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BLOCK RAMPS (BR) MADE OF NATURAL SANDSTONE RAPID HYDRAULIC STRUCTURES (RHS) OF PETERKA TYPE: STONE DIMENSION CALCULATIONS, A COMPARATIVE STUDY

Artur Radecki-Pawlik[1,2], Karol Plesiński[1], Bartosz Radecki-Pawlik[2], Wiktoria Czech[1]
[1]University of Agriculture in Krakow, [2]Cracow University of Technology

Abstract

The paper presents results of hydraulic modelling of block ramps (BR) made of natural stones (seven constructional solutions) and compares them with the results of classical research by Peterka. The main aim of the paper is to provide a simplified solution to determining the dimension of stones fixed to the sloping apron of the BR in order to reduce energy of flowing water along the ramp. This new way of assessing the dimensions of stones along BR sloping apron is presented with proposals on how to calculate stone dimension. The paper is dedicated to hydraulics engineers, scientists, designers, practitioners and also to researchers in the field of low-head hydraulic structures.

Key words: block ramps, mountain streams, hydraulic structures, low head hydraulic structures

INTRODUCTION

Regulation and river training of mountain streams is sometimes necessary in many respects, despite the fact that it might cause some environmental disturbances. To reduce the impact of such inevitable disturbances, river training should be performed taking into consideration nature and landscape beauty. There has been a prolonged debate, especially in Poland, among designers, river managers, fishermen and biologists on the application of all hydraulic structures and engineering methods meant to preserve river beds in best possible condition, as well as preserve river biological continuity and at the same time maintain a close to nature river morphology while preventing river bed erosion and providing flood protection. Because of that member states across Europe have been implementing Water Framework Directive (WFD) of the European Union. However along many sections of the Carpathian rivers, river bed systems are still affected by not always justified technical river regulation and therefore it is necessary to recognize which mountain river training structures can be accommodated in a mountain river fluvial system and positively affect the biological life of both macro benthos and fish (Korpak et al. 2008, Wyżga et al. 2012, 2013, 2014). Field studies were thus undertaken to examine block ramps (BR) – sometimes called interlocked-carpet block ramps (Oertel 2013) – already existing within the mountain channels and later to use the results of such investigations for modelling BR to improve their construction in terms of their hydraulics and their impact on river environment, especially for fish and macroinvertebrates.

Up to now typical hydraulic drop structures are unfortunately still occasionally designed on Carpathian Rivers, especially in places where they support river bed within bridges. However at present, such drop structures are replaced – where possible –with interlocked-carpet block ramps made of natural stones placed on the sloping apron of the structure (Ślizowski 1990, 2002). Thus, the interlocked-carpet block ramps (BR) made of natural stone with artificial roughness are used to stabilize smaller creeks and streams, especially in mountain areas where, apart from performing their technical functions they facilitate fish migration and cause beneficial water aeration (Schauberger 1957, Scheuerlein 1968, Hartung and Scheurlein 1970, Kališ 1970, Oertel and Schlenkhoff 2012, Pagliara and Bung 2013, Pagliara and Palermo 2012, 2013, 2015, Zastera, 1984; Ślizowski et al.2008, Radecki-Pawlik 2013, Radecki-Pawlik et. al. 2013, 2015, Skalski et al. 1012).

BR's are presently used to mitigate the negative impact on the river biota caused by previously designed hydraulic structures. Thus they enable the migration of fish and benthic macroinvertebrates (benthos) and additionally lead to water oxidation and blend into the landscape (Kłonowska-Olejnik and Radecki-Pawlik 2000, Kłonowska-Olejnik et al. 1999, 2006). The pools formed, the presence of which is justified by hydrodynamics of the flow, should be preserved at the sections between the block ramps. Stones of different sizes should be placed in the river bed, creating a shelter for fish and other living organisms (Ślizowski et al. 2008). Such shelters should also be located along river banks. The proposed solutions meet the ecological requirements – blending into landscape – as well as those connected with the stabilization of the stream channel. The proper choice of stone sizes and their positioning on the block ramp significantly influence the efficiency of the rapid and its integration with the natural environment.

The additional advantage of building BR is that we do not need expensive and not very efficient fish ladders that are usually built with other hydraulic structures spanning river channels. Interlocked-carpet ramp structures, also called rapid hydraulic structures (Ślizowski et al. 2008, Radecki-Pawlik 2013, Radecki-Pawlik et al. 2013), have been extensively investigated in recent years, both in the field and in hydraulic laboratories as physical and hydraulic models (Plesinski et al. 2015).

Interlocked-carpet block ramps are environment-friendly low-head hydraulic structures (Kłonowska-Olejnik and Radecki-Pawlik 2000, Kłonowska-Olejnik et al. 1999, 2006 Ślizowski et al. 2008). In Photos 1-7 there are some examples of BRs from Polish Carpathian rivers which mimic natural river rapids, allowing fish and invertebrates to migrate, and which at the same time function as engineering structures that stabilize river or stream bed. Figure 1shows main elements of the BR: L – length of the sloping apron with stones along it, h_g – water depth upstream of the BR, h_s – water depth downstream of the BR, h_{max} – water depth over a downstream sill of the BR, v $_{max}$ – water velocity over a downstream sill of the BR and ΔH – BR height.

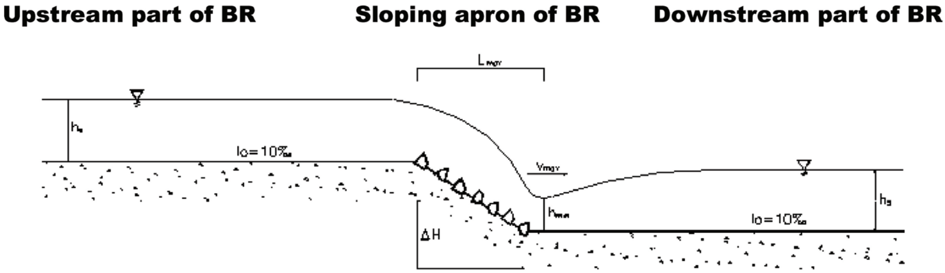

Figure 1. Elements of interlocked-carpet block ramp (BR): L – length of the sloping apron with stones along it, h_g – water depth upstream of the BR, h_s – water depth downstream of the BR, h_{max} – water depth over a downstream sill of the BR, v $_{max}$ – water velocity over a downstream sill of the BR, ΔH – BR height

In this study we focus on important issue concerning BR. On the basis of postulates by Peterka (1964) – Figure 2, tests and experimental studies, unit flows and velocities of water along the sloping aprons of the interlocked-carpet block ramp we attempt to devise a simplified method of calculating dimensions of stones to be placed along the sloping apron of BR. To do so we performed hydraulic model studies of seven interlocked-carpet block ramps constructed by different laboratories and compared the results of measurements of water depths and velocities along BR sloping aprons with Peterka's findings.

Figure 2. An example of interlocked-carpet block ramp (BR) of a Peterka kind constructed on Lubenia stream, phot. A.Radecki-Pawlik

In the literature, a dimension of the stones used to dissipate energy along the BR 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 BR plate (-)

This equation is accurate for discharges lower than 9 $m^3 \cdot s^{-1}$ 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:

$$D = hs \cdot 10 \cdot tan(\varphi) \quad (2)$$

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 BR sloping apron (Table 1). This velocity depends on the slope of the sloping apron of BR and is measured downstream of the BR sloping apron on the BR sill.

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

stone diameter (m)	V for a slope of the BR apron 1:8 ($m \cdot s^{-1}$)	v for a slope of the BR apron 1:10 ($m \cdot s^{-1}$)	v for a slope of the BR apron 1:15 ($m \cdot s^{-1}$)
0.6	2.50	2.70	3.70
0.8	4.60	4.90	5.80
1.2	7.00	7.60	8.90

Source: Radecki-Pawlik 2013

RESEARCH METHODOLOGY

Model tests were performed in a hydraulic flume 25.0 m long, 0.62 m wide and 0.80 m high (Fig. 3). The flume bed upstream and downstream of the interlocked-carpet block ramp was set as non-erodible, with slope of 10‰ and covered with stones which have diameter 0.011 m to increase roughness. Interlocked-carpet block ramp model was made in 1:10 scale as an exchangeable element. The following values were changeable elements in the course of tests: interlocked-carpet block ramp height from 0.10 to 0.30 m, interlocked-carpet block ramp slope 1:4.5; 1:6; 1:10, single flow 1.25; 2.50; 3.75$m^2 \cdot s^{-1}$.Roughness of the interlocked-carpet block ramp was achieved by in-concreting slab stones protruding about 0.045 m from the interlocked-carpet block ramp. The examined BRstructures are presented in Figure 3, their original nomenclature from hydraulic model studies was preserved. Velocity measurement along the interlocked-carpet block ramp sloping aprons was made using hydrometric miniature propeller meter Nixon which enable to measure velocities within a 6-150 cm s^{-1} range. We also measured water depths with a pin gauge.

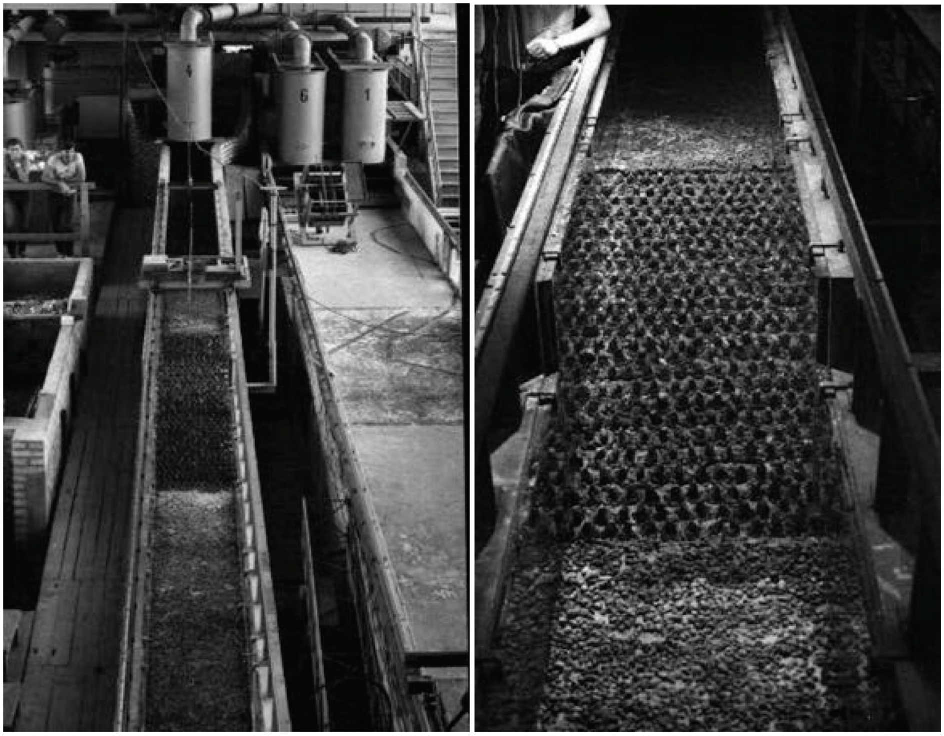

Figure 3. Example of a part of laboratory investigations of hydrodynamic parameters within an influence of interlocked-carpet block ramp

RESEARCH RESULTS AND DISCUSSION

Water velocities on the downstream sill of the BR sloping apron for seven different constructional solutions of interlocked-carpet block ramps depending on unit flow size were presented in the Figure 4. These results were compared with Peterka's tests results – Figure 5, 6. The tests were performed for unit flow range from q = 1.25 m2·s-1to q = 3.75 m2·s-1. The same was done for water depth measured over the same place.

When analyzing Peterka's results in comparison with our experiment findings it is clear that for lower BR heights (h up to = 1.0 m) better convergence of results occurs if the BR height is up to = 3.0 m. The differences in water depth between our experiment and Peterka's attain even 50%. It leads to the conclusion that the size of stones that create roughness of the interlocked-carpet block ramps for the BR up to h = 1.00 m will be approximately identical as the size of baffle piers used by Peterka on his low ramps. However, together with the increase in the height of interlocked-carpet block ramps made of natural stones, the size of the stones used along the sloping apron of the BR will have to be considerably larger than the size of baffle piers used by Peterka on higher ramps.

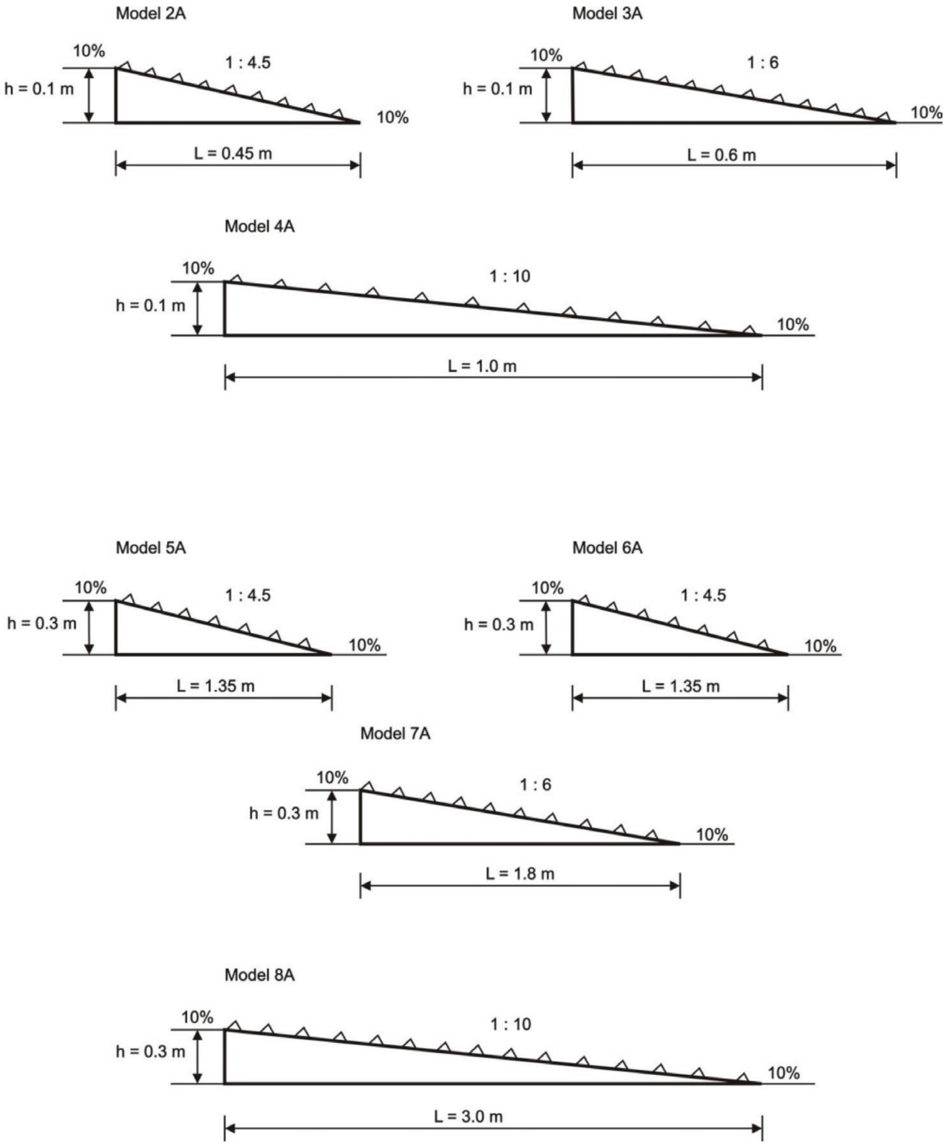

Figure 4. Examined structures preserving their original nomenclature from hydraulic model studies (compare within the paper); L – length of BR, h – height of BR. The number 10% on every single sketch (on its both sides) presents the river bed slope.

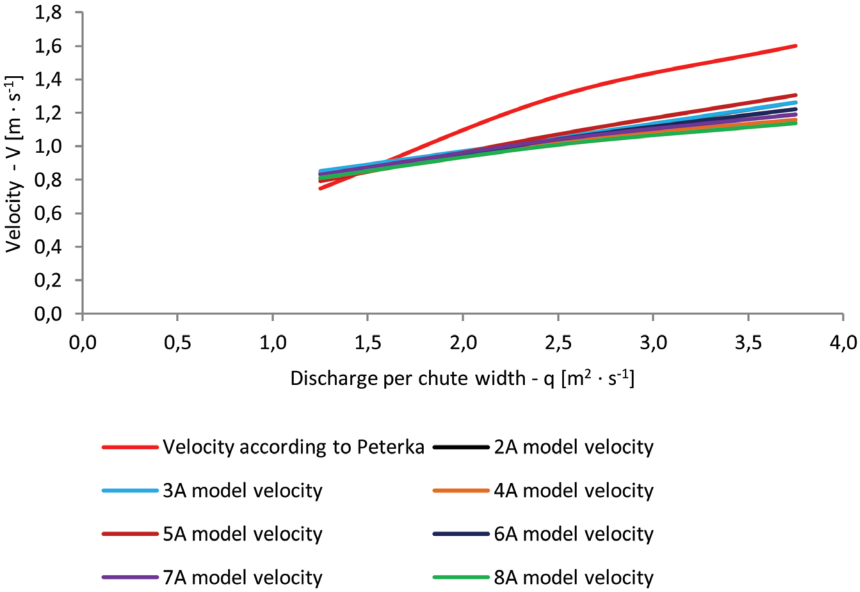

Figure 5. Water velocity obtained in the experiment was compared with Peterka tests effects

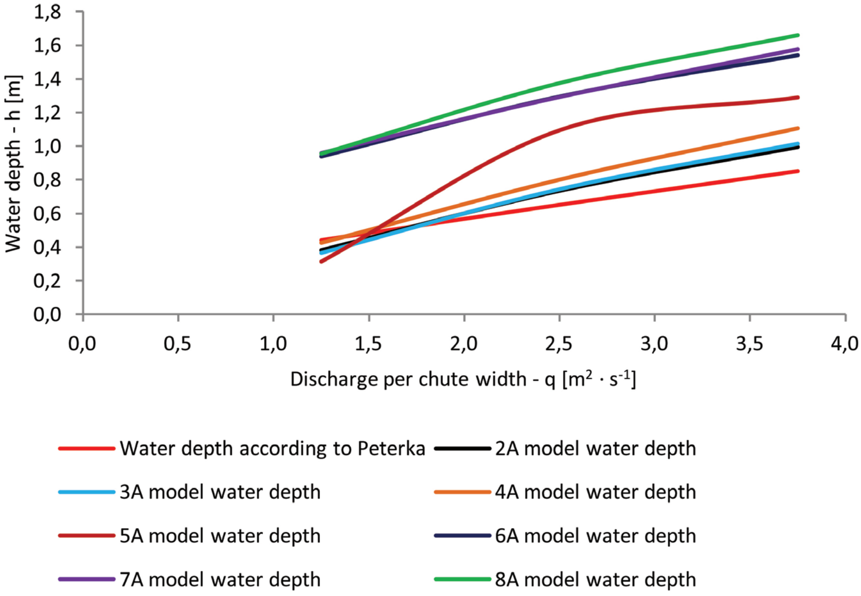

Figure 6. Water depths obtained in the experiment were compared with Peterka tests effects

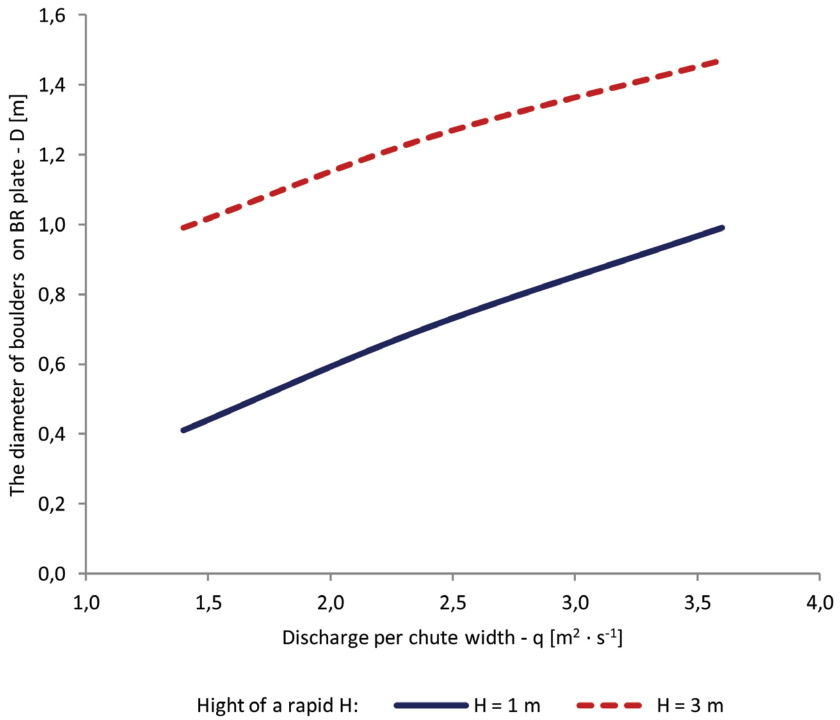

Figure 7. A diagram for choosing the dimension of boulder to install it on interlocked-carpet block ramp BR

In practice, to choose a ramp's height depending on unit flow size, Peterka (1964) presented diagrams of the relation of water depth h (m)and unit flow. According to Peterka (1964), that value ranges from 0.8 to 0.9 of the calculated critical water depth. In model tests of BR (2A, 3A and 4A) based on data analysis and their comparison with water depths recommended by Peterka, it was proposed that for the interlocked-carpet block ramp (BR) with the height of h = 1.0 m (h = 0.1 min model tests), water depths should be averaged and then the size of stones in the interlocked-carpet block ramp should be chosen on that basis of the averaged water depth. Similar procedure for models 6A, 7A and 8Awith BR height of 3.0 m (in model tests h = 0.3 m) was performed. In all cases averaged water depth was assumed to equal the size of selected stones in natural interlocked-carpet block ramp. Thus we proposed a diagram for choosing the boulder dimension – Figure 7 – boulder to install on interlocked-carpet block ramp BR

CONCLUSIONS

Unit flow on interlocked-carpet block ramp (BR) made of natural stone should not exceed maximum value of $q = 3.5\ m^2 \cdot s^{-1}$.

The size of stones placed along the sloping apron of the interlocked-carpet block ramp can be calculated but can also be read from the diagram for computable unit flow and the established interlocked-carpet block ramp height (Figure 7).

Distance between stones in the rows placed along BR should be equal to the size of stones used for creating roughness of the interlocked-carpet block ramp.

Distance between rows of stones placed along BR is suggested to be equal to 1.5 of the size of the stones used to build (create roughness of) an interlocked-carpet block ramp.

Downstream of an interlocked-carpet block ramp, river bed should be protected with heavy rip-rap to eliminate erosion process.

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Corresponding author: Prof. Eng. Artur Radecki-Pawlik, PhD, DSc.[1,2]
Eng Karol Plesiński, PhD[1]
Eng. Bartosz Radecki-Pawlik, MSc[2]
Eng. Wiktoria Czech, MSc[1]
[1]Department of Hydraulics Engineering and Geotechnics,
University of Agriculture in Krakow,
al. Mickiewicza 24/28, 30-059 Krakow
[2] Institute of Structural Mechanics,
Cracow University of Technology,
ul. Warszawska 24, 31-155 Krakow
rmradeck@cyf-kr.edu.pl
Phone: 693136686

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