Journal of Environmental Science Studies; Vol. 9, No. 1, 2026
ISSN 2591-779X E-ISSN 2630-4821
Published by July Press

Application of the Ramp With Assembled Boulders to Prototype

Youichi Yasuda[1]

[1] Department of Civil Engineering, College of Science and Technology, Nihon University, Tokyo, Japan

Correspondence: Prof. Youichi Yasuda, Department of Civil Engineering, College of Science and Technology, Nihon University, Tower Schola S1010, 1-8-14 Kanda Surugadai, Chiyoda-ku, 101-8308 Tokyo, Japan. E-mail: yasuda.youichi@nihon-u.ac.jp

Received: January 12, 2026 Accepted: February 3, 2026 Online Published: March 13, 2026

doi:10.20849/jess.v9i1.1550 URL: https://doi.org/10.20849/jess.v9i1.1550

Abstract

In boulder movement area, many gravel control structures were installed, and multiple types of aquatic organisms have inhabited in the area. Generally, fish passages were installed for the upstream migration at each drop structure. But most of structures are obstacles for both upstream and downstream migrations. Recently, the author proposed the ramp with the consecutively assembled boulders, and flow velocity and flow condition on the assembled boulders during floods were investigated experimentally as a scale model, considering the Froude similarity. The experimental results revealed that the flow velocity near boulders was reduced by the formation of the seepage flow inside boulders and that a surface jet flow was formed downstream of the ramp. The most significant point for the application from scale model to prototype is the evaluation of the seepage flow inside boulders. Seepage flow velocity inside the boulders may depend not only on gravity but also on water viscosity. In prototype, five different ramps with the assembled boulders were constructed in accordance with the experimental results. The size of boulders was determined based on the size of boulders transported during big floods. Especially, if the averaged size of boulders is larger than 0.6 m, boulders with 0.1 m to 0.2 m were inserted in assembled large boulders. In this paper, the flow condition in five different ramps with the assembled boulders during normal stage is discussed based on the application from experimental results to prototype. Also, the construction of the assembled boulders is explained.

Keywords: assembled boulders, migrations, surface water flow, seepage flow, prototype

1. Introduction

In boulder movement area, many gravel control structures (e.g., check dam, drop structure, ground sill) were installed, and multiple types of aquatic animals have inhabited in the area. Generally, fish passage was installed for the upstream migration at each structure. But most of structures are obstacles for both upstream and downstream migrations. The reason is that the flow velocity passing through the fishway is small, causing fish to lose their upstream migration path. Furthermore, sediment transport impacts cause the fishway to become impassable, rendering it inoperable. Flood flows cause localized scouring and a drop in the riverbed level downstream of structures, creating a drop immediately below the structure that hinders the upstream migration of aquatic animals.

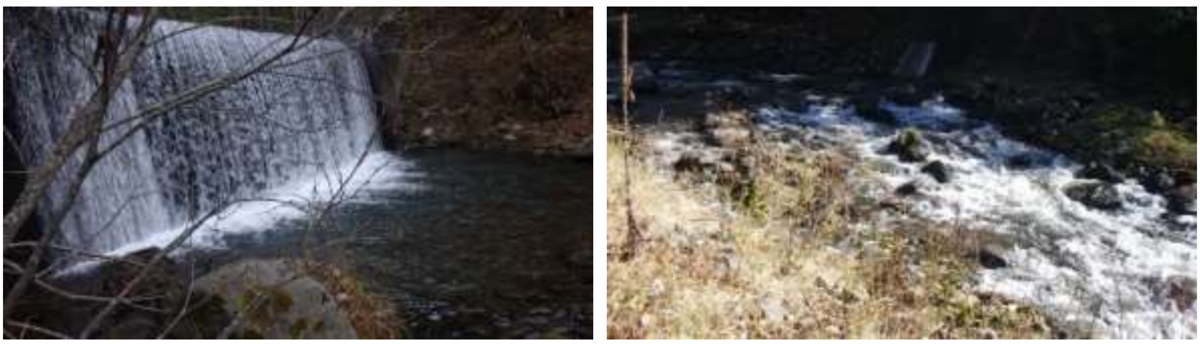
The installation of ramps with rocks may help aqua habitat at the drop structure (Kim et al. 2020, Chaudhary et al. 2021, Pagliara et al. 2016, and Zulfequar et al. 2009). In this case, the rocks on the ramp were secured with concrete for the stability of rocks during flood stages. The migration routes for aquatic animals on the ramp may depend on the size of the rocks and the gaps created by the unevenness of the rock. Recently, the author proposed the ramp with the consecutively assembled boulders, and flow velocity and flow condition in the assembled boulders during floods were investigated experimentally as a scale model considering Froude similarity (Yasuda et. al. 2022, Yasuda and Wang 2024, and Yasuda 2025). The experimental results revealed that the flow velocity near boulders was reduced by the formation of the seepage flow inside boulders and that a surface jet flow was formed downstream of the ramp. The most significant point for the application from scale model to prototype is the evaluation of the seepage flow inside boulders. Seepage flow velocity inside the boulders may depend not only on water viscosity but also on gravity from classical hydraulic consideration. According to Navaratnam et al. (2017, 2018), even when riverbed topography is identical, the presence of inter-sediment seepage has been reported to suppress flow velocities near the bed.

As a prototype, five different ramps with the assembled boulders (e.g., slope and average size of boulders) were constructed in accordance with the experimental results. The total drop height of structure and the slope of the ramp are different for each installation.

In this paper, the flow condition in five different ramps with the assembled boulders during normal stage is discussed from the viewpoint of the application from experimental results to prototype. Also, the construction of the assembled boulders is explained.

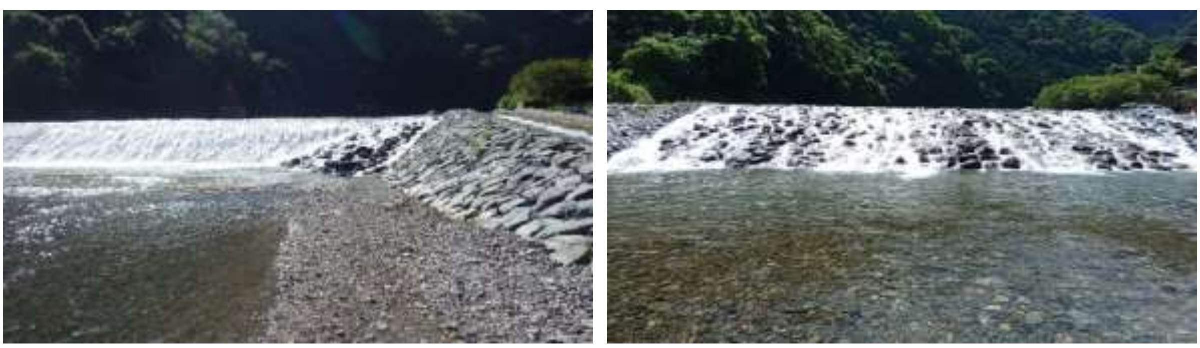
In Iwaubetsu River, Hokkaido prefecture, the check dam with 3.2 m height was improved to install the ramp with consecutively assembled boulders (0.70 m size, 1.6 m height, and 1/10 slope) as shown in Photo 1. In Kanna River, Gumma prefecture, the ramp with consecutively assembled boulders (1.0 m size, 3.0 m height, and 1/4.1 slope) was installed at the downstream face of gravel control dam with 50 degrees slope (Photo 2). In Ohmu River, Yamanashi prefecture, the ramp with the assembled boulders (1.2 m size, 2.1 m height, and 1/8 slope) was installed at the check dam (Photo 3). In Kama River, Tochigi prefecture, the ramp with the assembled boulders (0.3 m size, 0.9 m height, and 1/6 slope) was installed at a low drop structure (Photo 4). In Sanagouchi River, Nagasaki prefecture, the ramps with the assembled boulders (0.5 m size, 0.75 to 2.3 m heights and 1/10 slope) were installed at low drop structures (Photo 5). The insert thickness of concrete was different for each location, depending on flow condition including transported rocks and driftwoods in big floods. The size of boulders was determined based on the size of boulders transported during big floods except for Kama River located in residential area and Sanagouchi River in which a large dam was located at the upstream part of the drop structures. If the averaged size of boulders is larger than 0.6 m, boulders with 0.1 m to 0.2 m were inserted in assembled large boulders to keep a surface water flow during normal stages, and to prevent stones beneath the assembled boulders from being sucked out by flood flows. Standard construction methods involve installing waterproof sheets or filling with concrete to prevent stone erosion, but this obstructs water circulation beneath the assembled boulders and impacts aquatic animals inhabiting gravel beds. Similar environmental degradation may occur in the soil (Takada 2020).

Since the completion of the ramps, the assembled boulders have remained stable, and no localized scouring has occurred downstream of the ramp. These ramps enable the migration of aquatic animals, so no swimming fishes, benthic fishes and crustaceans have been found trapped downstream of the ramps.



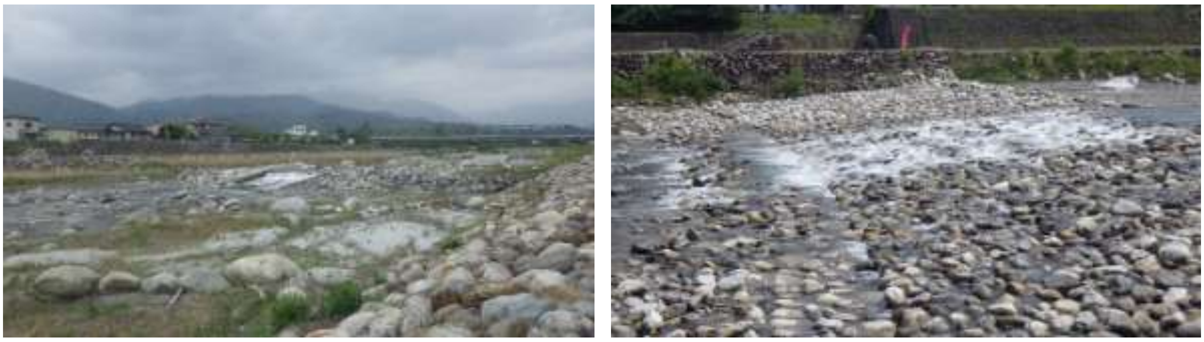
(a) Before improvement (b) After improvement

Photo 1. Check dam in Iwaubetsu River



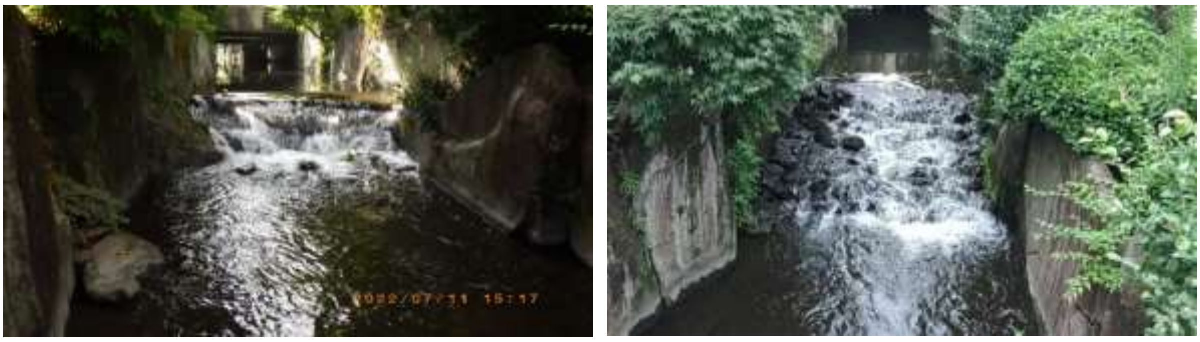
(a) Before improvement (b) After improvement

Photo 2. Check dam in Kanna River



(a) Before improvement (b) After improvement

Photo 3. Check dam in Ohmu River



(a) Before improvement (b) After improvement

Photo 4. Low drop structure in Kama River

(a) Before improvement (b) After improvement

Photo 5. Low drop structure in Sanagouchi River

2. Ramps With Assembled Boulders

2.1 Check Dam in Iwaubetsu River

As shown in Photo 1 (a), the height of check dam was 3.2 m height before the improvement. The check dam is in Shiretoko peninsula registered as a World Natural Heritage site. 1.6 m height was cut to improve the river environment around the check dam, and the ramp with the consecutively assembled boulders was installed for aquatic animals to migrate upstream and downstream safely at the drop part with 1.6 m height in 2022 [Photo 1 (b)]. In the assembled boulders, there was no concrete. The boulders were reused from the sediment region at the immediately upstream of the check dam. Before the improvement construction, there was no fish at the upstream of the check dam. While, after the improvement, more 50 migrated fishes including pink sermon fishes were recorded at the immediately downstream of the next check dam which would be improved as slit type dam. The ramp has 1/10 slope, and the boulders with averaged size 0.70 m were assembled consecutively. In addition, the size of the boulder was defined as the average of the long side, short side, and height. In prototype, as the size of the boulder in the ramp was larger for the reduction of flow velocity near the bottom due to the seepage flow during flood stages and for the formation of water surface flow during normal stages, crushed stones including pebbles were inserted inside boulders to adjust the porosity inside the assembled boulders. As shown in Photo 6, some boulders were transported on the ramp after floods, but the ramp has been kept safely. A local scouring is not formed at the downstream of the ramp, because a surface jet flow is formed during flood stages as a transition from supercritical to subcritical flows. Furthermore, the migration route for aquatic animals can be kept after floods.

2.2 Gravel Control Dam in Kanna River

In Kanna River, a gravity dam (Shimokubo dam) with 50 m height is located, and a dam lake (Kanna Lake) is formed. Gravel control dam with 3.6 m height, 74 m width is located at the upstream of the dam to reduce the sediment transport of gravels in dam lake. At the upstream of the dam lake, there are several kinds of aquatic animals. As shown in Photo 7, pool type fish passage was installed at both sides of the gravel control dam, but more 1000 fishes lost the migration route through the fish passage. Before the improvement, the control dam was obstacle for the upstream migration of aquatic animals. In 2021, the main part of the dam was destroyed partly by a big flood with transported boulders. For both gravel control and preservation of aquatic habitat, the ramp with the assembled boulders was installed at the downstream of the dam as shown in Photo 2. The slope of the ramp was set to 1/4 slope in order that the downstream end of the ramp was reached to the downstream end of the stilling basin. The average size of the assembled boulders was 1.0 m. Concrete was filled inside the assembled boulders up to 50% porosity to reduce the velocity of seepage flow occurring inside the boulders and to stabilize the boulders during floods, preventing its runoff. The boulders were transported from within the same watershed area. As the assembled boulders with 0.5 m concave shape were installed on the ramp, a surface jet flow is formed during flood stages as a transition from supercritical to subcritical flows. A local scouring is not formed at the downstream of the ramp. In Spring season, a lot of ayu fishes migrated upstream from the dam lake, and they could migrate upstream through the ramp easily. As other fishes could migrate upstream, it was recorded that the number of fishes downstream of the ramp was small.

2.3 Check Dam in Ohmu River

In Ohmu River, fifty check dams, averaging 2.0 m in height and 73 m in width, have been installed to reduce the transport of sand, gravel, and boulders during flood season. Each check dam incorporated a partial fishway. However, during floods, transported sand, gravel, and boulders destroyed or rendered inoperable 95% of these fishways (see Photo 8). Since 2021, three check dams were improved as shown in Photo 3. The consecutively assembled boulders with averaging 1.0 m size were installed as the ramp with 1/8 slope. Concrete was filled inside the assembled boulders up to 50% porosity to reduce the velocity of seepage flow occurring inside the boulders and to stabilize the boulders during floods, preventing its runoff. The boulders were sourced from this local river. To form the mainstream of 20 m wide, the bottom level of middle part was set to 0.20 m lower at the upstream end of the ramp. The other bottom level changes with 3 % slope increase for both sides of upstream end of the ramp. Several kinds of surface flow velocities are formed transversely, and multi-aquatic animals can be acceptable for the upstream migration at the ramp. It was recorded that the number of fishes downstream of the ramp was small. As shown in Photo 9, some boulders were transported on the ramp after floods, but the ramp has been kept safely.

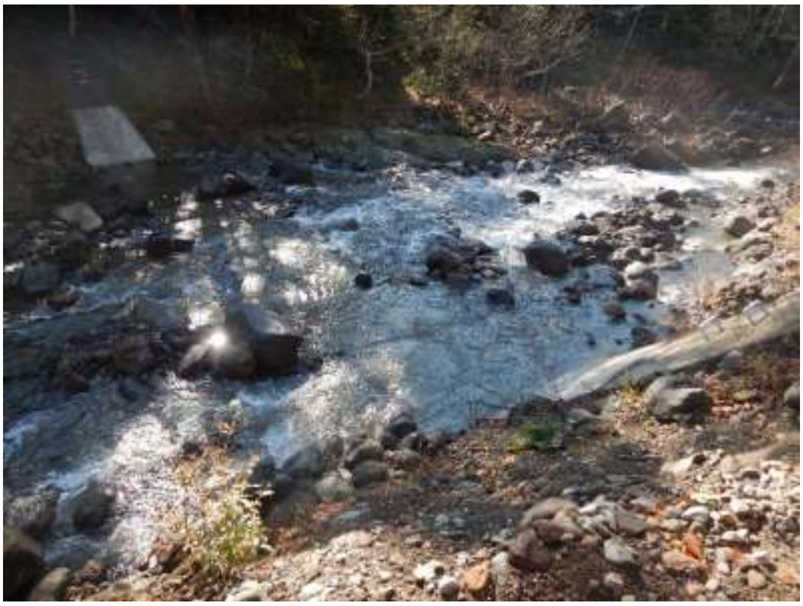


Photo 6. Flow condition on the ramp due to assembled boulders after a big flood in November 2025

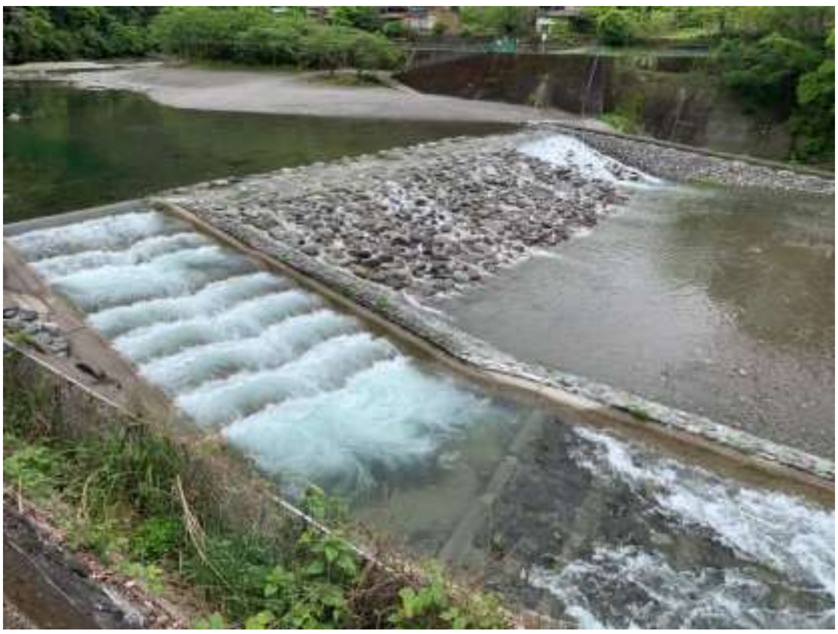
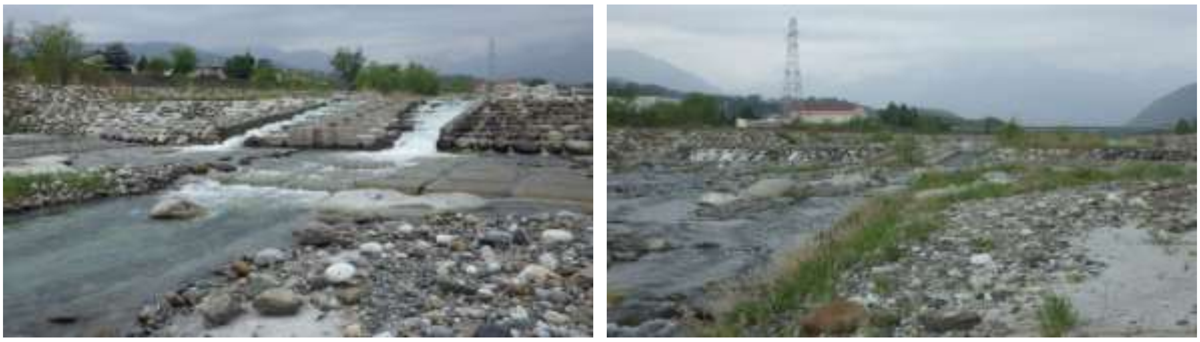


Photo 7. Flow conditions of pool type fish passages installed on both sides



(a) Flow condition in pool type fish passage (b) Non-functional pool-type fish passage

Photo 8. Unstable fishway functionality in areas prone to debris flows

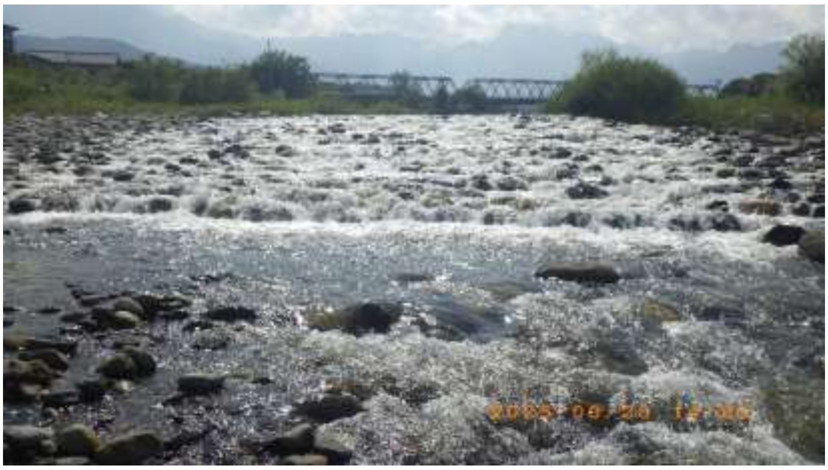


Photo 9. Flow conditions on ramp due to assembled boulders after multiple floods

2.4 Low Drop Structure in Kama River

Kama River is an artificial river located in Utsunomiya city, residential area, and there are many low drop structures with 0.90 m in drop height. As the downstream face of the drop was almost vertical, the upstream migration of aquatic animals was obstacle. There are many fishes between each drop, but the population of fish decreases year by year. Furthermore, the noise of the flow over the drop is not neglected, and it may be difficult for residents to stay in a rest area on the bridge located 5 m downstream of the drop for a long time. This river has a dual structure that divides flood flows. The upper limit of the flow depth at the top of the drop reaches approximately 0.50 m in a critical depth. The ramp with consecutively assembled boulders were installed to improve aquatic habitat and sound of flow passing drop structure (Photo 4). For the installation of the assembled boulders, the boulder with 0.30 m average size was used, and 2.5 hours were taken for the construction. In this case, no concrete was used for the stabilization of assembled boulders during floods. Crushed stones with 0.02 m averaged size and boulders with 0.15 m averaged size were used to insert inside the assembled boulders and to form stepped mount as a base of the ramp. 2 years have passed since construction, and the ramp has been stabilized. The sound of the flow passing over the ramp was improved, and the rest area on the bridge have been used for a long time by residents. The aquatic habitat around the ramp has improved, and it is easy to find swimming river fishes in the river along traffic road.

2.5 Low Drop Structure in Sanagouchi River

The Sanagouchi River suffered damage from torrential rains along a 1.6-kilometer section downstream of the dam. Restoration work was carried out between 2020 and 2025 with support from the national government. For this section, it is essential not only to regulate floods but also to secure agricultural water facilities and conserve the aquatic animals (river mussels, crustaceans, benthic fishes, and swimming fishes) and aquatic plants inhabiting this river. The river width in the restoration section was expanded to 1.7 times its original size. Six low-drop structures were constructed to serve dual purposes of irrigation and sediment transport control. Each structure features a continuous masonry ramp (1/10 gradient). This enables the upstream and downstream migrations of diverse aquatic animals. Furthermore, the ramp installation contributes to preventing localized scouring. Additionally, it is easy to rise the position of mainstream during flood stages, thereby also helping prevent localized scouring downstream of the drop structures. The average size of the boulders is approximately 0.45 m. To ensure safety in accordance with administrative guidance, the stacked boulders are secured with concrete up to a thickness of 0.10 m (Photo 10). The seepage flows between the assembled boulders remain intact as migration routes, protected from predation. Controlling river water temperature is possible by creating seepage flow inside the assembled boulders. Here, the water diversion facilities minimize interference with the upstream and downstream migration routes of aquatic organisms. Since multiple small-scale facilities were installed, these structures themselves did not form storage basins, resulting only in minimal pooling of water near the intake point. Despite being a project that significantly altered the river's conditions, the fact that improvements were advanced from upstream to downstream allowed aquatic animals inhabiting the upstream section of the improved stretch to migrate downstream. This facilitated the easy recovery of aquatic animals and accelerated the return of aquatic plants.

Photo 10. Condition of concrete placement beneath the lower part of the assembled boulders

3. Discussion

Table 1 shows the summary of structural information introduced in Sections 2.1 to 2.5. The drop structures shown in Photos 1 to 5 were improved for multi-aquatic animals to migrate upstream and downstream by installing the ramp with the assembled boulders. The formation of the seepage flow inside assembled boulders is significant for both the migration route of aquatic animals during normal stages and the velocity reduction near the bottom during flood stages. On the ramp due to consecutively assembled boulders, a surface water flow is generated through the gaps between the boulders, or seepage flow is generated through the voids within the assembled boulders.

In the check dams shown in Photos 1 through 3, the use of large boulders as the assembled structure (Table 1) allows gaps formed where the boulders overlap to be filled with concrete or gravels, promoting the formation of surface water flow. With a longitudinal gradient of 1/10, the formation of surface water flow is suitable for swimming fish approximately 1 meter in length (e.g., cherry salmon). With a longitudinal gradient of 1/4.5, the pools formed within the assembled boulders become smaller in scale, making them suitable for small fishes, crustaceans, and benthic fishes.

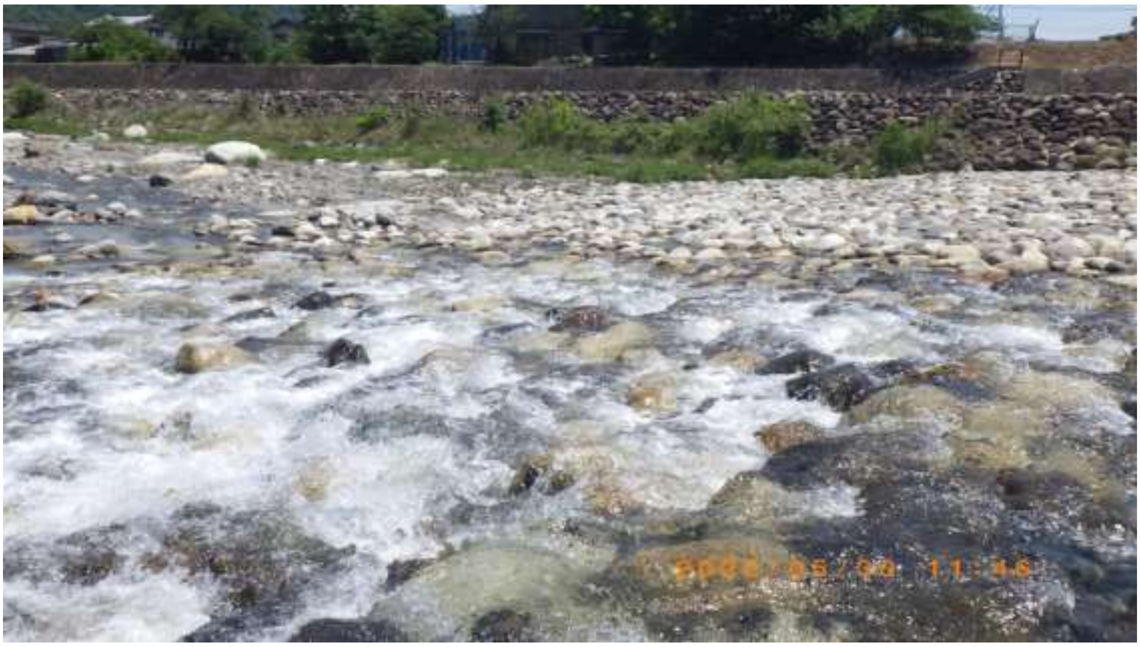
In the drop structures shown in Photos 4 and 5, the smaller boulder size means seepage flow through the voids between the boulders becomes the primary migration route. In this case, the formation of seepage flow within boulders (Photo 11) provides beneficial refuge and migration pathways for small fishes (less than 0.20 m body length), including benthic fishes and crustaceans.

The flow condition of surface water passing through gaps between boulders during normal stages is a three-dimensional flow, like local flows in step and pool formed at mountain river (Photo 12). The velocity required for rest during migration and the velocity of the moving flow passing through the gaps both exist at the continuously assembled boulders. Regarding the flow condition of seepage flow inside the assembled boulders, as the boulders are arranged in a staggered pattern, the time-averaged flow velocity within the enclosed space is necessarily controlled. Consequently, the time-averaged flow velocity remains unchanged even when the boulder size varies from 0.05 m to 0.40 m. However, a turbulence intensity inside boulders is somewhat larger as the boulder scale increases. In addition to the examples introduced here, inclined structures using assembled boulders have been introduced at other locations, each creating an environment where crustaceans, migratory fish, and benthic fish can migrate upstream and downstream.

Table 1. List of Structural Information by Five Locations

Types of Structures River name	**Slope of Ramp**	**Size of Boulder (m)**	**Width (m)**	**Height (m)**
Check dam in Iwaubetsu River	1/10	0.7-0.9	13.0	1.6
Check dam in Kanna River	1/4.2	0.6-1.0	26.1	3.0
Check dam in Ohmu River	1/8	0.7-1.0	74.0	2.1
Low drop structure in Kama River	1/5	0.3-0.4	4.0	0.9
Drop structure in Sanagouchi River	1/10	0.4-0.5	15.0	0.9-2.33

Photo 11. Surface water and Seepage flows on the ramp with the consecutively assembled boulders



(a) Main flow region

(b) Side flow region

Photo 12. Water surface flow on the consecutively assembled boulders

Integrating applications across the five sites can be summarized as follows:

In areas prone to debris flows and driftwood outflows, assembled boulders are constructed using boulder around 70 cm in size. To prevent the assembled boulders from sliding within the ramp, the lower third of the inclined gravel layer is reinforced with concrete. As a result, the construction of assembled boulders is stable. During normal flow conditions, surface flow between overlapping boulders becomes the primary current. By varying the top level of the assembled boulders across the river, the width of the flow area changes according to flow discharge, allowing for varying flow velocities. This enables the movement of diverse aquatic animals. However, since energy dissipation via seepage flow between the boulders cannot be expected, the energy dissipation function of seepage flow downstream of the slope contributes to riverbed protection. While, in the Iwaubetsu

River case, concrete was only used for the foundation retaining wall. The 0.70 m-sized boulders are filled with gravel smaller than 0.20 m, enabling energy dissipation utilizing seepage flow. Even over time, the gravel within the bed does not get sucked out, making it suitable for both disaster prevention and providing a migration environment for aquatic animals.

In the Sanagouchi River case, the foundation consists of concrete slabs, with stonework using gravel around 40 cm in size placed on top. Downstream of the ramp, the riverbed is protected by gravel mixed with boulders around 60 cm in size. Additionally, pools form locally around the large boulders, serving as habitats and refuge areas for aquatic animals. The assembled boulders on the ramp are stable, and seepage flow forms inside boulders, contributing to its flood energy dissipation function. Furthermore, during low water periods, flow occurs only inside the assembled boulders, helping to suppress water temperature increases.

In the ramp due to the assembled boulders installed in the urban area, a base of 0.10–0.20 m gravel is used. Boulders around 0.30 m size are used for the ramp, and sand and gravel are then placed on top. This ensures that only the sand and gravel necessary for water compaction remain, preserving voids within the ramp. Furthermore, the seepage flow inside assembled boulders controls the force of the current, ensuring the sound of flowing water does not cause discomfort. Even with a maximum overflow depth of 0.50 m during high water, the stability of the ramp is maintained.

4. Conclusion

For drop structures, a ramp construction with consecutively assembled boulders is optimal for enabling diverse multi-aquatic animals to safely migrate upstream and downstream without encountering predation. The structure of the assembled boulders is stable during flood stages. The size of the boulders used in the assembled boulders varies depending on the structure's function and whether large boulders and draft woods move during floods. When the size of the boulder is large, the volume of voids between the assembled boulders increases. Filling these voids with concrete or gravels smaller than 0.20 m creates surface water flow in gaps between the boulders, forming migration routes for aquatic animals migrating upstream and downstream during normal stages. Using the Froude similarity law, the flow velocity can be estimated in model experiments excluding air-entrainment. If the size of the boulder is smaller than 0.4 m, the seepage flow inside the assembled boulders is used as migration route for aquatic animals. The time averaged flow velocity of the seepage flow remains same order even if the boulder size varies from 0.05 m to 0.40 m. However, a turbulence intensity inside boulders is somewhat larger as the boulder scale increases. In the seepage flow region, as the flow velocity depends on absolute space and the combination of assembled boulders, the Froude similarity may not be applicable between physical scale model and prototype. In near future, systematic post-construction monitoring data (e.g., fish counts, velocity measurements) to provide stronger evidence of ecological efficacy might be required.

References

Chaudhary, R. K., Nayan, S., & Zulfequar, A. (2021). Block ramps for stream power attenuation in gravel-bed streams: a review. *Water Supply, 21*(2), 493-512. https://doi.org/10.2166/ws.2020.339

Kim, S., Salmasi, F., Ghorbani, M. A., Karimi, V., Malik, A., & Kahya, E. (2020). Energy Dissipation in Rough Chute: Experimental Approach Versus Artificial Intelligence Modeling. *Intelligent Data Analytics for Decision-Support Systems in Hazard Mitigation*, Springer Transactions in Civil and Environmental Engineering (STICEE), Singapore, Chapter 12, pp. 227-249. https://doi.org/10.1007/978-981-15-5772-9_12

Pagliara, S., Radecki-Pawlik, A., Palermo, M., & Plesiński, K. (2017). Block ramps in covered rivers morphology analysis and prototype data supported design criteria for mild bed slopes. *River Research and Applications, 33*(3), 427-437. https://doi.org/10.1002/rra.3083

Takada, H. (2020). *Soil Environment (Dochuu Kankyou)*. Kenchiku Shiryō Kenkyūsha, Japan, 224 pages, ISBN-10: 4863587007, ISBN-13: 978-4863587007 (in Japanese).

Yasuda, Y. (2025). Application of Consecutively Assembled Boulders Around Hydraulic Structures. *Journal of Environmental Science Studies, 8*(2), 1-34. https://doi.org/10.20849/jess.v8i2.1537

Yasuda, Y., & Fuchino, N. (2022). The Efficacy of Artificially Assembled Boulder Installations in Improving Migration Routes for Aquatic Animals. River Basin Management Under a Changing, Intech Open, United Kingdom, pp. 1-20. https://doi.org/10.5772/intechopen.105198

Yasuda, Y., & Wang, J. (2024). Countermeasure of Protection against Local Scouring Downstream of Concrete

Check Dams. *Journal of Environmental Science Studies, July Press, 7*(1), 10-20.

Zulfequar, A., Nadimetla, M. P., & Bernhard, W. (2009). Energy Dissipation on Block Ramps with Staggered Boulders. *Journal of Hydraulic Engineering, ASCE, 135*(6), 522-526. https://doi.org/10.1061/(ASCE)HY.1943-7900.0000039

Copyrights