Experiences in Planning, Construction and Maintenance of Navigation Training Works on the River Danube

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1 Introduction

River Danube is the most important segment of the Mid-European navigation network, being an international waterway of the fourth class according to the criteria of the ECE countries.

The total length of Danube in Yugoslavia is about 590 km, the section downstream from Belgrade (km 1166) and upstream from the Yugoslav-Bulgarian border (km 845) being practically entirely canalized, after completion of the power-plants "Iron Gate I" (km 943) and "Iron Gate II" (km 863). The necessity of classical river training works on this sector is thus avoided, except for bank protection against waves due to winds or passage of ships.

The purpose of this article is to review experiences gained over a long period of design, construction and maintenance of training works ensuring safe navigation on the 260 km long reach of Danube upstream from Belgrade (km 1166), up to the location of Bezdan on km 1433 (Fig.1).

The training works on Danube have a long tradition. During the 19th century, these works have been undertaken in order to stabilize the river bed and to prevent floods by construction of levees. After this period, the regulation has been directed toward improving navigational conditions.

In 1948. Yugoslavia has signed a Convention under the Danube Commission, thus accepting important responsibilities to form and to maintain this important international waterway. Since that time, efforts have been made to plan, design, systematicaly construct and to maintain the system of training structures. All these activities are being coordinated and executed by a special government Institution for maintenance of inner waterways, with its seat in Belgrade. The intention of the authors is to inform river engineering specialists about these efforts and the achieved results.

2 Historical review of training works

Historically, three main periods of training works on this particular reach of Danube can be considered:

The first period dates far back to 1860, when the first large-scale works have been recorded. These works have been primarily undertaken to protect the nearby land from flooding. The first important structure in the river bed was 1.5 km long revetment of the river bend on location Dalj (km 1390, Fig.1). This first period, ending by 1918, is characterized by the most extensive and systematic works up to now, with about 70 km of revetments, 71 km of various other regulating structures, 3 km of closure dikes, and about 20 km of river bend cutoff channels.

The second period is the period between the two World Wars, when activities on ameliorating navigational conditions on this part of Danube have been sporadic, and unsystematic. Only 18,5 km of revetments have been added in this period.

The third period begins after the Second World War, when large-scale construction takes place once again, this time as the result of the mentioned Convention of the Danubian Commission. New structures have been carefully planned and designed in order to integrate with the old ones. This article focuses on this period, after the completion of the Iron Gate Power and Navigational System, which has significantly relieved navigational problems on Danube downstream from Belgrade.

In 1965 the Danube Commission has determined navigational standards, and fulfilment of these standards necessitated long-term training works to be completed after the following phases:

- In the first phase (1965–1970), minimal navigable depths had to be ensured on several critical sectors with the total length of 80 km;

- In the second phase (1970–1974), the minimal navigable depth of 2,5 m had to be ensured along the entire waterway;

- In the last, third phase, in addition to the given depth, other elements of the waterway, such as the navigable widths and radii, had to be ensured according to the prescribed standards. This phase was initially planned to end by 1980, but due to financial problems, it has not been completed to the

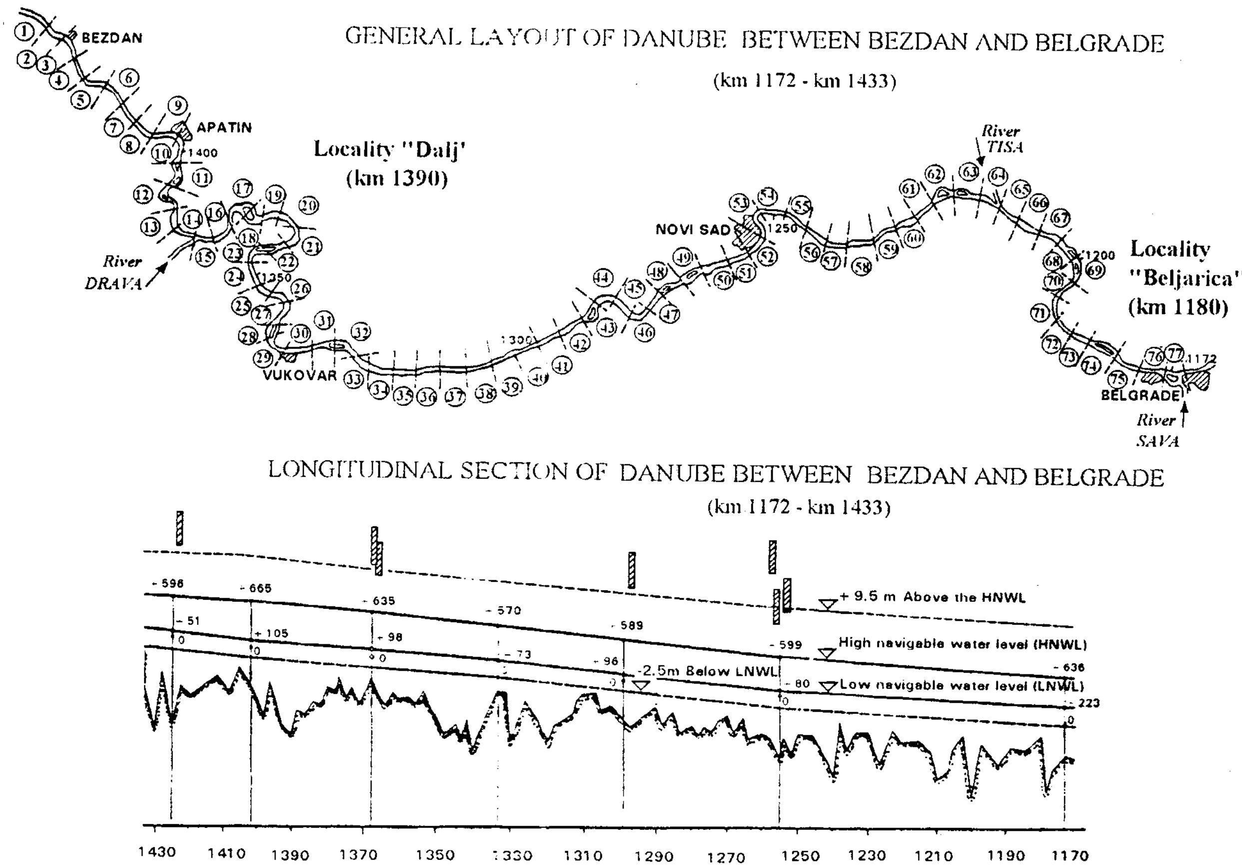

Figure 1: Layout and longitudinal cross-section of the considered reach of the river Danube between Bezdan and Belgrade

Table 1: Critical sectors for navigation (1965)

River reach	Sections (Fig.1)	Chainage (km)	Length (km)	Critical sectors (km)	Critical sectors (%)
Bezdan-conf.r.Drava	1–14	1433-1382	51	42.4	83.1
conf.r.Drava-conf.r.Tissa	15–64	1382-1215	167	99.0	59.3
conf.r.Tissa-conf.r.Sava	65–77	1215-1166	49	15.5	31.6
	Total:		267	156.9	58.8

Table 2: Completed structures 1965–1985

Type of structure	Total length (km)
Groynes	25.475
Parallel structures	4.400
Revetments	40.90
Closure dykes	3.065
Longitudinal dykes	1.325
Sills for bed fixation	1.040
Stone depositories	2.740

present day.

Assessment of critical sectors in 1965 is given in Table 1. An Investment programme has been defined with construction priorities and deadlines of completion.

As can be seen from Table 1. in the mid-sixties some 60 % of the considered reach of Danube had not been adequate for navigation. Prior to design and construction, hydraulic studies and laboratory investigations have been undertaken, based on significant field measurements and sediment sampling. In this way possible effects of river training structures have been analyzed. As a result, the structures completed in the period 1965–1985 (Table 2) have not only improved the navigational conditions, but have also ameliorated flow, sediment and ice regimes

The total quantity of material used for construction is about 1.6 million m^3 of stone, 600 000 m^3 of fascine mattresses and 120 000 m^3 of sand (filled plastic bags).

By 1990 positive effects have been achieved, and the total length of reaches with unfavorable navigable conditions decreased to 33.6 km, or 11.17 % of the considered reach of Danube. Less than 5 km (or 1.5 %) are critical due to inadequate radii of curvature. It must be emphasized that the minimal navigable depth of 2.5 m has been ensured along the entire waterway (according to the so-called "Low Navigable Water Level" (LNWL) corresponding to the 92-95 % of stage duration), but adequate navigable widths have not been fully provided, their variability depending on location and discharge. The most critical sector from this point of view is the sector on km 1267 ("Futog"), in the vicinity of city of Novi Sad (see Fig.1), where the navigable width reduces in low discharge periods to only 50 m.

Figure 2 shows chronologically the effects of training works at one of the navigationally unstable sectors (km 1295–1289) over a period of 10 years (1969–1979). The river branch has been closed by a stone structure about 300 m long, built in the very first construction period prior to 1918. This structure is combined with a system of groynes built at a much later date (in the sixties), with one purpose to increase navigable depths by making the river bed narrower. Positive effects of these structures are quite evident.

At the present time there are still three reaches critical for navigation: "Futog" km 1267–1261, "Slankamen" km 1227–1218, and "Preliv" 1200–1195 with a total length of about 20 km.

3 Experiences and Recommendations

3.1 Continuity of construction and maintenance

The most imperative factor for navigation on such an important international waterway is certainly the continuity of construction and maintenance. According to experience gained over a long period of time, the minimal annual quantity of material required for maintenance is about 1% of the material used to build the structures. In this particular case, it is a quantity of 40–50 $\times 10^3$ m^3 per year. An additional quantity of about 15 $\times 10^3$ m^3 per year per every 100 km of the watercourse. is to be used for acute interventions

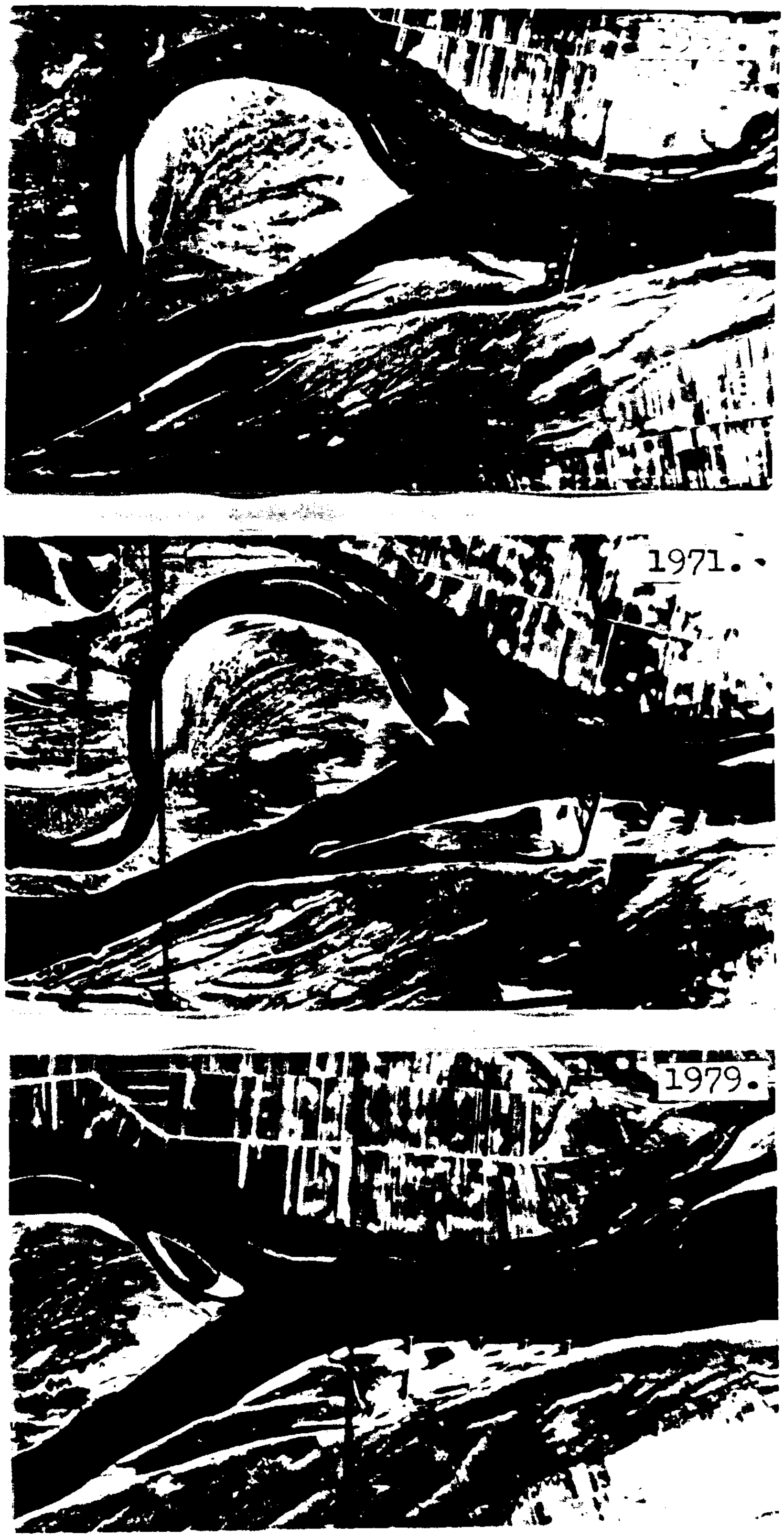

Figure 2: River training for navigation km 1295–1289 [3]

at locations where no training works have been undertaken. For the reach of Danube between Bezdan and Belgrade, these quantities amount to a total of 70–100 $\times 10^3$ m^3 of stone per year. However, due to chronic financial shortages, only 10–15 % of the required quantity (10–15 $\times 10^3$ m^3) has been achieved in the last decade. As a consequence, there is a number of locations with degraded structures, particularly revetments.

Considering huge financial requests for completion of these works, experts have paid attention at an early design stage to avoid, or to minimize any unfavourable consequences. All possibilities at designers' disposal have been used - field investigations and measurements (hydrometric, morphologic sediment, etc.), morphological analyses, numerical and (if necessary) hydraulic models, even 1:1 scale experiments, in order to develop new technologies of construction and to reduce the costs of construction and maintenance.

3.2 Design modifications

The training structures conceived from 1965 to 1970 can be considered today as the classical ones, made of traditional materials, and in accordance with technological facilities of the time. However, significant modifications have been introduced later in order to cut down the expenses, but under condition not to impair the quality of works, and not to prolong the time necessary for the positive effects to manifest.

Groynes

Experience has shown that the best effects on flow and sedimentation conditions are obtained by a special type of groynes with parallel elements ("wings"), Fig. 3. The length of the upstream wing is 10-30 m, and of the downstream one, 20-100 m. The design height of groynes has been chosen to correspond to the level 1 m under the "Low Navigational Water Level" (LNWL), while the distance between groynes is about 250-1250 m.

Favorable flow conditions have been recorded with this kind of groynes, and a very rapid sediment deposition. The positive effects are shown in Fig.4, pertaining to the reach of Danube on km 1185–1180. (The light area on this photograph represents the stabilized "new" bank formed by the deposited river sand).

Other modifications include: (a) exclusion of special groyne "rooting" to the bank (a local revetment has proved to be sufficient), (b) an increase of the downstream slope (1:1.5, instead of the traditional 1:2), and (c) an

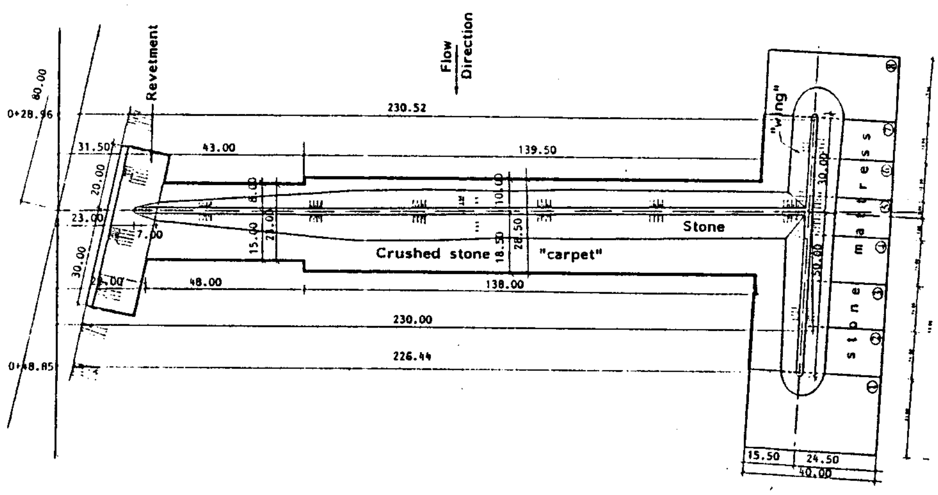

Figure 3: Typical groyne on Danube

Figure 4: Positive effects of groynes (locality "Beljarica", km 1185–1180) [3]

extension of the crushed stone mattress downstream from the groyne body by a factor of 2.5–3 × the groyne height (Fig. 3). All these modifications have significantly reduced investments and contributed to the safety of the structure.

Closure dikes

A typical dike structure used to close the river branch has the downstream of 1:1.5, and its connection with banks is in the form of local revetments. The crushed stone mattress is extended downstream from the dike body over a length of 2.5–3 × the dike height in order to act as a stilling structure once the dike is being overflowed.

Revetments

The sufficient thickness of revetments has been determined to be 25 cm (previously 30 cm), and the sand filter thickness 20 cm (previously 30 cm). The revetments have traditionally been built by stone blocks 10-30 cm in diameter. Instead of massive stone ballast in the form of a prismatic structure on a fascine mattress, the base of a revetment can be formed as a crushed stone "carpet" without endangering the safety of the revetment.

Sills

Classical sills for river bed fixation can be successfully replaced by special type of sills formed by sand-filled plastic bags. This technology has given good effects on a number of locations, as will be shown in sequel.

3.3 New materials and technology of construction

The design modifications resulted in introduction of new materials and technology of construction. Traditional materials, such as stone, gravel, crushed stone, and sand are indispensable. However, elements of structures built by biological materials, such as fascine mattresses, have been successfully substituted on Danube by gravel and crushed stone layers. Efficient machine construction techniques have replaced expensive manual work, both under water and on land. The introduction of automated mechanical work has significantly improved the quality of works. However, new problems have emerged, such as:

- a low coefficient of efficiency of the machinery due to a relatively low quantity of the material used per unit length of the structure;

- an important influence of natural factors (temperature, hydrologic regime, waves, etc.) upon the continuity of works;
- a chronic financial shortage for continual investments in river training works, affecting a continual engagement of machinery with high annual costs.

These problems have prompted engineers to think about new materials and new construction technologies. The idea of using river sediment as the primary building material has proved to be a very sound one, since this material can be found in abundance wherever river training works are executed. No transport costs are necessary, as in the case of stone, which has previously been, (and to a great extent still is), the dominant building material in Yugoslav river engineering practice. The sand, dredged from the river bed, is used to fill plastic, porous bags by a centrifugal pump ("hydrocyclone") which separates sand from the water-sand mixture. The sand-filled bags are used as construction elements for river training structures, with a stone protection layer placed on top of the bags. This new technology has been used in several cases, three of which are mentioned here, as being typical:

- Construction of upstream-inclined groynes, with the purpose to reduce the width of the river bed, and to increase the sediment transport capacity. The top width of the groyne is 2 m, and side slopes 1:1,25 (upstream) and 1:1,5 (downstream). A 70 cm thick stone protection layer has been initially designed (stone size ranging from 6-25 cm), but the new bank made of deposited sand has been so rapidly formed, that no protection layer was necessary. The task has been thus completed with a considerable saving of time and money;

- Construction of submerged sills in order to stabilize the river bed in sharp river bends. It is well known that the channel depth increases excessively along the concave bank, endangering the stability of revetment and modifying the cross-section in such a way that the width of the navigable channel may become insufficient. It has been found by morphology analysis, that such phenomena occur on Danube whenever the radius of curvature is less than 1,500 m. One possible solution of this problem is application of sills across the deepest cross-section of the reach. The system of sills affects the flow pattern directing the bed currents towards the convex bank and causing scour at places where otherwise deposition of sand would occur. Economic

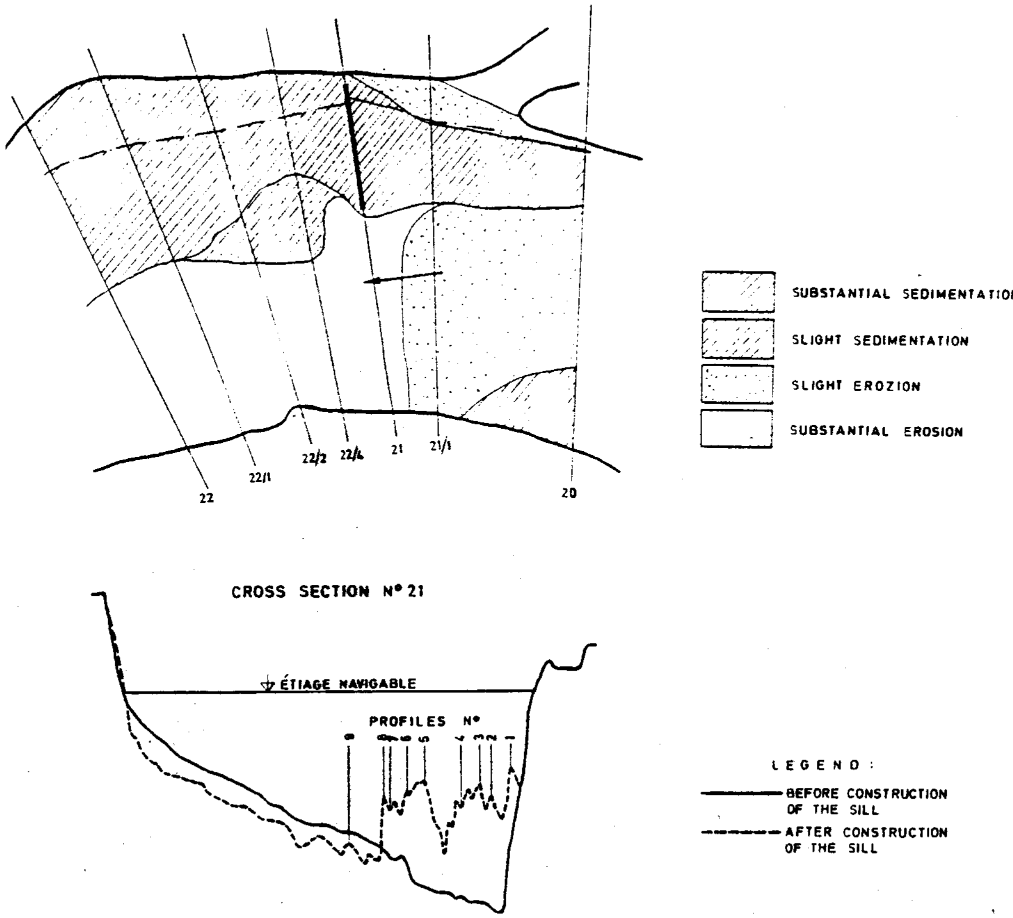

Figure 5: Results of laboratory investigations [1]

analysis of the sills made of sand-filled plastic bags, has shown that savings by this technology at the locality called Dalj, on km 1390 (Fig. 1), would amount up to 70 %. Field measurements hydraulic model tests have been undertaken to study flow conditions at this particular river bend with the maximal water depth of about 30 m. The 5 km long reach of Danube has been modelled in distorted scale (1:200 horizontal, and 1:40 vertical). The movable-bed model investigations provided valuable information concerning the effects of sill on sediment erosion-deposition (Fig. 5), and helped to solve the problem of submerging the sand- filled plastic bags in running water;

- Construction of embankments for protecting concave banks from erosion. Classical soil embankments have been replaced by special structures made of sand-filled plastic tubes 50 m long, 0,5-1,0 m in diameter [2] (Fig.6). Each tube, containing 10–30 m^3 of sand, can be filled in about 10 minutes, by a crew of only 4 men. The system of tubes is covered by a layer of stone

Figure 6: Sand-filled plastic tubes [2]

revetment, protecting the plastic material from ice impact and ultraviolet radiation.

4 Conclusions

This brief review can be used to make several general conclusions:

1. The standards set by the Danube Commission for waterway of the fourth class, have imposed significant financial responsibilities pertaining to formation of necessary navigable widths and depths, and their subsequent maintenance. These responsibilities can be met only if activities are executed in a continuous, systematic and rational way. The reach of Danube between Bezdan and Belgrade is a good example for this, although the financial support has chronically been insufficient.

2. Since 1965, the total length of sections not complying to the navigation standards set by the Danube Commission, has been reduced by the completed river training works from 60 to only 11 %.

3. In order to cut down the cost of works, significant modifications have been introduced in design and construction. These include: a special type of groynes with "wing" elements and reduced volume (steeper side slopes), revetments with foundation in the form of a crushed stone carpet, sand-filled plastic bags as construction elements for sills, groynes and other structures, geotextile filters, etc. The structures made by the new technology proved to be efficient, faster to build and less costly than the traditional ones.

References

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Abstract

This paper presents a review of activities undertaken from 1860 to the present day in construction and maintenance of navigation training works on the Yugoslav reach of the river Danube, upstream from Belgrade. An assessment of critical sectors for navigation is given, as well as the state of completed structures - groynes, revetments, closure dikes, sills, etc. Experience shows that significant investment reducing modifications in design and construction can be introduced, without impairing the quality of river training works. Examples of new technologies, such as the use of sand-filled plastic bags for construction of revetments and sills, is also presented. Positive effects of the undertaken works are shown by aerial photographs taken in the course of time.