VELOCITY AND WATER DEPTH ANALYSIS ON DIFFERENT TYPES OF BLOCK RAMPS

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ABSTRACT

Block ramps are used to protect rivers against dangerous bed erosion and to enhance fish migration. To ensure fish passage, hydraulic criteria like maximum flow velocities, minimal water depths and maximum water level differences must be fulfilled. A systematic laboratory study was performed in order to measure these hydraulic criteria fixed for trouts. Statistical and spatial distributions of velocities, water depths as well as the ratios of water depth and velocity head were compared for the different types of block ramps. The results have revealed that uniform block ramps can rarely satisfy the criteria for fish migration. Structured block ramps are more efficient. Nevertheless optimum conditions for fish migration can only be reached for ramp slopes under 6\%.

INTRODUCTION

Block ramps are used to protect rivers against dangerous bed erosion. They are an alternative to sills which severely hinder fish migration. Nevertheless, for block ramps some criteria have to be fulfilled in order to ensure fish passage. A systematic laboratory study was performed in order to measure these hydraulic criteria fixed for trouts. The aim was to determine the maximum discharge on various types of block ramps which still satisfy the criteria for fish migration. Four different types of block ramps were studied: a uniform type with a 10\% slope, a sill type construction with a 6\% slope and a meandering type with a 10\% and a 6\% slope. Statistical and spatial distributions of velocities, water depths as well as the ratios of water depth and velocity head were compared for the studied types of block ramps.

EXPERIMENTAL SETUP

Installation: The study was made in a 7.7 m long, 0.5 m wide and 0.5 m deep rectangular 11\% inclined flume (Figure 1). The influence of the relatively smooth surface of the side walls (acrylic glass and aluminium) compared to the much larger roughness of the bed was considered as negligible for the flow resistance. The
morphology of the ramps was built with crushed stones. To calm the water coming from a jet box, a rough approaching stretch 2.5 m long with a 3.5 % slope was installed. This approaching stretch was followed by the 3 m long ramp with a slope of 10 % respectively 6 %.

Figure 1. View of laboratory flume with block ramp without water (left) and with water (right).

**Measurement method:** The measured parameters were the bed topography of the ramp, the water level and the flow velocity. The velocities were measured with a 1 cm high micro-propeller, the morphology and the water depths with a leveling gauge. The measurement points were regularly distributed on the block ramp in a 12 x 3 cm grid. For more complicated morphologies the grid was reduced to a 6 x 3 cm grid (390 to 675 measurement points on the ramp).

**Granulometry of block ramps:** A rougher granulometry for the exposed blocks was used for the transversal sills of the type II (6 %) and the whole ramp of the meander types III (10 %) and IV (6 %) (see Table 1). For less exposed blocks, a finer granulometry was used for the smooth type I (10 %) and the places between the transversal sills of the type II (6 %). For the approaching stretch to the ramp and the flume outlet, rougher granulometry was used.

**Measured migration criteria:** Trout fish species were selected for the criteria of fish passage, since this is the most dominant fish species in Alpine rivers. The migration passage criteria are maximum flow velocity ($v_{\text{max}} \cdot 2 \text{ m/s}$), maximum water level differences ($\Delta h_{\text{max}} \cdot 20 \text{ cm}$), minimum water depths ($h_{\text{min}} \cdot 20 \text{ cm}$), and minimum pool depths ($h_{p,\text{min}} \cdot 60 \text{ cm}$) (DVWK 1996).

<table>
<thead>
<tr>
<th>Block diameter</th>
<th>$D_m$ [mm] (m)</th>
<th>$D_{50}$ [mm] (m)</th>
<th>$D_{65}$ [mm] (m)</th>
<th>$D_{90}$ [mm] (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less exposed blocks</td>
<td>36 (0.90)</td>
<td>35 (0.87)</td>
<td>38 (0.94)</td>
<td>40 (1.00)</td>
</tr>
<tr>
<td>Exposed blocks</td>
<td>51 (1.26)</td>
<td>49 (1.24)</td>
<td>52 (1.29)</td>
<td>53 (1.33)</td>
</tr>
</tbody>
</table>
Tested ramp morphologies: Four ramp types were tested. The ramp with a uniform monotonous morphology having a 10% slope was called smooth type I (10%). The ramp having transversal sills with a 6% slope was called transversal sill type II (6%). The upper half of the ramp consisted of irregular undulated transversal sills, with a distance up to 7.7 m between each other (Figure 2 upper part left). The lower part of the ramp consisted of regular straight transversal sills according to Gebler (1991), spaced from 2.8 to 3.3 m between each other (Figure 2 upper part right). For the sills, the coarser granulometry of the blocks was used. The bed between them was covered with the finer granulometry (see Table 1). The sills had an average height of 0.75 m. The meanders were obtained by arranging the blocks to resemble a hilly topography along the ramp. In such a way several meandering channels along the ramp were obtained resulting in zones with high and low flow velocities. The meander ramp type with a slope of 10% was called meander type III (10%). The crests and the depressions between them were situated in average 0.4 m above and below the mean bed level. The first 25 m were composed of two meanders with an offset of a half phase. The rest of the ramp consisted of only one meander. The crests were spaced out by about 8.4 m from each other. The mean amplitude of the meanders was 3.75 m and the wave length about 17 m. The meander ramp type with a 6% slope was called meander type IV (6%) and can be seen in Figure 2. The number of crests was increased compared to the type III, in order to obtain two meanders over the whole length of the ramp with an offset of a half phase. The crests and depressions were situated on average 0.6 m above and below the mean bed level. The crests were spaced about 8.3 m from each other. The amplitude and the wave length of the meanders were the same as for type III.

Figure 2. Plan views and longitudinal profiles of ramp types II and IV with a 6% slope.
RESULTS

Influence of slope: As the first 25 m of the meander type III (10 %) and the meander type IV (6 %) had the same morphology, the influence of the slope could be studied. On Figure 3 the contour lines of the flow velocities on meander types III (10 %) and IV (6 %) are represented. The rectangles show the part with similar morphology (two meanders) which was used to analyze the influence of the slope. It appears that the velocities are clearly higher on the ramp with a steeper slope than expected. For higher discharge (4.6 and 6.5 m$^3$/s/m) it could be observed that the mean values changed much less between a 10 % and a 6 % slope than for lower discharges (2.7 m$^3$/s/m). But the extreme values (lowest and highest 15 % of the measurements) increased much more for higher discharges.

Influence of discharge: In Figure 4 it can be seen that the standard deviation of the flow velocities changes much less for higher discharge than the mean values. The slopes of the central part of the flow velocity occurrence curves which correspond to the standard deviation are much more constant than the mean values situated around the 50 % value of the curves. The extreme values (the lowest and highest 15 % of the measurements) are wider distributed for higher discharges than for lower ones.

Morphology: From distribution curves (Figure 5 a), the very narrow distribution of the smooth type I (10 %) can clearly be seen. The morphology (z-values) of this type has the narrowest distribution (standard deviation ± 0.22 m). The probability of occurrence curves (Figure 7 a) for this type shows the steepest slope which is another indicator for a small variation of the values. The variation of the morphology of the types II (transversal sill) to IV (meander) is about in the same order of magnitude. Type II (6 %) shows a marginal smaller distribution (± 0.38 m) than type III (± 0.45 m) and IV (± 0.44 m). All z-values from type IV are significantly higher than the z-values of the other types. This fact can be explained by the selection of a lower reference point for the calculation of the z-coordinate.

Water depth: The distribution of the water depths corresponds to the variation of the morphology. The water depths of the smooth type I (10 %) again have the narrowest distribution (± 0.23 m). The variation of the water depths of the types II (transversal sill) to IV (meander) are about in the same order of magnitude (Figure 5 b). Type II (6 %) shows a marginal smaller distribution (± 0.35 m) than type III (± 0.41 m) and IV (± 0.40 m). But the transversal sill type II (6 %) and meander type IV (6 %) has the highest mean values with 0.90 and 0.94 m. At a unit discharge of q = 1 m$^3$/s/m, 89 % of the pools have a minimum water depth of 0.6 m. For the unit discharge of q = 2.7 m$^3$/s/m 97 % of the pools fulfilled this criterion. The ramp type which has the smallest ramp surface (86 %), fulfilling the minimum water depth criterion of 0.2 m is the transversal
sill type II (6 %) with a unit discharge of 1 m$^3$/s/m. For all other ramps and discharges, the ramp surface satisfying the minimum water depth for trouts of 0.2 m was larger.

Figure 3. Contour lines of flow velocities in m/s for unit discharges 2.7 and 6.5 m$^3$/s/m on meander ramp types III (10 %) and IV (6 %); (flow direction is from left to right).

Figure 4. Probability of occurrence of flow velocities for the transversal sill type II (6 %) (left) and the meander type IV (6 %) (right).
**Velocity:** On smooth type I (10%) the highest mean value of the flow velocity with 4.2 m/s occurs (Figure 5 c). The standard deviation of the velocity is only ± 0.61 m/s. The widest distribution can be observed on the meander type III (10%). This type has also the highest standard deviation (± 1.31 m/s) but its mean value of 3.2 m/s is somewhat higher than the mean value of the transversal sill type II (6%) and the meander type IV (6%) which are both about 3.0 m/s. On Figure 6 the areas where a fish passage for trouts for a discharge of 1.5 m$^3$/s/m is possible is indicated by a thick line (v • 2 m/s). For the transversal sill type (6%), it can be seen that the part with regular transversal sills is an easier passage for trouts than the part with irregular sills. 41% of the ramp surface with irregular transversal sills and 66% of the ramp surface with regular transversal sills fulfill this criterion. For the meander type IV (6%) the central part of the ramp between the crests and the border of the ramp are areas where fish can pass more easily than along the meander. 45% of the ramp surface fulfills the criterion for the maximum flow velocity of 2 m/s.

![Figure 5. Distribution of bed elevation (a), water depth (b), flow velocity (c) and kinetic energy head compared to water depth (d) for a discharge of 2.7 m$^3$/s/m for the ramps type I, II, III and IV.](image-url)
Figure 6. Contour lines of flow velocities (m/s) for a unit discharge of 1.5 m$^3$/s/m on meander types III (10 %): above and IV (6 %): below; (The thick line indicates regions with flow velocities smaller than 2 m/s).

**Ratio between kinetic energy and water depth:** The “($v^2/2g$)/$h$” generally show the higher mean values for higher discharges. The values of the smooth type I (10 %) have the widest distribution and the highest mean values. Regarding fish passage, it can be concluded that the lower the ratio of kinetic energy and water depth, the better the possibility of a fish passage. It could be observed that 95 % of all measurement points fulfilling the criteria of the maximum flow velocity (• 2 m/s) as well as the minimum water depth (• 0.2 m) had a ratio between 0 and 0.45. Therefore, ratios higher than 0.45 were considered as not favorable for a trout passage. Transversal sill type II (6 %) and the meander type IV (6 %) clearly show good conditions for trout passage.

Figure 7. Probability of occurrence of bed elevation (a), water depth (b), flow velocity (c) and kinetic energy head compared to water depth (d) for a discharge of 2.7 m$^3$/s/m for the ramps type I, II, III and IV.
CONCLUSION

From the measured parameters for different discharge conditions, the following conclusions can be drawn:

The smooth ramp type I (10 %) did not show to be favorable trout passage conditions for the measured unit discharges (2.7 – 6.5 m$^3$/s/m). Although more than 98 % of all water depths were above the minimum value (0.2 m), the measured flow velocities were at every point far above the maximum velocity for trouts (2 m/s). The upper half of the transversal sill type II (6 %) allows trout passage up to a unit discharge of q = 1 m$^3$/s/m. The minimum water depth of 0.2 m was satisfied on 88 % of the ramp surface and the maximum flow velocities (v • 2 m/s) on 67 %. The part with densely spaced straight sills has favorable passage conditions up to a unit discharge of q = 2 m$^3$/s/m. Here the minimum water depth of 0.2 m was satisfied on 95 % of the ramp surface and the maximum flow velocities (v • 2 m/s) on 56 %. Trout passage on a meander ramp type IV (6 %) is possible up to a unit discharge of q = 1.5 m$^3$/s/m. The minimum water depth of 0.2 m was satisfied on 90 % of the ramp surface and the maximum flow velocity (v • 2 m/s) on 45 %. On the meander ramp type IV (10 %), higher discharges were studied than on the meander ramp type III (6 %). For the studied discharges (2.7 – 6.5 m$^3$/s/m) the meander type III (10 %) did not fulfill the criteria for trout passage. The similarity of the velocity fields between the meander types with a 10 % slope and a 6 % slope allows the conclusion that the meander ramp type III (10 %) allows fish passage only until a unit discharge of 1 m$^3$/s/m. It can be concluded, that uniform block ramps can rarely satisfy the criteria for fish migration regarding trouts. Structured block ramps are much more efficient. Nevertheless optimum conditions for trout passage can only be reached for slopes below 6 % and unit discharges below 1.0 – 1.5 m$^3$/s/m.

REFERENCES
