Applying fluvial geomorphological riffle-pool sequences concept when rebuilding the existing drop hydraulic structure

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doi: 10.4316/GEOREVIEW.2014.24.1.163

GEOREVIEW

Article history
Received: January 2014
Received in revised form: May 2014
Accepted: July 2014
Available online: August 2014

ABSTRACT: The paper deals with the problem of rebuilding the existing water straight drop structure in Brenna on the Brennica river (Polish Carpathian mountains), which was changed into the rapid hydraulic structure. The technical project was set up in 1988 and finished in the same year. The structure was rebuilt in the field in the early autumn of 1990. One of the concepts of applied fluvial geomorphological solution was used to improve the river channel bed condition. In that case it was found that the existing hydraulic structure reducing river slope and stabilizing river bed can be changed without any harm in to semi-natural riffle structure which could be tolerated by river and organisms living in. Artificial roughness of the slope plate of the rapid hydraulic structure was obtained by placing cobbles along all the slope apron of the structure. The diameter of cobbles was calculated applying various methods, and the optimum value for that dimension was chosen. The cobbles, used for rebuilding purposes, were taken directly from the riverbed, so that the structure is environmentally similar to the site. All work was done due to European Framework Directive for Rivers.

KEY WORDS: rapid hydraulic structure, straight drop structure, roughness, chute wall, rebuilding

1. Introduction

When rebuilding any engineering construction we are very often faced with much more challenge then we building it from its foundations. It is obvious that sometime there is no need to reassemble the structure, and some reconstruction work is enough to repair it, especially when its construction corpus is not seriously damaged. Hydraulic structures work in special conditions (water) thus a careful way of thinking is needed when designing, building and reconstructing them. Thus finding out and applying some research results into engineering works seems to be very beneficial from practical point of view. These two ways of thinking, based on scientific and engineering experience, have been combined in the Brenna project in the Polish Carpathian mountains when the water straight drop spillway structure on the Brennica river had been repaired (Radecki-Pawlik, 1993; Radecki-Pawlik, 2013). The site of the structure is situated in 7+964 km along the Brennica River. The object is of great local importance because it is the last hydraulic structure of the river training works built upstream of it. It means that it supports all other water sills and bank revetments upstream.

2. Ideas used and repairs done

As has been noticed during field-expert visit some parts of the 7+964 km straight drop weir had been damaged. The downstream sill and the floor of the energy dissipating pool (a silting basin) had been seriously damaged (Figure 1). The condition of the two sidewalls along the energy dissipating pool was also very poor and needed repairs.

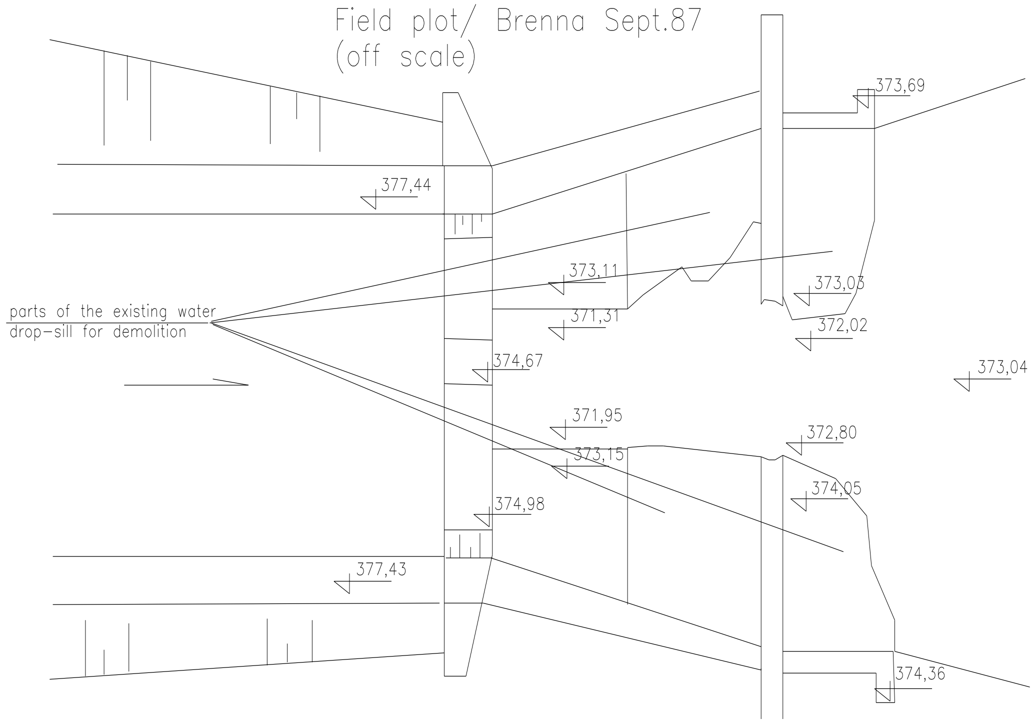

Figure 1. Drawing of the Brenna straight drop hydraulic structure needing rebuilt (by A.Radecki-Pawlik).

19 years after finishing the weir the river bed decreased in some places about 2 meters downstream of the structure, which was probably caused by illegal exploiting procedure of gravel from the riverbed. People took out the gravel from the riverbed, destroying it seriously, which also seemed to be the main cause of damage to the hydraulic structure (Radecki-Pawlik and Wójcik, 1987).

Because of the good condition both of the straight drop wall of the weir and the upstream revetments, the new concept of the repair of the structure was applied which took into account some existing local conditions. It was decided to transform the existing structure into a rapid (spillway) hydraulic structure with an artificially rough slope chute plate to reduce the energy of flowing water. It was done following the fluvial geomorphological concept of riffle-pool sequences which are common for gravel rivers (Figure 2; Photos 1-3).

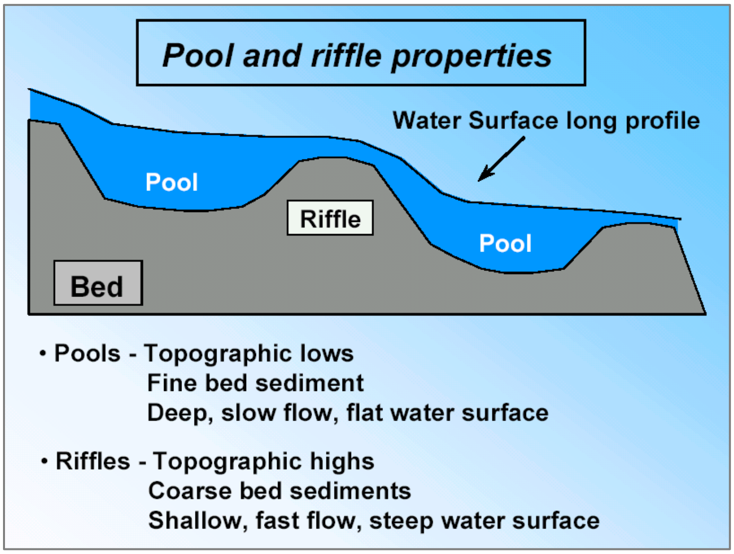

Figure 2. Riffle-pool sequences concept from applied fluvial geomorphology (adopted by A.Radecki-Pawlik).

Photo 1. Photo of the rapid in the rock channel (from Yellowstone Park).

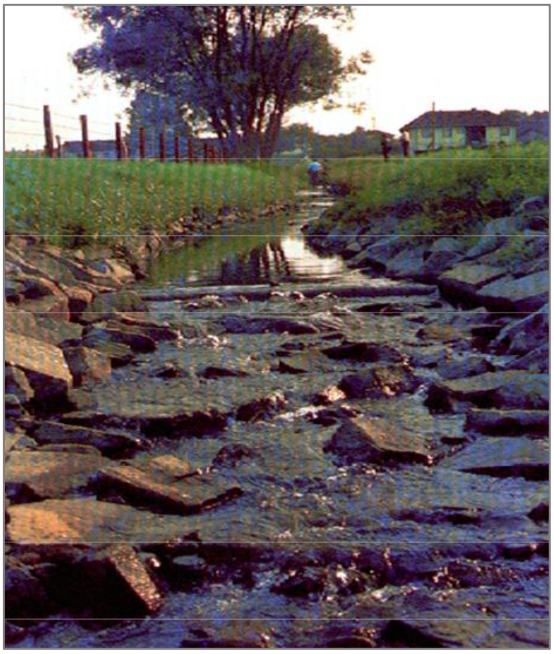

Photo 2. Photo of the riffle hydraulics structure build with cobbles.

This application gave the basis for the idea of the rebuilding. Artificial roughness was obtained using stones from the riverbed. In a technical design project it was advised to fix stones into the slope plate of the structure.

Photo 3. Photo of the gravel riffle structure and pool sequence in a natural river.

The dimension of the stones used to dissipate the energy of water flume can be calculated in different ways. In Austria Niel [1960] suggested to determine the dimensions of the stones used on the rapids as below:

$$\mathbf{D = h \cdot I}$$

where: D - dimension of a stone (m),
h - water depth (m),
I_s - inclination of a plate (-).

This equation is accurate for discharges less than 9 m^3/s and for c = 0.560 (discharge coefficient). The velocity on the chute plate was measured Scheuerlein and Hartung (Scheuerlein, 1968). They worked with four chute slopes: 1.5 : 1 , 2.5 : 1, 5 : 1, 10 : 1, and used the same artificial roughness in all cases of their experiment. The velocity of water on rapids could be calculated as:

$$\mathbf{v = \sqrt{\frac{8 \cdot g}{\lambda}} \cdot \sqrt{h_s \cdot \sin(\phi)}}$$

where: v - mean velocity on the plate (m/s),
h_s - mean water depth (m),
ϕ - angle of inclination of a plate (-),
λ - coefficient (-),
g - acceleration (m/s^2).

$$\mathbf{\frac{1}{\sqrt{\lambda}} = -3.2 \cdot lg(c \cdot \frac{k}{4 \cdot h_s})},$$

$$\mathbf{c = B_a \cdot (1.7 + 8.1 \cdot k_{max} \cdot \sqrt{w \cdot \sin(\phi)})},$$

$$\mathbf{B_a = 1 - 1.3 \cdot \sin(\phi) + 0.08 \cdot \frac{h_s}{k}},$$

where: B_a - aeration coefficient (-),
k_{max} - maximum stone protrusion above a plate (m),
k - mean stone protrusion above a plate (m),
w - number of stones per sq metre

Knauss [1980] following the Scheuerlein and Hartung equation, found that the optimum slope for the chute plate for a rapid hydraulic structure is of 8 : 1 to 10 : 1. He determined the diameter of stones providing artificial roughness from the formula:

$$D = h_s \cdot 10 \cdot tg(\phi)$$

where: h_s - mean water depth (m),
ϕ - angle of inclination of a plate (-).

He also gave some suggestions concerning the maximum water discharge that is possible to reach on a chute plate (Figure 3). This discharge depends on the parameters mentioned above.

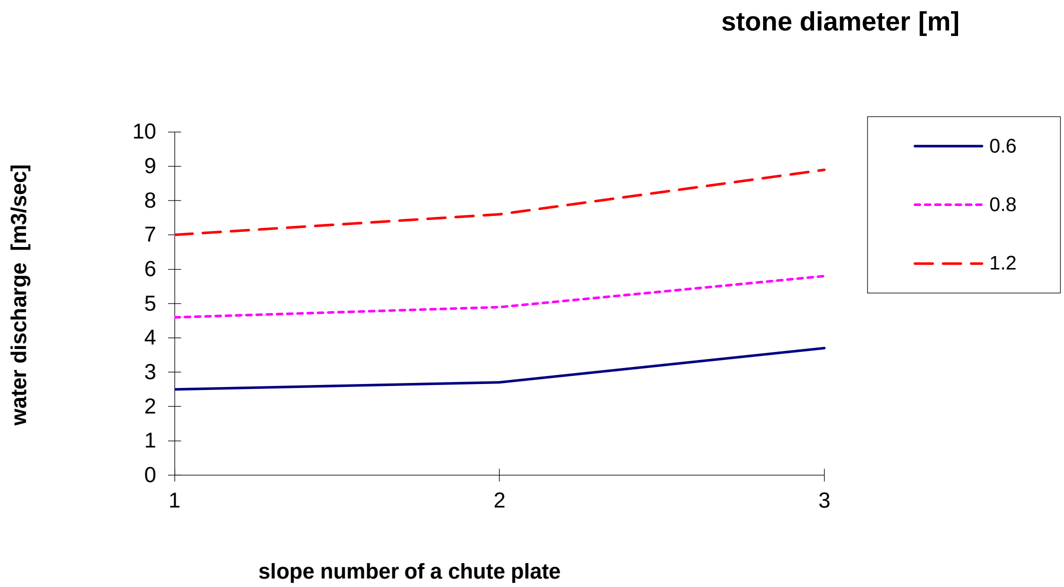

Figure 3. Maximum discharges for a chute plate of a rapid structure. Source: Knauss J. 1980, Drsne skluzy, Vodni Hospodarstvi. Rada AC1.

Note that slope numbers are representing inclinations of a rapid plate n:1. Thus for a slope no1 n : 1 = 8 : 1, for no2 n : 1 = 10 : 1 and for no3 n : 1 = 15 : 1.

Using the above mentioned approaches and the other experiences - "Hydroprojekt" design office instructions and Polish standards (Radecki-Pawlik and Wójcik, 1987) a technical project of the rapid hydraulic structure was proposed. The theoretical plot of the rapids hydraulic structure with stones fixed in a chess-like manner to the chute plate is shown in Figure 4.

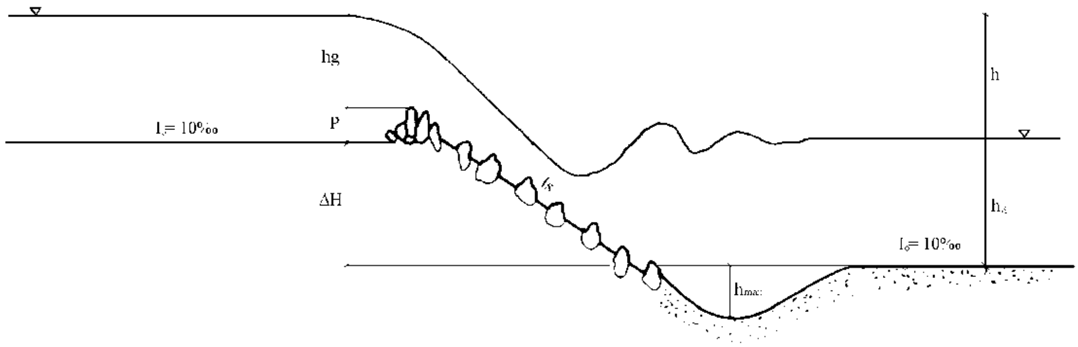

Figure 4. Drawing of a theoretical rapid hydraulic structure (by A.Radecki-Pawlik).

3. 3. The rapid hydraulic spillway structure on the Brennica river

For the designing reasons basic river discharges are always needed before one starts to rebuild any hydraulic structure. Thus, the main water discharges for a rapid hydraulic structure cross-section in the Brennica river are as follows: NNQ - low flow is 0.033 (m^3s^{-1}), SNQ - mean-low flow is 0.21 ($m^3 s^{-1}$), SRQ - mean flow is 1.58 (m^3s^{-1}), SWQ - mean- high flow is 57.20 (m^3s^{-1}), Q-50% is 32.00 (m^3s^{-1}) and finally Q-5% is 173.00 (m^3s^{-1}). The methods of calculating the discharges meet the requirements of Polish standards. Presented numbers were calculated by IMGW (Polish River Authority).

Photo 4. Photo of the rapid hydraulics structure after the rebuilding (photo by A.Radecki-Pawlik).

Having hydrological data, the hydraulic calculations were carried out using the Q-50% and Q-5% discharge values as design discharge values, according to Polish standards. These calculations were conducted in three ways: as for the straight drop spillway structure (Chow, 1959), for ramp structure (Radecki-Pawlik and Wójcik, 1987) and finally using the USBR stilling basin method II (Dziewoński, 1973). With all those calculation methods engineers are familiarised. As a result the structure presented in Figure 5 was designed (also Photo 4).

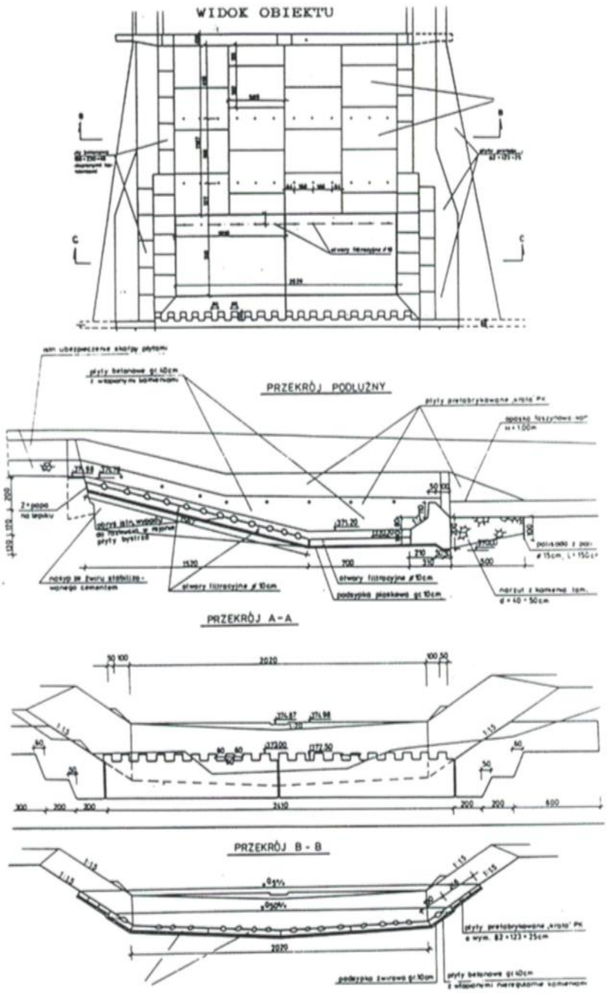

Figure 5. Drawing of the rapid hydraulics structure after the rebuilding (by A. Radecki-Pawlik).

As a result of hydraulic calculations involving artificial roughness (stones in a slope plate), it was decided to decrease the length of a silting basin (calculated following a usual USBR set of equations) down to 70% of its initial value because of the reduced a velocity of flowing water through the structure. This reduction in water velocity was possible thanks to the artificial roughness of the slope chute plate. The dimension of the stones used on the plate was calculated according to Niel and Knauss.

The results were as follows: for Q-50%, using the Niel concept led to the stone diameter for a chute plate equal to 0.2 m, whereas using the Knauss concept - 0.4 m.; for Q-5% the stone diameters were 0.6 m. and 1.0 m. respectively. Finally, the water discharge Q-50% was chosen as a design flow, thus the 0.4 m stones were chosen as the best fit for a chute wall in terms of water energy dissipating.

4. Recapitulation

It is important to combine the results of scientific research and designing practical experience when building any hydraulic structure. Such an approach was adopted for the Brennica river site where the existing straight-drop hydraulic structure has been rebuilt using applied fluvial geomorphological concept of riffle and pool sequences. The artificial roughness on the slope rapid plate of the rapid hydraulic structure which has replaced the previous weir has been used to reduce the energy of the stream water flow. That roughness was obtained by putting cobbles into the slope rapid plate along its length. Some formulae were presented and used to find the dimension of the cobbles used. Based on the results of the calculations, the length of the silting basin pool of the rapid hydraulic structure has been reduced. The cobbles ensuring artificial roughness of the slope plate were taken out from the riverbed and the hydraulic structure is therefore very well fitted in the environment site (Ratomski, 1992; Ślizowski, 1993: Ślizowski and Radecki-Pawlik, 1996, 2013). Thus, the object seems to work like natural rapids in a stream. Such a solution combines then engineering and environmental needs.

The project was finished in 1988. The rebuilding of the structure in the field was finished in early autumn 1990. For designers as well as for users of any structure quite important is what we could call "the natural test of an object". Such the "natural test" had place in 5th of August 1991 when the water discharge of the order of was observed Q-50%. Its rate was 33.8 m^3/s (close to the competent flood). Since then the structure had been working properly and no damages had been noticed. The authors of the project hope that such designing solutions will be applied in the future when working in similar conditions.

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