INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr III/1/2016, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 835–847
Komisja Technicznej Infrastruktury Wsi

DOI: http://dx.medra.org/10.14597/infraeco.2016.3.1.061

BLOCK RAMP REBUILDING AND EXPLOITATION PROBLEMS: CHUTE STONE DIMENSION CHOOSING; UPSTREAM THE RAMP RIVER CHANNEL EROSION

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Abstract

The paper shows a rebuilding example of drop hydraulic structure which was changed into the block ramp hydraulic structure. Artificial roughness of a slope plate of the block ramp was reached by placing cobbles along the chute slope. The dimension of cobbles was calculated applying different methods and the optimum value for that dimension was chosen. Also the diagram of Radecki-Pawlik et al. 2015 was used. Finally we are showing the distribution of velocities and shear stresses upstream of the block ramp for exploitation and river channel bed protection reason to give the information on the possible erosion process there and seek some suggestions for river bed protections. The work was carried on in Polish Carpathians on the Brennica River.

Key words: discharge, shear-stress, ramp hydraulic structure

INTRODUCTION

According to River Framework Directive of European Union we need to keep the river corridor useful for fish and invertebrate migration (Radecki-Pawlik et. al. 2013, Radecki-Pawlik 2013, Plesinski et al. 2015). That is another words we need to be in line with river continuum of water. On mountain creeks, however, even nowadays we meet very often some hydraulics structures which stop mentioned river continuum, like for example check dams or drop hydraulic structures. When they are not armed with fish passes which are built parallel to them, they are hindrances for fish and benthos movement (Skalski et al. 2013). That is why we very often plan to rebuilt drop structures or check dams and in their place we plan to build another, environmental friendly hydraulic structures which are block ramps (Oertel 2013, Oertel and Schlenkhoff 2012, Pagliara and Palermo 2013, Pagliara and Palermo 2012, Zastera, 1984; Ślizowski et al.2008, Radecki-Pawlik 2013, Radecki-Pawlik et. al. 2013) – Photo. 1, 2 and 3. Hydraulic structures work in special conditions thus a careful way of thinking is needed when designing, building and reconstructing them.

Photo 1. The bloc ramp on Porebianka stream – please notice curtain walls, photo A.Radecki-Pawlik

In the present paper we describe the situation in mountain stream s when the water straight drop hydraulic structure in the Brennica River had been rebuilt and changed into block ramp (Radecki-Pawlik, 1993). The structure is of a large local importance because it is the last hydraulic structure of a river training cascade supporting it. There are two aims of the paper: to show how to choose the dimensions of chute blocks on the sloping apron of the ramp and present the distribution of velocities and shear stresses upstream of the block ramp for exploitation and river channel bed protection reason (usually we consider the erosion of downstram part of hydraulic structures but the upstream part is also under the influence of the structures and washout process have pleace here as well) . It might give the information for the future to use the most appropriate engineering way to reduce possible erosion process.

Photo 2. The bloc ramp on Bienkowka stream – please notice upstream edge of a curtain wall, photo A.Radecki-Pawlik

MATERIALS AND METHODS

During field-expert visit it was seen that some parts of the existing straight drop weir had been damaged. Downstream-sill as well as the floor of the energy dissipating pool (a silting basin) had been seriously damaged. The conditions of the two side-walls along the energy dissipating pool had also been very poor and needed repairs. It has been noticed after 19 years from finishing the weir that a river bed decreased in some places about 2 meters downstream of the structure. The main reason for that was probably a not formal exploiting procedure of gravel from the river bed. People take out the gravel from the river bed destroying it seriously. It also seemed to be the main reason for damaging the hydraulic structure (Radecki-Pawlik, Wójcik, 1987). Because of good conditions of the straight drop wall of the weir as well as upstream revetments the new concept of the repair of the structure was applied which combined some existing local conditions. It has been decided to rebuild the existing structure into a rapid (spillway) hydraulic structure with an artificial roughness on its slope chute plate to reduce the energy of flowing water. The artificial roughness has been reached using stones from the river bed. It was advised to fix stones into the slope plate of the structure. A dimension of the stones used to dissipate the energy of water flume was calculated in different ways.

In the literature, a dimension of the stones used to dissipate energy along the ICBR sloping apron is presented in different but similar ways. For example, in Austria Niel (1960) (also Jarabač 1973, Jarabač and Vincent 1967) suggested determining the dimensions of the stones used on the rapids as below:

$$D = h \cdot I \tag{1}$$

where: D – dimension of a stone (m), h – water depth (m), I – slope of a ICBR plate (-)

This equation is accurate for discharges lower than 9 m3· s-1 and for c = 0.560 (c – discharge coefficient).

Knauss (1980) found that an optimum slope for a chute plate for interlocked-carpet block ramp is from 1:8 up to 1:10. He determined the dimension of stones causing artificial roughness as:

$$D = h_s \cdot 10 \cdot \tan(\phi) \tag{2}$$

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

He also gave some suggestions about the maximum values of water velocity which are permissible (acceptable in terms of erosion forces) along the ICBR sloping apron (Table 1). This velocity depends on the slope of the sloping apron of ICBR and is measured downstream of the ICBR sloping apron on the ICBR sill.

Table 1. Maximum water velocities for the downstream sill of sloping apron along ICBR after Knauss (1980)

stone diameter (m)	v for a slope of the ICBR apron 1:8 (m· s-1)	v for a slope of the ICBR apron 1:10 (m· s-1)	v for a slope of the ICBR apron 1:15 (m· s-1)
0.6	2.50	2.70	3.70
0.8	4.60	4.90	5.80
1.2	7.00	7.60	8.90

Finally in Poland Radecki-Pawlik et al. [2015] developed a diagram to find the stone dimensions of the apron block rapid. One can read from it (Fig.1) according to the unit discharge and height of the hydraulic structure the dimensions of the stones.

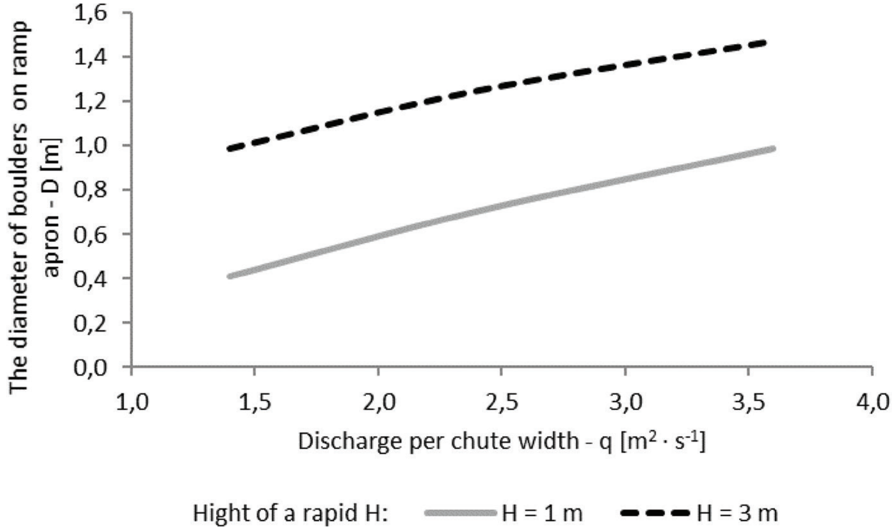

Figure 1. A diagram for choosing the dimension of boulder to install it on block ramp

Using the above mentioned and the other experiences – "Hydroprojekt" design office instructions and Polish standards (Radecki-Pawlik, Wójcik, 1987) – the technical project of the block ramps structure was proposed. The theoretical plot of a block ramp structure and the stones fixed in chess-like manner to the chute apron.

The value of the dynamic velocity and shear stress upstream of the block ramp along the river channel was calculated based on the knowledge of the velocity profile distribution in the river, as proposed by Gordon et al. 2007. According to that, the dynamic velocity was obtained by plotting the regression line between the values of instantaneous velocities and the logarithmic values of the distance between the measurements from the bottom. If the regression follows a straight line, then the dynamic velocity can be calculated from the coefficient that gives its slope to the abscissa axis (Gordon et al. 2007):

$$V_* = \frac{a}{5{,}75}\,[m \cdot s^{-1}] \tag{3}$$

where: a – slope coefficient of a straight $v = f(h)$, adopting the equation form $y = ax + b$ (where: x – height above the bottom over which the velocity was measured; b – intercept of the equation)

The calculated value of the dynamic velocity was used to determine the forces which act on the stream bottom, i.e. the shear stress, according to the formula (Gordon et al. 2007):

$$\tau = \rho \cdot (V_*)^2 [N \cdot m^{-2}] \tag{4}$$

RESULTS

To start with interpreting seems to be good present firstly distribution of velocities and shear stresses just upstream of the upstream curtain wall of the block ramp. It is both done in the table and graph manner below.

Table 1 . Shear stress and shear velocity values for a riverbed upstream of the rapid hydraulic structure

Cross section number Nr przekroju/ punktu	Distance from the upstream curtain wall of the block ramp L [m] Odległość od progu górnego bystrza L [m]	Shear velocity V* [m/s] Prędkość ścinająca V* [m/s]	Shear stress τ [N/m2] Naprężenie styczne τ [N/m2]
1.1	50	0.03	0.8
1.2	50	0.034	1.17
1.3	50	0.026	0.68
2.1	30	0.088	7.99
2.2	30	0.045	2.04
2.3	30	0.07	5.59
3.1	15	0.071	5.01
3.2	15	0.019	0.38
3.3	15	0.09	8.81
4.1	10	0.027	0.77
4.2	10	0.03	0.87
4.3	10	0.05	2.49
5.1	5	0.12	15.33
5.2	5	0.082	6.68
5.3	5	0.099	9.86
6.1	1	0.17	29.16
6.2	1	0.12	15.03
6.3	1	0.111	12.39

In the table 1 one can notice the distribution of shear stresses along the 50 meter upstream of the upstream curtain wall of the ramp. To present this distribution in the graph manner (Figures 1,2) helps understand better the phenomena having place here.

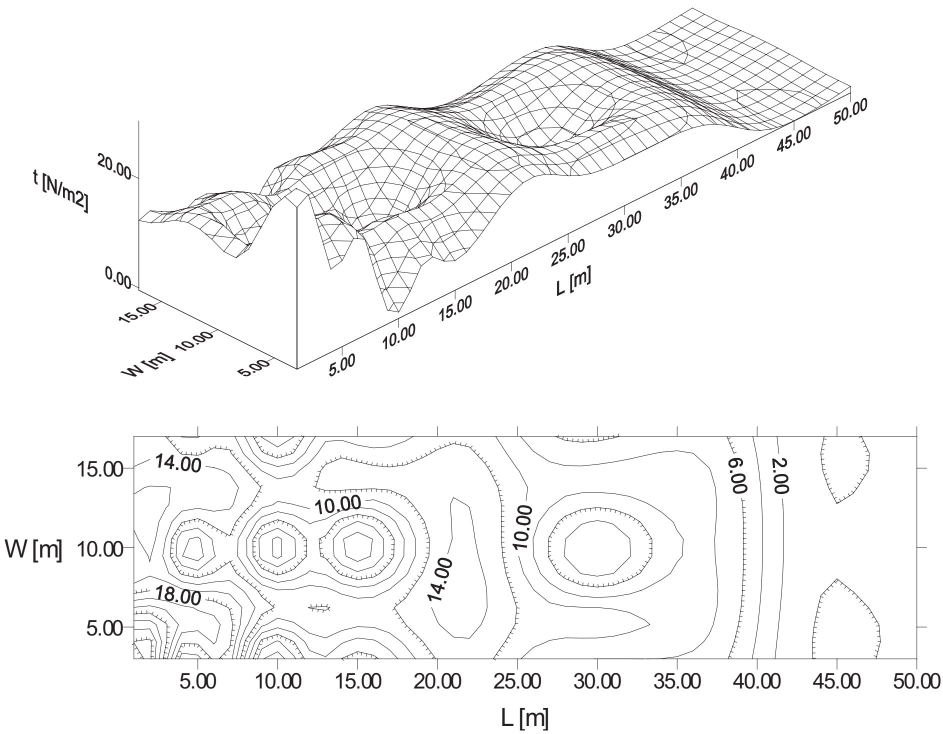

Figure 2. Shear stress values for the river bed upstream of the upstream curtain wall of the block ramp hydraulic structure

For the calculations of the dimensions of chute block placed along the sloping apron of the ramp hydraulic structure we needed some hydrological information. Below there are presented here some main water discharges for a block ramp structure cross-section in the Brennica River. They are as follows: NNQ – low flow is 0.033[m^3s^{-1}], SNQ – mean-low flow is 0.21[m^3s^{-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}]. Discharges shown there are for the designing reasons. The discharges were calculated by IMGW (Instytut Meteorologii i Gospodarki Wodnej). Hydraulics calculation has been carried out using Q-50% and Q-5% discharge values as design discharge values, according to Polish standards. Calculations have been carried out in three ways: like for straight drop spillway structure (Chow, 1959), for ramp structure ("HYDROPROJEKT" – 1980) and finally using USBR stilling basin II method (Dziewoński, 1973). With all those mentioned calculation methods engineers are well familiarised. Finally, the USBR method was applied. As a result the structure presented in the Figure 4 was finally designed.

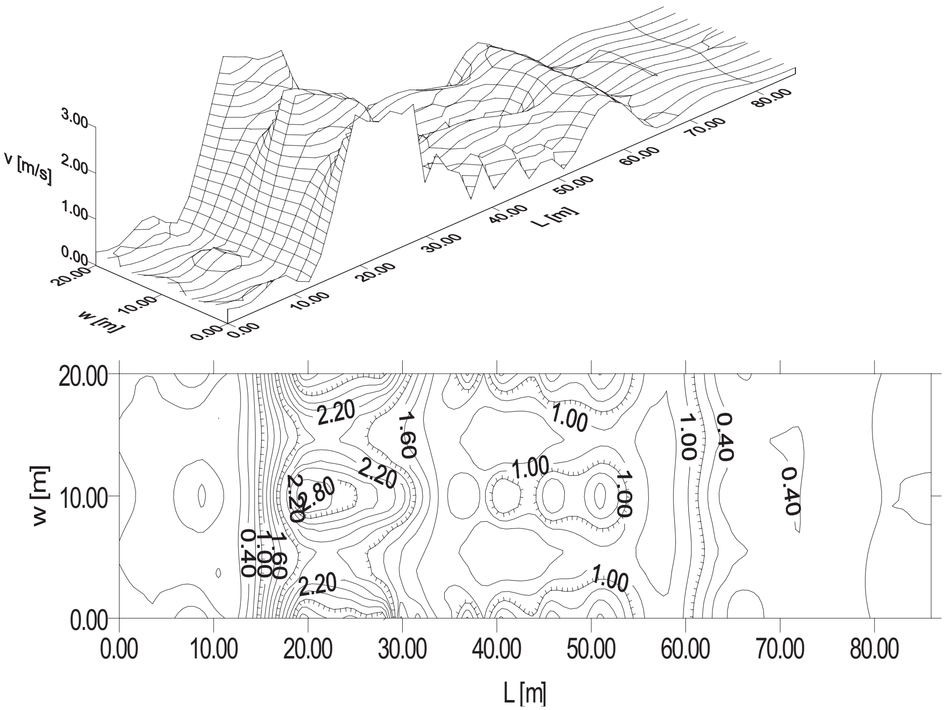

Figure 3. Water velocity values for a sloping block ramp apron and for the upstream curtain wall part of the river channel upstream of the block ramp hydraulic structure

As a result of hydraulics calculations involving artificial roughness (stones on a slope plate) the silting basin length (calculated following a usual USBR sets of equation) was decided to reduce down to 70% of its value because of reducing a velocity of flowing water through the structure. This reduction in water velocity was possible by using the artificial roughness of a slope chute plate. The dimension of the stones used on the plate has been calculated according to Niel and Knauss. Finally, the 0.4 m stones have been chosen as larger. The results of the calculations are gathered in Table 1 .

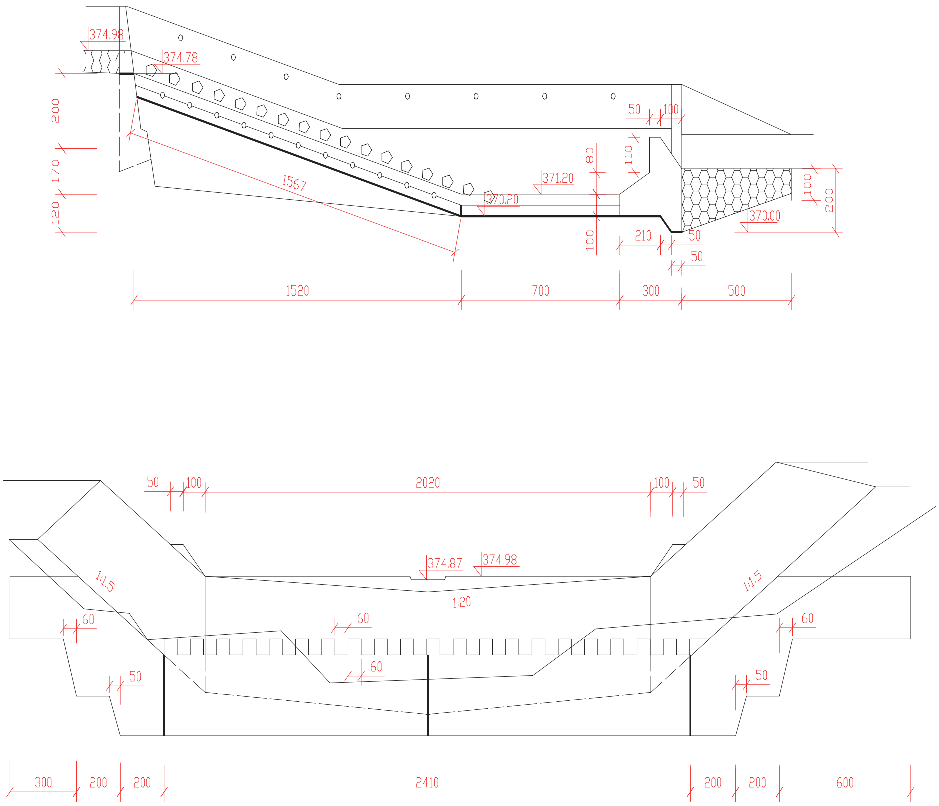

Figure 4. The block ramps structure designing plots

Table 3. Stones dimensions for the chute plate of a block ramp structure (note: a slope of a plate is 1:4)

Formulae	stone diameter for water discharge Q-50% [m.]	stone diameter for water discharge Q-5% [m.]
NIEL	0.2 .	0.6
KNAUSS	0.4	1.0

RECAPITULATION AND CONCLUSIONS

Along the paper we showed a rebuilding example of drop hydraulic structure which was changed into the block ramp hydraulic structure. We presented how to reach artificial roughness of a slope plate of the block ramp by calculating block dimension along the chute slope. It is important to combine the results of scientific research and designing technique when building any hydraulic structure. Such a situation appeared in the Brennica River site where the existing straight-drop hydraulic structure has been rebuilt. The artificial roughness on the slope rapid plate of the block ramp hydraulic structure which has replaced the previously existed weir has been used to reduce the energy of the stream water flume. That roughness was reached by putting cobbles into the slope rapid plate along its length. Some formulae were presented and used to find out the dimension of cobbles used (equation 1 and 2). As a consequence of that the length of the silting basin pool of the block ramp hydraulic structure has been reduced. To reach the artificial roughness of a slope plate the cobbles were taken out from a river bed and the hydraulic structure is therefore very well fitted in the environment site (Ślizowski, 1993, Ślizowski, Radecki-Pawlik, 1996). Thus, the object seems to works like natural rapid in a stream. Such a solution combines then engineering and environmental needs.

Photo 3. The bloc ramp on the Brennica river, photo. A.Radecki-Pawlik

Parallel we present in the paper the field investigation of water velocities and shear stress distribution on a bloc ramp hydraulic structure apron and along the riverbed upstream of an edge of the upstream curtain wall. For the nearly annual average water discharge value Q=1.28 m^3/sec, it was found that velocity fields are situated symmetrically in a longitudinal profile. Two maximum values of velocities were found: at the top of a curtain wall (v=1.0 m/sec) and at the bottom at the downstream part of the block ramp (v=2.6 m/sec). For the given discharge shear stress values are between $\tau = 0.38 - 29.16$ N/m^2.

From figures 2 and 3 and the table 1 presented above and knowing that L stands for the length (the distance) measured from the edge of upstream curtain wall upstream the river and W stands for the river channel width we could conclude the following things:

1. The influence of block ramp stops when L/W = 2.5. This info is important for somebody who would like to protect the river bed upstream of the ramp hydraulic structure.
2. The most intensive changes of shear stresses are for L/W = 1.75.
3. The most dramatic changes of water velocities are for L/W = 1.5.
4. For L/W<1,75 one can notice the bigger drop of shear stresses. That is the part of the river channel which looks as the most sensitive for erosion.

To sum up: the whole project had been finished in 1988. The rebuilding of the structure in the field had been 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 a range Q-50% had been noticed. It was 33.8 m^3/sec (close to the competent flood). During that time the structure had been working properly and no damages had been noticed. The authors of a project hope that such designing solutions would be applied in the future when working in similar conditions.

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Received: 15.04.2016
Accepted: 3.06.2016