論文の内容の要旨

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論文題名：Experimental study on environmental improvements of alternated gravel mounts in straight channelized rivers during flood stages（洪水期における直線河道内に交互に設置した礫層マウントによる環境改善に関する研究）

The water inside straight channelized rivers flows fast and very homogeneously, causing the aquatic habitats to disappear. While river restoration strategies are successful tool to invert this trend, significant research and costs are often required to be implemented. This thesis proposes a simpler and more cost-effective alternative that does not require alteration of the river cross section: the installation of gravel mounts on alternated sides of the channel.

Experiments are conducted inside a 0.800 m wide, 0.600 m high rectangular channel with glass side walls. Elevation is recorded using a point gauge, while longitudinal and lateral velocity components were measured using an electrical-magnetic current meter. Four different discharges are set: Q=0.00370, 0.00550, 0.0588 and 0.155 m^3/s, and a hypothetical model scale of S=15 is used. Using the hydrological data from Japanese rivers similar to the hypothetical prototype, the first two discharges are expected to be very small floods, while the third should have a return period of 10 years. The largest discharge is the pump capacity discharge and it is used to test the models' stability under major floods. The models are constructed using coarse gravels (d_{50}=0.017 m) and/or medium boulders (d_{50}=0.063 m). Flow conditions are defined by the average water depth and the Froude number. The measured longitudinal and lateral velocity components are important in defining the suitable swimming conditions for small-sized fishes (body length smaller than 0.200 m). According to literature and own experiments, refuge able areas are mathematically defined as everywhere inside the flow field where time-averaged velocity is lower than 0.100 m/s and standard deviation of the velocity is smaller than 0.070 m/s. Refuge areas are regarded as the empty spaces between assembled boulders (porosity of 30%) where small fishes have been observed to escape the main flow and turbulence. The empty spaces between gravel grains are ignored because they are too small for this research's target species. The performance of each model is quantified by comparing the total refuge volume (the sum of refuge and refuge able volumes) against the mounts volume.

The first experiments are conducted installing 0.600 m long, 0.650 m wide, triangular gravel mounts on alternated sides of the channel. Different heights 0.0240, 0.0440 and 0.0640 m, are tested, while models with flat gravel bed are constructed for reference purposes. Two different channel slopes are studied (I=0.00200, 0.0100) while the discharge is Q=0.0588 m^3/s. The introduction of gravel mounts causes the water surface to rise and waves to form along the central area of the channel. Changes get stronger when the channel's steepness and/or the height of the gravel mounts increase. The flow remains subcritical. The triangular shape forces the flow to meander around the mounts, generating pockets with slow-flowing water behind each one. There, refuge able areas are found, although the total refuge volume is never larger than 20% of the mounts volume. The model stability is confirmed for the tested medium-sized flood, but not for the pump capacity discharge when critical erosion is observed. The overall best results are found when the gravel mounts height is 0.0440 m.

Experiments of the second phase focus on the flow conditions around rectangular groynes with length 0.600 m, width 0.200 m and height 0.0440 m, build from three-layered, downstream-facing assembled boulders structures on alternated side of the channel. The channel slope is set to I=0.0100. Due to the uniform height of the groynes, surface waves are formed along the entire cross section of the channel. The flow is subcritical and the average water depth is higher than what observed above triangular grave mounts. Surface waves can be reduced if further assembled boulders are installed along both sides of the channel. Assembled boulders easily resist the force of pump capacity discharge, although an increase in the gravel bed erosion is observed. Large refuge able areas are found behind each groyne and, at best conditions, assembled boulders generate a total refuge volume 105% their own. The main drawback of this design is a hydraulic drag force caused by the flow impinging on the upstream face of each groyne, causing strong surface waves and the increased average water depth.

In third phase of the experimental study, triangular gravel mounts with height 0.0440 m, width 0.650 m and length 0.500 m are installed on alternated sides of the channel. The shape of each mount is reinforced with two layers of assembled boulders, while two further layers are built along both sides of the channel. Assembled boulders always face downstream and follow the mounts' profile while increasing their resistance. The channel slope is 0.0100 and four discharges are tested: Q=0.00370, 0.00550, 0.0588 and 0.155 m^3/s. Experimental results are very satisfactory. The water surface profile is flat thanks to the assembled boulders along the sides of the channel. At same experimental conditions, the averaged water depth is the smallest between all tested designs. The boulder reinforcements allow gravel mounts to withstand the pump capacity discharge. A discharge above 0.00580 m^3/s is required to completely submerge the model, while supercritical flow is partly formed in case of discharges greater than 0.130 m^3/s. The flow meanders around triangular gravel mounts and refuge able areas are found mainly behind the mounts and in the gaps between boulders and gravel. With increasing discharge, the flow straightens, particularly along the central area of the channel. Calculations suggest that each gravel mount is 22% empty and it can generate a total refuge volume up to 38% its own. Limiting factors such as shallow water or large discharges, do not appear to affect this latter value.

Future studies could investigate the feasibility of a first real prototype on the base of the proposed design. Field data will be important to finally evaluate how simple and cost-effective this method could be. Also, the investigation of habitat, spawning, and refuge environments of various aquatic organisms will be essential. In further laboratory studies, systemic investigation might be significant. Particularly, priority should be given in finding the still-unknown applicability range of the proposed design.