INSTALLATION OF GROUND SILL WITH STACKED BOULDERS IN CHANNELIZED RIVER

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ABSTRACT

Kando River located in Shimane prefecture and Etaibetsu River located in Hokkaido prefecture, as gravel-bed river was partly constructed as a channelized river for flood control. In channelized region of Etaibetsu River, degradation of river bed and the formation of naked rocks were happened after the construction, and it was impossible for aquatic fishes to pass the winter. This paper presents practical approaches for the improvement of channelized river in both Kando River and Etaibetsu River. In Kando River, the ground sill with stacked boulders was installed for the improvement in the channelized gravel river. The balance between flood control and preservation of aquatic habitat was confirmed, and field observation might support the effect of the installation of the ground sill with stacked boulders on the improvement of channelized river. In Etaibetsu River, as the installation of boulders was difficult, the installation of the ground sill with concrete blocks was conducted. Naked rocks could be covered by transported gravels, and the flow condition around the ground sill may help for the preservation of aquatic habitat. From the point of aquatic habitat in channelized river, the flow condition passing over the ground sill with concrete blocks might be inferior by comparing the flow condition passing over the stacked boulders in normal stages.

Keywords: Stacked Boulders, Ground Sill, Habitat, Flood Control, Channelized River

1. INTRODUCTION

From point of flood control in residential area, natural gravel river was constructed as a channelized river. Also, artificial river bank and flat gravel bed were constructed in compound cross section. In this case, the top width of the river is limited, and the aspect ratio during flood stages becomes small. The main flow concentrates to the center of channelized river during floods, and degradation of river bed was happened during floods [Oishi et al. (2014)]. In the channelized river, there was no refuge area for aquatic animals, because bed velocity with strong turbulence became higher than that in natural gravel river. In order to preserve habitat for aquatic animals in channelized river with steep slope, refuge area must be kept from a high velocity flow with sediment transfer.

As a refuge area for aquatic animals in gravel bed, the top width of river should be changeable in order that the location of the main flow changes with discharge. Besides, a deep water in natural scouring should be formed behind either shallow stream or fallen big tree (Sedell et al. (1990)). Further, it was reported that benthic fishes used a space in boulders as a refuge space during flood stages (Dole-Olivier et al. (1997)). Unfortunately, there is little information on hydraulic design for the improvement at channelized gravel river in alluvial fun even if aquatic habitat is required in gravel bed. Furthermore, small drop structures were constructed as ground sill for the stabilization of gravel bed, but flood flows suffered fatal damage with the degradation of gravel bed and the formation of bare rocks, because the location of the main flow passing over the ground sill was not controlled.

The flow resistance on gravel bed was investigated, and the field data of different mountainous rivers and of different size of bed materials by different investigators such as Bathurst (1978,1981,1985), Bray (1979), Griffiths (1981), Hey (1979), and Thorne and Zevenbergen (1986) et al. were used (Rickenmann and Recking. 2011). In these cases, empirical equations for the friction coefficient were shown in accordance with field data, but the effect of stacked boulders on the flow resistance was not discussed. Recently, Harada and Yanda (2018) have developed a numerical simulation model that can directly evaluate habitat of organisms dependent on riverbed at the same time as calculating flow and river bed variation in reach scale by changes in flow rate and sediment supply from upstream. Regarding the installation of stacked boulders in subcritical flow as a ground sill, the application of the momentum equation reveals that the drag force acting on stacked boulders depends on the combination of stacked boulders for different discharges (Yasuda. 2017). Also, the experimental investigation on velocity distributions yields that the main flow passing over optimal stacked boulders lifts to the water surface for large discharges.

In Kando River located in Shimane prefecture and Etaibetsu River located in Hokkaido prefecture, as gravel-bed river was partly constructed as a channelized river for flood control. In channelized region of Etaibetsu River (Photo 1), degradation of river bed and the formation of naked rocks were happened after the construction, and it was impossible for aquatic fishes to pass the winter. In channelized region of Kando River (Photo 2), a high velocity flow with strong turbulence was formed near the river bed after the construction, and it was impossible to preserve habitat area and refuge for aquatic animals.

This paper presents practical approaches for the improvement of channelized river in both Kando River and Etaibetsu River. In Kando River, three ground sills with stacked boulders were installed within three weeks. In Etaibetsu River, 19 ground sills with concreate blocks were installed within two years. The channelized river could be improved quickly after the construction in accordance with the field observations in which swimming and benthic fishes in abundant habitat area could be found around ground sills. In this area, several sizes of gravels and rocks could be transported after floods, aquatic insects could be observed in space in rocks.

2. FIELD APPROACH FOR CHANNELIZED RIVER IN KANDO RIVER

2.1 Background for approach

As shown in Photo 2, in Kando River which is blanch of Hii River, a channelized river was constructed as there was flood accident in this region 14 years ago. The compound cross section with 20 m bottom was formed in order to prevent from bank erosion. The slope of river was varied from 1/200 to 1/400, and the position of main flow was fixed under a wide range of discharges. Impacts of riverbed armoring in the channelized region have been developed. In order to extend top width of water during flood stages and to keep the refuge area in the channelized region, the installation of ground sills was proposed. In this case, the construction must be finished in a short period. Also, the boulders must be brought from the same catchment area. The other construction for the reinforcement of pier against earthquake was conducted at the same season, and digged boulders around pier could be obtained in order to apply to the improvement of the channelized river.

2.2 Setting for installation

In June 2019, three ground sills were constructed by using boulders with averaged diameter of 1 m. The installation of stacked boulders was constructed in 3 days. The stocked boulders were installed in accordance with the experimental results on the stability of stacked boulders [Yasuda (2017)] as shown in Photo 3. The top level of stacked boulders was adjusted in order to keep the difference of water level around ground sill as 0.20 m difference in normal stage. The main flow lifts to the water surface easily even if the plunging flow is formed at the immediately downstream of stacked boulders (Photo 4). After the construction, small velocity flows in which small fishes could swim gracefully behind the ground sills were formed. The region was extended to more 100 m long. The velocity near the gravel bed was recorded as less than 0.40 m/s.

Photo 1 Channelized area in Etaibetsu River

Photo 2 Channelized area in Kando River

Photo 3 Installation of Stacked Boulders

Photo 4 Flow conditions passing over stacked boulders in normal stage

Photo 5 Flow conditions during flood stage in 29th August 2019

2.3 Flow conditions around ground sills with stacked boulders

As shown in Photo 5, in the end of August 2019, a big flood was happened by the occurrence of typhoon, and the water level of river was increased up to 1.2 m in the improved region. The installation of ground sills was stable after floods (Photo 5). Also, several sizes of gravels were accumulated below the ground sills during flood stages. The size of the sediments was distributed from 2 mm to 100 mm diameters. After floods, in the improved channelized river, swimming fishes (Ayu fish, Pale chub, Japanese dace, Loach, and etc.), benthic fishes (Eel, Goby), crustacean (Prawn and Swamp shrimps, Mitten crab), and aquatic insects (Nymph) could be found.

3. FIELD APPROACH FOR CHANNELIZED IN ETAIBETSU RIVER

3.1 Background for approach

As shown in Photo 6, in Etaibetsu River which is blanch of Uryuu River, a channelized river with 1/100 slope was constructed for flood control even if Etaibetsu River was rich river as habitat for Salmon, Pink salmon, Japanese dace, Lampern, Goby, Cottus amblystomopsis, Stone loach, and etc.. Further, many drop structures were installed in order to keep the stabilization of river slope. As the fish passage was not installed in most of drop structures, the migration for region, as shown in Photo 7, the main flow passing over the drop was plunging completely for a wide discharge from normal to flood stages, and the degradation of river bed and the local scouring were happened easily. During flood stages, plunging flow should not be formed, and also the main flow should lift to the water surface in order to prevent from local scouring. Then, in the region of 400 m downstream the drop structure, the installation of 19 ground sills with concrete blocks were proposed in order to preserve the aquatic habitat at the aquatic animals was impossible around drop structure In the channelized s. gravel-bed river with 1/100 slope as shown in Figure 1. This proposal may help the protection from both degradation of river bed and local scouring during flood stages.

3.2 Setting for installation

In order to keep over flow depth as 0.20 m in normal stage, as shown in Photo 8, 19 ground sills with concrete blocks were designed as compound section in the channelized river with a trapezoidal cross section. If the over flow depth becomes larger than 0.3 m, the flow might be passing over the ground sill entirely. The top level of ground sill was adjusted in order to keep the difference of water level around the ground sill as 0.20 m difference in normal stage. Before the construction, the effect of the installation of ground sills on flood control was investigated experimentally by using 1/20 scale model (Photo 9). As shown in Photo 10, the formation of surface jet flow was confirmed for several discharges, and the undulation of the water surface was formed mainly at the center part of channel. During flood stages, sediments of transported gravels were recorded. In accordance with the experimental results, the construction was conducted for two years.

Photo 6 Flow condition at Channelized area in Etaibetsu Riber


Photo 7 Degradation of gravel-bed river at immediately downstream of ground sill


Photo 8 Installation of 19 ground sills with concrete blocks in channelized area

Photo 9 Experimental set up with 1/20 scale model

Photo 10 Flow condition during flood stage (Q_p = 390 m^3/s in prototype)

3.3 Flow conditions around ground sill

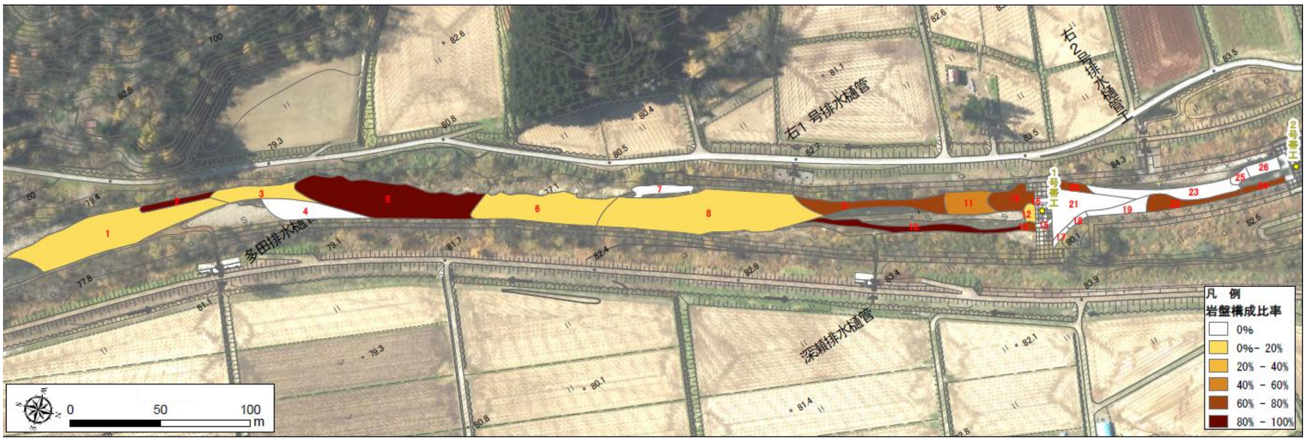
On the way of the construction, flood occurred in September 2017, and the construction yard was flooding as shown in Photo 11. But, local scouring was not recorded, because a surface jet flow was formed in the completion region. The flow near the water side was stable without the formation of undular water surface, because the configuration of cross section was trapezoidal. In normal stages, as shown in Photo 8, a plunging flow was formed at the center part of ground sill, but the main flow did not impinge to gravel bottom. If the discharge becomes larger, the main flow becomes to lift to the water surface. Also, the undulation of water surface is formed at the center part of channelized river during flood stages. In the installation region, habitat of Japanese dace, Cottus amblystomopsis, and Stone loach could be recorded. As several sizes of gravels were accumulated below the ground sills during flood stages, gravel bed could be covered on naked rocks (Photo 12). Figure 2 shows the existence of naked rocks in the installation region before and after the construction. As shown in Figure 2, naked rocks could be covered by transported gravels, and the flow condition around the ground sill may help for the preservation of aquatic habitat.

(a) The construction area was flooding

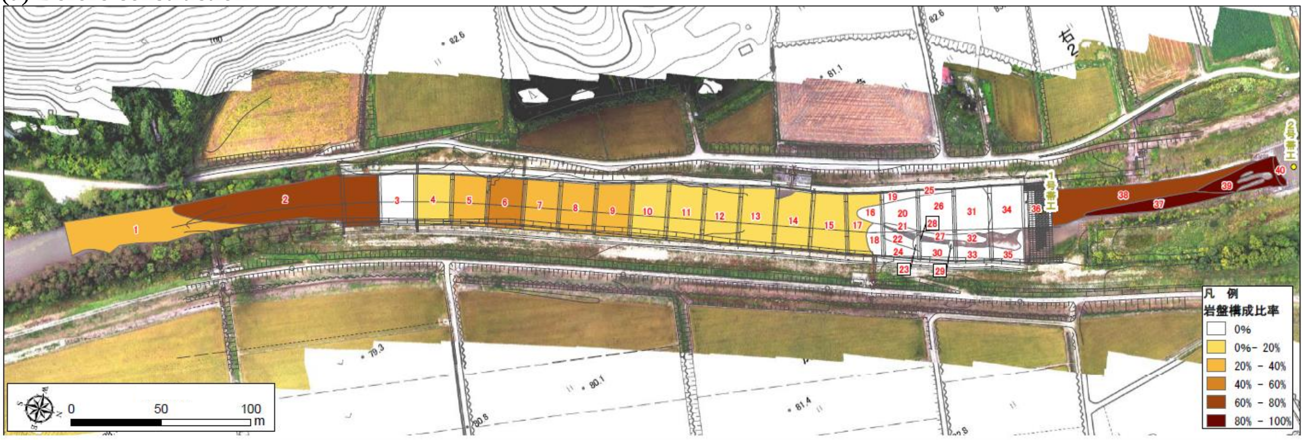
(b) The flow at water side with trapezoidal section

Photo 11 Flow condition passing over ground sills during construction in flood stage

Photo 12 Gravel bed in channelized area after the installation of 19 ground sills



(a) Before construction



(b) After construction

Symbols: 0 % 0%-20% 20%-40% 40%-60% 60%-80% 80%-100%

The ratio (%): existence of naked rocks in each space between ground sills

Figure 2 Distribution of existence of naked rocks in each space between ground sills

4. DISCUSSION

For the improvement of channelized river in both Kando River and Etaibetsu River, the installation of ground sill was conducted. From point of flood control, the ground sill with stacked boulders shown in Photo 3 might have similar function for that with concreate blocks shown in Photo 11, because the surface jet flow was formed during flood stages. In normal stages, as the flow passing over stacked boulders has seepage flows through the space of stacked boulders, aquatic animals can select favorite flow by considering their habitat. Unfortunately, as the hydraulic design method for stacked boulders was not established, it might be difficult for engineers to design the structure of stacked boulders. Also, the application of stacked boulders might be restricted by the place of origin for the boulder. While, as the design of ground sill with concrete blocks has been established fundamentally, the installation of the ground sill should be noted for the formation of the surface jet flow during flood stages.

5. COCLUSIONS

The ground sill with stacked boulders is effective for the improvement in the channelized gravel river. The balance between flood control and preservation of aquatic habitat was applied to the improvement in Kando River, and field observation might support the effect of the installation of the ground sill with stacked boulders on the improvement of channelized river. In normal stages, the flow passing over stacked boulders has seepage flows through the space of stacked boulders, aquatic animals can select favorite flow by considering their habitat. For flood control, the formation of surface jet flow is significant to lift to the water surface without plunging. In Etaibetsu River, as the installation of boulders was difficult, the installation of the ground sill with concrete blocks was conducted. From the point of aquatic habitat in channelized river, the flow condition passing over the ground sill with concrete blocks might be inferior by comparing the flow condition passing over the stacked boulders in normal stages. Further investigation on hydraulic design of the ground sill with stacked boulders might be required in order that most of civil engineers can propose for the improvement of the flow condition in channelized river.

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