГОРДАНА ЂУКАНОВИЋ

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Особине и трајност противерозионих материјала, при заштити акумулација у јужној и источној Србији, испитиване су на терену и у акредитованим лабораторијама у земљи. Теренско испитивање трајало је 15 година у источној Србији, до 30 година у јужној, и наставља се и даље, праћењем стања и евентуалних оштећења изведених, консолидационо-депонијских преграда, зидића и осталих противерозионих објеката. Материјали коришћени за заштиту акумулација „Селова“ и „Грлиште“ су класични конструкцијски материјали: отпоран природни камен и бетон групе Б I, тј. МБ 20, агрегат, синтетички, биотехнички елементи и др. Вишегодишње снимање њиховог стања и евидентираних мањих промена у наведеном временском интервалу показало је да су материјали, искуствено, добро одабрани и трајни и да не постоје значајнија оштећења, сем очекиваних мањих осипања и ситнијих пукотина, због незнатног поткопавања објеката. Оваква ситуација је резултат, претходног, темељног, искуственог и лабораторијског атестирања, предвиђених и примењених материјала. Тиме је постигнута функционалност и дуговечност објеката у њиховој намени спречавања засипања акумулација ерозионим наносом. Такво стање је допринело смиривању ерозионих процеса, количине наноса, побољшању квалитета воде, као и појави и бујању аутохтоне вегетације. Појавиле су се врсте родова *Salix* L., *Robinia* L., *Carpinus* L., *Quercus* L., као и *Ailanthus glandulosa* Desf. и др. Подручје припада свезама *Fagetum submontanum* Rud., *Querceto-carpinetum* Rud. i *Querceto- fraxinetum* Rud. То је додатно ублажило ерозију, смањило заплаве и учврстило изведене објекте, а тиме и подигло еколошки квалитет сливова и целог истраживаног подручја.