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A NATURAL APPROACH TO RIVER ENGINEERING PRACTICE. A CASE STUDY OF THE LJILJANSKA RIVER

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Abstract. *In the past 30 years the efforts to protect river beds and banks have increased significantly. The selection and design of proper structural solution means finding a solution in accordance with construction principles, river geomorphology, avoiding channel aggradation, bed scour, bank erosion, resulting structure failure and significant harm to the stream and nearby property. On the other hand, the structure should be environmentally-friendly. Hydraulic structures generally have a strong impact on the environment, so providing "the right solution" presents a real challenge to engineers.*

Key words: *hydraulic structures, environmental impact, river training*

1. Introduction

In the long history of mankind, the global balance between nature and human activities was sustained until the twentieth century when stunning technological progress ćcaused very serious environmental problems [1]. Environmental awareness has become one of the most important issues nowadays.

In the past 30 years the efforts to protect river beds and banks have increased significantly. The selection and design of proper structures means finding a solution in accordance with construction principles, river geomorphology, avoiding channel aggradation, bed scour, bank erosion, resulting structure failure and significant harm to the stream and nearby property [2]. On the other hand, the structure should be environmentally-friendly. Hydraulic structures generally have a strong impact on the environment, so providing "the right solution" presents a real challenge to engineers.

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1.1. Empirical construction principles

River training works have been practiced since ancient times. The construction principles were developed on the grounds of abundant experience during which the assessment criteria and requirements were modified almost constantly.

In addition to the applied loads, the design of a river channel takes into consideration other criteria, such as the:

- Operating period;
- Construction method;
- Flow rate and/or level regime;
- Submersed or immersed nature of the works;
- Cost of materials used;
- Compatibility in terms of environmental factors (particularly flora and fauna).

A number of principles regarding the general construction design are accepted nowadays, and according to them, the main principles in selecting river training structures are the following:

- The construction must be plastic (commonly named "elastic"), able to bear deformations of the foundation;
- The construction must be designed knowing that during the operation, inevitably, it will suffer some degradation (damage);
- The construction should not prevent the free flow of water, ice or other floating objects, particularly during flooding;
- The construction should be properly fixed both upstream and downstream to avoid deteriorations under construction caused by erosion;
- The construction should primarily be aimed at the protection of the environment and ecosystems (maintaining the habitats and water quality).

In order to ensure the restoration of the dynamic ecosystem in the area affected by the works, the design should provide possibilities for plant and animal colonization. The design may be endorsed if it provides ways and elements that facilitate the restoration of ecosystems. Considering their highly diverse nature, establishing a number of work categories from several perspectives is required, which will ensure coverage of the field and highlight its inseparable link with the environment, without claiming the complete classification.

1.2. River geomorphology – general principles

The most important natural functions of rivers and their adjacent riparian areas are the following [3]:

- a fish habitat, offering optimum breeding conditions;
- a habitat for birds, mammals, amphibians, reptiles and very diverse invertebrates;
- water and sediment retention;
- water self-cleaning by storing and recycling the nutrients and by transforming organic and non-organic pollutants;
- biodiversity – trees in floodplains are very fertile;
- its socio-economic function: the water source, waterway, exploitation of construction materials (sand and gravel), tourism, recreation and education.

The development of geophysics and ecology (especially aquatic habitats) of rivers depends almost exclusively on the dynamics (hydraulics and hydrology) and morphology of the river flow. Under natural conditions, the river flow forms a relatively stable connection between the variables that characterize the river flow.

The independent or control variables are the:

- river flow;
- sediment transport;
- hydraulic gradient;
- riverbed and bank sediment characteristics;
- riparian vegetation.

The dependent or response variables (degrees of freedom) are:

- the width of the river;
- average water depth;
- maximum water depth;
- river channel slope;
- the velocity of a river;
- spatial energy dissipation of the river flow;
- river meandering;
- mean sediment size;
- the percentage of fine-grained sediment;
- the wavelength.

In a river stream flow that is in dynamic equilibrium, the dependent variables constantly change and adjust their values. Following strong anthropogenic changes (pressures), the river tends to return to its initial parameters, and consistent natural conditions, but only if the intervention works are properly designed and performed. The structures unable adjust during the dynamic rebalance process will modify the riverbed, distorting and endangering the ecological balance of the river on much wider river sectors than the working area [4].

1.3. Environmental impacts of the river training works

The planet's human life system is an interactive force, composed of the activities of people and their institutions, ecologically dependent, which irreversibly affect the environment. Under natural conditions, the process composed of the "disturbance (ecological stress) – impact (response) – natural recovery" is a process that requires time, but will, likely, be a successful one. However, the restoration of the riverbed after morphological modification is possible; but, if the nature of the planned works, incorporated materials and location of the structure are inadequate, restoration of the ecosystem is unlikely. The impacts of river training structures are numerous and complex and are summarized in Figure 1 [4].

Reducing the number of morphological forms of the riverbed (at great depth in concaves) and reducing the instability of the riverbed shape, cause a reduction in the available habitats of endemic species and fish populations. Rivers and their corridors form a complex ecosystem that includes their inundation, flora, fauna and river flows. These ecosystems depend on river flow regimes in which flow, sediment transport, water temperature and other variables have a clearly defined role. If these variables are changed, in comparison to natural state values, the balance is disturbed. For this reason, river engineering structures should be directed toward maintaining the global dynamic equilibrium of the river flow over time and space.

The construction of embankments on long sectors of the river flow not only leads to a decrease in the biodiversity of the aquatic environment, but also to an increase in maximal flow values. The new concept of river management, "more space for the river", implies harmonization of social and economic requirements, water supply, flood protection as well as others, within the environmental requirements. To this end, the continuity of the river and its connection with the flooded area should be ensured, so that habitats (riparian areas) necessary for the preservation of aquatic flora and fauna, flood mitigation and nutrient retention will be formed. By creating connections with flooded areas, new areas for flood mitigation and nature are created. That is where novel ecosystems will be developed to provide optimal conditions for aquatic flora and fauna, as well as for recreation and tourism [4].

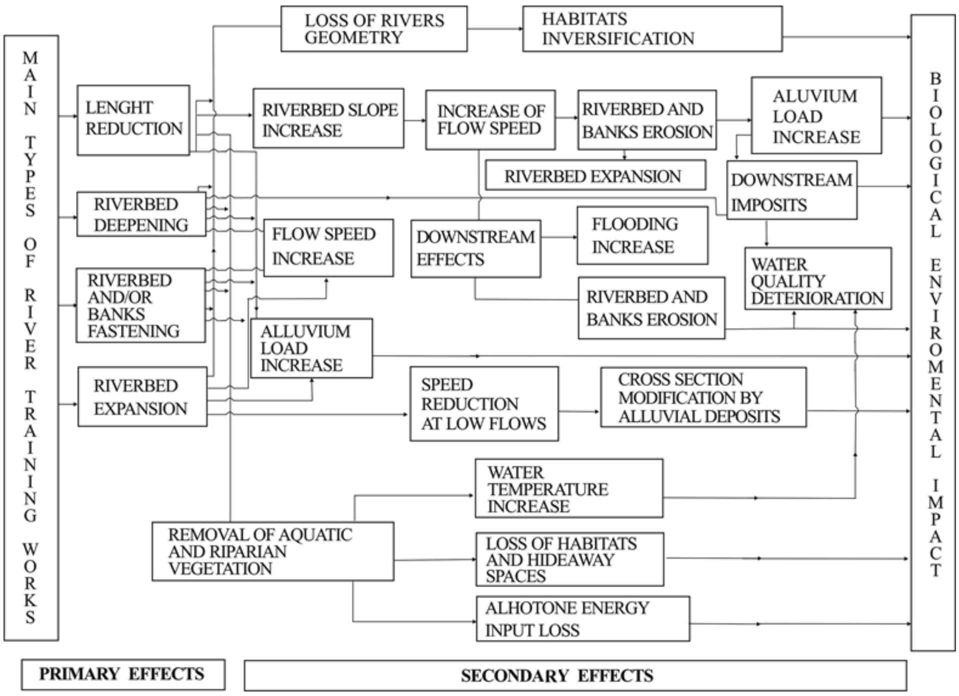

Fig. 1 Environmental impact of the river training works

It must be emphasized that there is also an environmental impact generated by the construction site. This type of impact is, usually, persistent and it covers a much larger area than the working area, experienced at high distances from the construction site.

In some cases, the impact, generated during the works execution period, is very strong and usually additionally pollutes the environment (turbidity, oils and fuels from the machineries, remains of construction materials, etc.). Therefore, in the case of river training works that cover a larger area or in which works on excavation and backfilling of riverbeds are performed, it is necessary to have a technological project, which would specify all the important measures that provide a minimum and acceptable environmental impact (finding and arranging landfills, accesses, waste disposal, conditions for control and maintenance of machines, etc., masonry cladding the river bank). A technological project receives the same requirements as a project design and must be approved alongside it. This project must be subjected to the same requirements as the river training works project and shall be approved along with the project.

1.4. Main types of river training works and their impact on the physical environment

The intensity of the impact of hydraulic structures on the environment depends to a certain extent on the type and nature of structures and accompanying river training works. The following scheme (Figure 2) indicates the main types of river training works, grouped according to the purpose of river training [4].

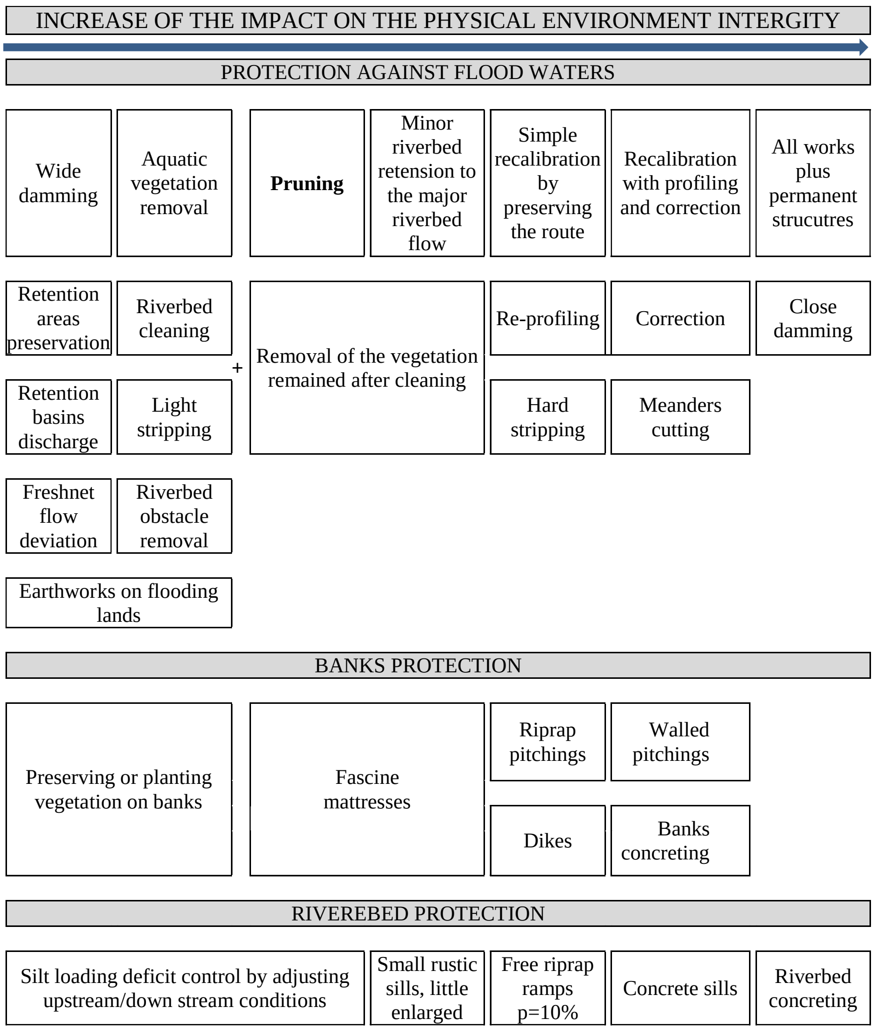

Fig. 2 Main types of river training works and their impact on the physical environment

Types of structures whose intensities are ranked starting from the highest are: all solutions that include non-adaptable structures (permanent structures), embankments, recalibration with rectification and reprofiling, meander cutting, concreting the bottom of the riverbed, concrete check-dams, masonry cladding, concrete blocks. Summarizing the types of morphological influences, it was noticed that there are three significant types of necessary data: current or long-term influence, intensity of influence and long-term stability.

The impact intensity is classified into four classes: very strong, strong, medium and weak. The very strong impact class includes the following river training work types: river course corrections, bank reshaping and reprofiling, meander curvature change, damming, derivation and deviation of the minor riverbed; the strong impact class includes: decreasing of inundation, check–dam construction and river-bank protection. The construction of embankment and meander curvature change generate, practically, irreversible environmental effects.

2. River Training Works Good Practice. A Case Study of the Ljiljanska River

The Ljiljanska river is a right tributary of river Juzna Morava. The river mouth is 2,5 km downstream from small town of Bujanovac or 2 km form the mouth of the Trnovacka river. The main stream forms the Kosaracka River and Jastrebacka or Selacka river, upstream from the village Ljiljance. The catchment area encompasses 18 km^2. The length of the stream of the Ljiljanska river is approximately 4 km. The Selacka river, as her right tributary, has a length of approximately 8 km, and the Kosaracka river, as her left tributary, has a length of 9 km. In the catchment area, the hydrographic network is a dense total area of 17,6 km^2. The approximate vegetable land cover is about 62% forest, 20% arable land and about 18% meadows and pastures [5].

Fig. 3 Willow wattles

The Ljiljanska river is one of many unregulated right torrential tributaries of the river Juzna Morava (the Bujanovacka river, Bogdanovacka river, Ljiljanska river, Zvebecka river, Krsevicka river etc.). These streams in the area of the inflow into the river Juzna Morava intersect with the Nis-Skopje railway. The constructed waterway has a lack of flow capacity and due to high water in the tributaries, upstream of the railway the coastal area was often flooded. Along the above-mentioned tributaries, a few settlements had severe problems with torrential floods. An extreme case of endangering the coastal area from the torrent of the Ljiljanska river took place in January 1996 in the section of river that passes through the village of Ljiljance, situated about 4 km from the mouth of the Ljiljanska river [5]. On this location there was specific influence of heavy and deep erosion, so the local village road – street was destroyed, several electric poles undermined and a recently constructed bridge in the village affected. A very wide river bed was formed (of over 40 m), with steep unstable river banks of average height of about 3 m. The most threatened section runs through the Ljiljance village at a length of 1400 m. The Ljiljanska river bed tends towards a permanent deepening in the middle course and collapsing banks in particular through the Ljiljance village, creating a lot of damage [5].

Fig. 4 Cascades

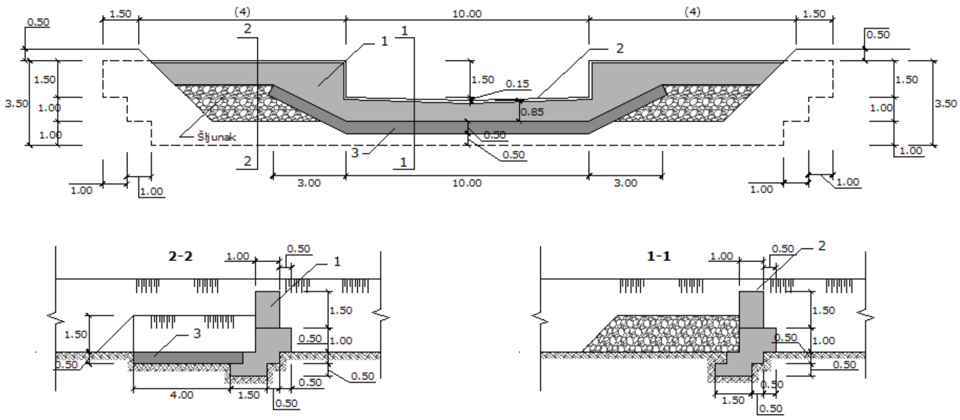

Fig. 5 Typical transverse cross section [5]

In the catchment area of the Ljiljanska river, erosion control works on sanitation erosion processes were carried out. In order to raise the profound river bed, check dams from gabions were constructed with biological regulations between the check dams. The designed flow capacity is $Q_{2\%}=25{,}43\ m^3/s$. At a distance of 115 m, 11 check dams have been constructed (cascade flow). The river flow discharge profile has a trapeze shape: its bottom width is 10m and slope inclination is 1:2. The formation of a trapeze flow profile provides willow wattles for a distance of 15m, as well as one row of willow seedlings at a distance of 1m along the left and right regulation line. The dimensions of the check dams are adjusted so gabion wire boxes are from 0,5 m to 1,5 m. The weir has a rectangular shape on the check dams with a width of 10 m, and height of 1.5 m. The analysis of the constructive solution is presented in Table 1 [5].

Table 1 Analysis of structural design

<table>
<tr><td colspan="5">I Structural properties</td></tr>
<tr><td>Name of the structure</td><td>Scope of work</td><td>Flexible/ rigid structure</td><td>Free draining</td><td>Erosion velocity</td></tr>
<tr><td>River training works on the Ljiljanska river</td><td>Rehabilitation of the river bed and protection of the village, bridge, roads</td><td>Flexible</td><td>Free draining</td><td>Cascades and willow wattles decreased erosion velocity</td></tr>
<tr><td colspan="5">II Operation/ maintains</td></tr>
<tr><td colspan="3">Repairing</td><td colspan="2">Maintains</td></tr>
<tr><td>Difficult</td><td>Medium
Due to turbulent river flow</td><td>Simple</td><td>Difficult</td><td>Medium difficult
Simple, accessible, low cost</td></tr>
<tr><td colspan="5">III Investment costs</td></tr>
<tr><td colspan="5">Duration, life time period</td></tr>
<tr><td colspan="5">6 to 7 years, after that period repairing works are necessary, wattles - many years</td></tr>
<tr><td colspan="5">IV Environmental issues</td></tr>
<tr><td colspan="3">Environmentally friendly</td><td colspan="2">Landscape</td></tr>
<tr><td colspan="3">The solution is environmentally friendly</td><td colspan="2">Due to major floods, the landscape has been destroyed, after construction works, greening is planned</td></tr>
<tr><td colspan="5">V Work performance</td></tr>
<tr><td>Land ownership</td><td colspan="2">Work impact</td><td colspan="2">Local acceptance</td></tr>
<tr><td>To expropriation problems solved</td><td colspan="2">Road damages</td><td colspan="2">Good</td></tr>
<tr><td colspan="5">VI Alternatives for better achievement</td></tr>
<tr><td colspan="5">Alternative rigid solutions with deteriorating impact on the environment and landscape, higher cost, more difficult to maintain and repair, which decrease erosion velocity (concrete structures)</td></tr>
</table>

3. CONCLUSION

Protection of the environment is an imperative of the modern era, and in this respect there must be a general social consensus. All scientific disciplines related to nature, whether directly or indirectly, must take ecology into account. In this framework, water has a very important role to play because of the huge importance of water for the environment. Any approach to the development and use of water courses must be based on the harmonization of water management and environmental objectives. Regardless of the current financial state of the Serbian Water Management, this approach must be our commitment to the future.

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EKOLOŠKI PRIHVATLJIV PRISTUP U HIDROTEHNIČKOJ PRAKSI. STUDIJA SLUČAJA NA LJILJANSKOJ RECI

U proteklih trideset godina ulažu se značajno veći napori da bi se zaštitila rečna korita i obale reka. Izbor i projektovanje odgovarajućeg konstruktivnog rešenja podrazumeva nalaženje rešenja koje je skladu sa principima gradnje ali i geomorfologijom rečnog toka. Na ovaj način se izbegava mogućnost urušavanja regulisanog rečnog korita i vertikalna i bočna erozija rečnog korita čime bi došlo do loma konstrukcije, značajno ugrožavanje rečnog toka i okolnih poseda. S druge strane, konstrukcija treba da bude ekološki prihvatljiva. Hidrotehničke konstrukcije generalno imaju snažan uticaj na životnu sredinu, tako da nalaženje „pravog rešenja" predstavlja pravi izazov za inženjere.

Ključne reči: *hidrotehničke konstrukcije, uticaj na životnu sredinu, uređenje vodotoka*