Application of Environmentally Active Concrete (EAC) for River Structure

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Abstract. An increase in floods due to climate change has concern for causing enormous erosion damage. Concrete is demanded to play an even more important role in the development of river structures for disaster prevention and mitigation. In Japan, river structures using concrete have been actively developed to protect river banks and riverbeds from floods. Under these circumstances, in the River Act partial amendment in 1997, in addition to the previous concept of flood control and water utilization, the concept of the environment (improvement and conservation of river environment) was incorporated. Therefore, various efforts have been made, such as developing products and methods that utilize natural materials other than concrete and researching new environmentally friendly materials. The authors have developed "Environmentally Active Concrete (hereinafter referred to as EAC)" with environmental functions by mixing arginine, one of the amino acids, into the concrete and have put it into practical use. Demonstration experiments have confirmed the environmental performance of EAC in rivers. In river structures where EAC has been applied, the effects of promoting the growth of attached algae and habitat conservation for various organisms such as sweetfish, Japanese eel and Japanese giant salamander have also been confirmed. Utilizing EAC will make it possible to achieve river structures with both disaster prevention and environmental conservation functions.

Keywords: Environmentally Active Concrete · Amino acids · Working with nature · River and lake protection · Disaster prevention

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1 Introduction

The IPCC 6th Report (AR6) Working Group I (WG1) Report Summary for Policymakers (SPM), released in August 2021, determined that it is "unequivocal" that human activities influence global warming. It also reported that global surface temperature will exceed 1.5 °C and 2.0 °C during the 21st century compared to pre-industrial levels unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades. There is a concern that the increases in annual mean precipitation, the rate of occurrence of extremely intense tropical cyclones, and peak wind speeds due to the rise in global surface temperature cause enormous erosion damage to riverbanks and lakeshores. In order to preserve the inland waterway and achieve sustainable operations of inland ports, countermeasure works to protect riverbanks and lakeshores are important.

In Japan, where heavy rains occur every year, especially during the rainy season and typhoon season, river structures such as revetment works, foot-protection works and riverbed protection works have been actively developed to protect riverbanks and riverbeds from floods. In the River Act partial amendment in 1997, in addition to the previous concept of flood control and water utilization, the concept of the environment (improvement and conservation of river environment) was incorporated. Under the circumstances, various efforts have been made, such as developing products and methods that utilize natural materials other than concrete and researching new environmentally friendly materials.

The authors have developed "Environmentally Active Concrete (hereinafter referred to as "EAC")" with environmental functions by mixing arginine, one of the amino acids, into the concrete and have put it into practical use. This paper introduces demonstration experiments on the environmental performance of EAC in rivers and specific application examples to river structures in Japan.

2 Environmentally Active Concrete (EAC)

EAC is a new concrete mixed with arginine, one of the amino acids, developed by Sato et al. (2011) and Nishimura et al. (2014). We have confirmed that arginine that slowly elutes from the concrete surface over a long period promotes the growth rate of microalgae and small-sized seaweeds attached to the concrete surface. EAC with attached microalgae is expected to contribute to the creation and improvement of habitat environment for various organisms and improvement of biodiversity, such as being used as habitats and feeding grounds for fish and benthos. In Japan, EAC has been applied to more than 500 projects. In 2018, the demonstration experiment at the Port of Wajima using EAC was certified by PIANC Working with Nature (Photo 1).

Photo 1. EAC Demonstration experiment in the construction of the 6th breakwater at the port of Wajima (PIANC Working with Nature Certificate of Recognition)

3 Demonstration Experiment of EAC in Rivers

3.1 Growth-Promoting of EAC in Rivers

In order to verify the growth-promoting effect of attached algae in rivers, a demonstration experiment was conducted in the middle basin of the Fushinogawa River, where sweetfish are naturally distributed (Photo 2). In the experiment, an EAC block mixed with 10% arginine by cement weight ratio (45 cm x 18 cm x 18 cm, hereinafter referred to as EAC), an ordinary concrete block of the same shape (hereinafter referred to as OC) and a natural stone collected from the river and stripped of attached algae on the surface (approx. 30 cm diameter) were used as test specimens for measurements. The amount of attached algae was evaluated by stripping off the adhering substances from within a 5 cm x 5 cm frame on the surface of each test specimen (2 locations/test specimen) and measuring the amount of chlorophyll-a.

Figure 1 shows the measurement results of the amount of chlorophyll-a in each test specimen. The amount of chlorophyll-a on the EAC surface is 1.7 to 2.2 times higher than that on the OC surface both 13 days and 41 days after installation. A comparison of EAC and natural stone shows similar values for 13 days and 41 days after installation. These results indicate that EAC can be expected to have the growth-promoting effect of attached algae equal to or higher than natural stone.

Fig. 1. Survey point of Fushinogawa river

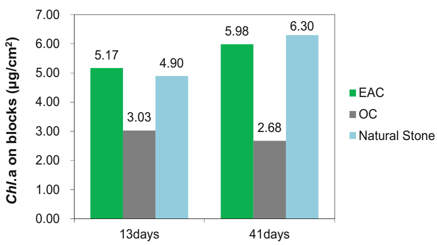

Photo 2. Comparison of chlorophyll-a on test piece and natural stone surfaces

3.2 Gathering Effect on Sweetfish

In order to verify the gathering effect of EAC on sweetfish, a demonstration experiment was conducted in an outdoor water tank (area of 60 m^2, water depth of 0.5 m) using water taken from the Fushinogawa River. Similar test specimens of EAC and OC as 3.1 were installed in the outdoor water tank. Two weeks later, 300 sweetfish were released, and the feeding times of sweetfish were observed with an underwater camera (Photo 3).

Figure 2 shows the measurement result of the feeding times of sweetfish for EAC and OC. The feeding times of sweetfish were remarkably higher for EAC in both the first and second times, with an average of 21.5 times/minute for EAC and 0.5 times/minute for OC. Since sweetfish have a taste response to arginine, we consider that many sweetfish gathered in EAC due to the taste and smell response to arginine eluted from concrete or arginine contained in algae.

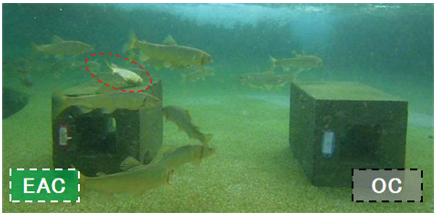

Photo 3. The moment when sweetfish feed on algae

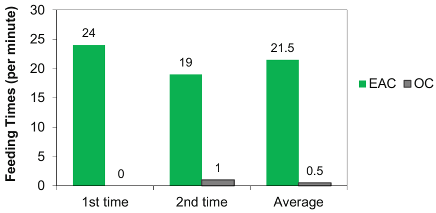

Fig. 2. Comparison of feeding times by sweetfish

3.3 Gathering Effect on Japanese Eel

For verifying the gathering effect of EAC on Japanese eels, a demonstration experiment was conducted in the outdoor water tank used in 3.2. In the experiment, a total of four sets of five vinyl chloride pipes (7 cm diameter x 100 cm long) were prepared, of which two sets contained EAC (50 mm diameter x 50 mm long) and the remaining two sets contained OC (same shape as EAC) and installed in the outdoor water tank. Two weeks later, 10 Japanese eels were released into the outdoor water tank and the vinyl chloride pipes were collected at intervals of about two days to observe the gathering condition of the Japanese eels.

Photo 4 shows the gathering condition of the Japanese eels, and Fig. 3 shows the measurement results of the total number of Japanese eels in each pipe. As shown in Photo 4 and Fig. 3, Japanese eels gradually began to gather in the pipe where the EAC was installed as the day progressed. Similar results were also obtained by conducting experiments in which the installation positions of EAC and OC were replaced. As with the sweetfish mentioned above, we consider that Japanese eels also have a smell response to arginine eluted from EAC.

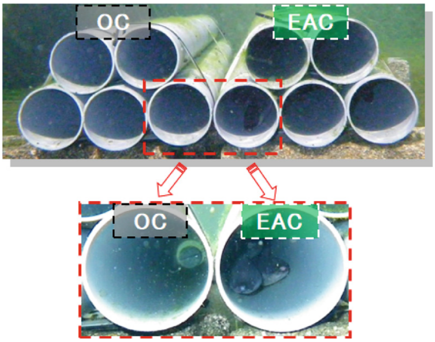

Photo 4. Gathering condition of Japanese Eels

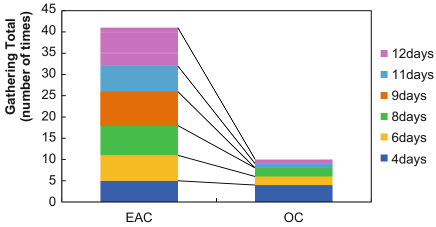

Fig. 3. Cumulative number of Japanese Eel gathering

4 Application Example of EAC for River Structures

4.1 Application Example for Riverbed Protection Work

At Katsuuri weir, which is an important intake facility for agricultural water in the Kinugawa River, Tochigi Prefecture, the riverbed protection work using concrete armor blocks (STONE-BLOCK 4-ton) are installed in the downstream area. At this site, four EAC panels (28 cm x 15 cm x 13 cm), which are expected to have an attractive effect on sweetfish, were attached to each of the 151 concrete armor blocks downstream area of the fishway facility in order to guide the sweetfish that run-up the Kinugawa River to the fishway attached to the riverbed protection work (Photo 5 and 6).

One month after the blocks were installed, many attached algae were observed growing on the EAC panels (Photo 7). As shown in Fig. 4, we also observed that the density of bite marks of sweetfish was up to 20 places/100 cm^2 downstream on the right bank side where the fishway is located. In addition, many sweetfish were found in the fishway (Photo 8).

We consider that sweetfish were guided to the fishway to run-up without straying into areas other than the fishway, based on the condition of the bite marks of sweetfish around the fishway. In addition to the effect of the EAC, the installation of a “Guide-flow waterway” that generates a strong current downstream entrance of the fishway is also thought to be a factor to improve the induction effect for sweetfish into the fishway (Fig. 4).

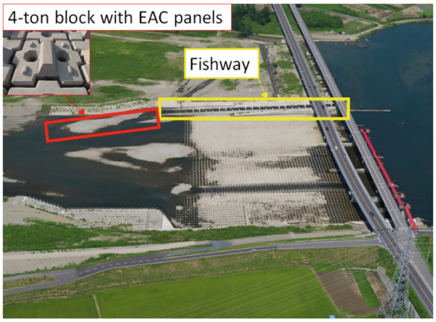

Photo 5. Aerial photograph of Katsuuri weir

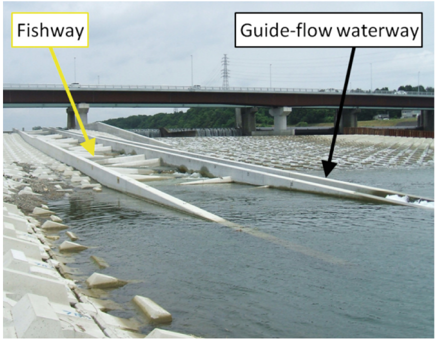

Photo 6. Full view of the fishway (From downstream to upstream)

Photo 7. Attached algae on EAC panel

Photo 8. Sweetfish in the pool for fishway

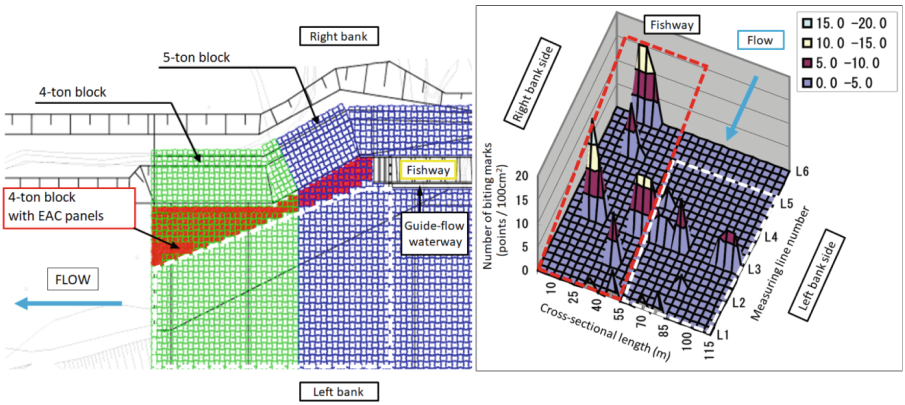

Fig. 4. Distribution chart of sweetfish bite marks

4.2 Application Example for Spur Dikes

In the Waragawa River, Gifu Prefecture, due to the restoration work of the revetment damaged by the heavy rain in July 2018, spur dikes with foot-protection blocks are being maintained. The Waragawa River is famous as a clear stream inhabited by many Japanese giant salamanders, which are designated as a special natural treasure. There is a locality that sweetfish grown in this river is also popular as a luxury food. Based on this background, 4-ton blocks (GASSHO-BLOCK) with high porosity and EAC panels (28 cm x 15 cm x 13 cm) were applied to the spur dikes aiming the habitat conservation for Japanese giant salamanders and sweetfish.

Six blocks with EAC panels were installed in each of 11 of the 19 total spur dikes (Fig. 5). The blocks with EAC panels were expected to attract fish by placing one upstream and one downstream of the center side of the stream at the first layer, where the running water always hits without stagnation (Fig. 6). In addition, for the second layer, the gathering effect was expected by using all four blocks with EAC panels.

Three months after the installation of the spur dikes, for each 4-ton block with EAC panels installed in spur dikes No.9, 11, and 15, the conditions of attached algae on the surface of the EAC panels (hereinafter referred to as EAC) and the surface of the ordinary concrete block (hereinafter referred to as OC) were compared. In each block, more attached algae were confirmed in EAC than in OC (Photo 9). Furthermore, the adhering substances in the 7 cm diameter frame on the EAC and OC surfaces were stripped off, and the amount of chlorophyll-a was measured and evaluated.

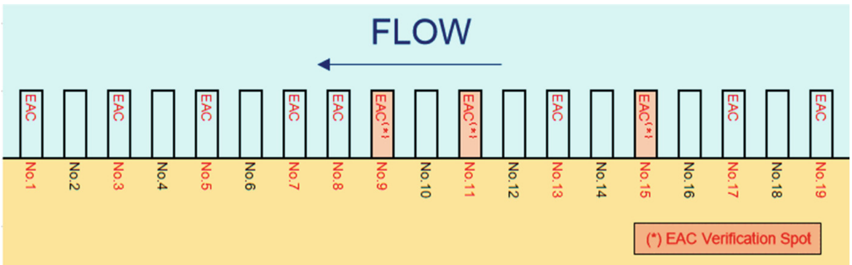

Fig. 5. Layout drawing of spur dikes (EAC applied to 11 out of 19 total spur dikes)

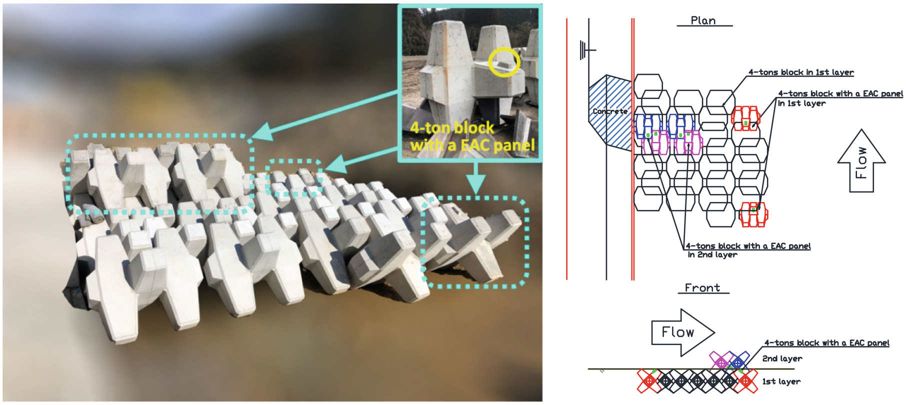

Fig. 6. Installation of 4-ton blocks with EAC panels

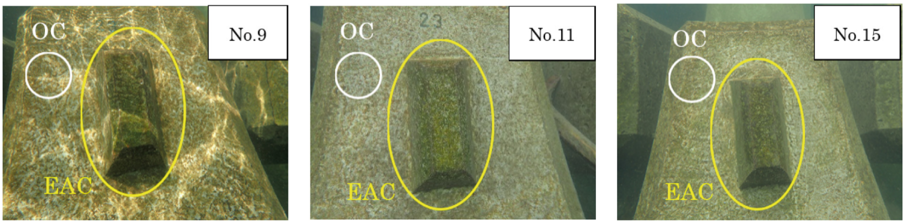

Photo 9. Attached algae on EAC and OC (Spur Dikes No.9, No.11, and No.15)

Figure 7 shows the measurement results of the amount of chlorophyll-a in the attached algae. The amount of chlorophyll-a was 0.12 μg/cm^2 for EAC and 0.035 μg/cm^2 for OC, confirming that EAC is about 3.4 times higher than OC. The number of appeared species and individuals of attached algae are shown in Fig. 8. The number of species was 30 in both EAC and OC. In regard to the composition of the species by class, the number of species of Bacillariophyceae was the most common in both EAC and OC, and the number of individuals was large in both Bacillariophyceae and Cyanophyceae. Among them, the Bacillariophyceae and Homoeothrix janthina of Cyanophyceae, the dominant species for both EAC and OC, are mainly used as food for sweetfish. The number of individuals was 147,863 for EAC and 49,984 for OC, resulting in a larger number of EAC. This result shows that EAC does not promote the growth of a specific species, but rather the growth of the entire algae species growing in the river.

In addition, seven months after the installation of the spur dikes, the growth of algae and the habitat conditions of sweetfish and Japanese giant salamander were investigated. The algae habitat conditions were good for the EAC, OC, and surrounding natural stones in each block of spur dike No.9, 11, and 15. Sweetfish were often found around the blocks with EAC panels (Photo 10). Bite marks of sweetfish were also confirmed everywhere on the surface of EAC, OC and the surrounding natural stones, indicating that blocks with EAC panels in the spur dikes contribute to creating the habitat for sweetfish.

A total of two individual adult Japanese giant salamanders were confirmed, one for each in the void parts of the 4-ton blocks of No. 9 and No. 15 (Photo 11). Both of them used the space created by 4-ton blocks as a habitat. Furthermore, many fishes such as sweetfish and Japanese dace lived in the void parts of the 4-ton block as well as Japanese giant salamanders. Since Japanese giant salamanders feed on fish, it is assumed that they prey on the fish around the block. In other words, benthos and sweetfish prey on the attached algae that grow on the surface of the EAC panels, which is thought to enrich the ecosystem base and the feeding environment of the Japanese giant salamanders, which are at the top of the ecological chain (Fig. 9).

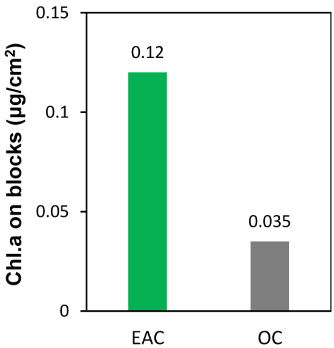

Fig. 7. Amount of chlorophyll-a in attached

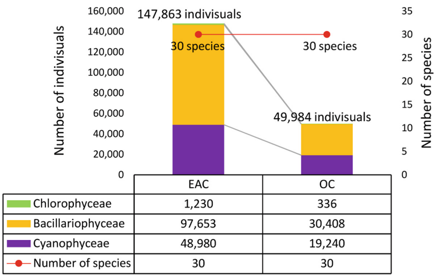

Fig. 8. The number of species and individuals of attached algae

Photo 10. Sweetfish swimming around the 4-ton block and bite marks on the surface of EAC

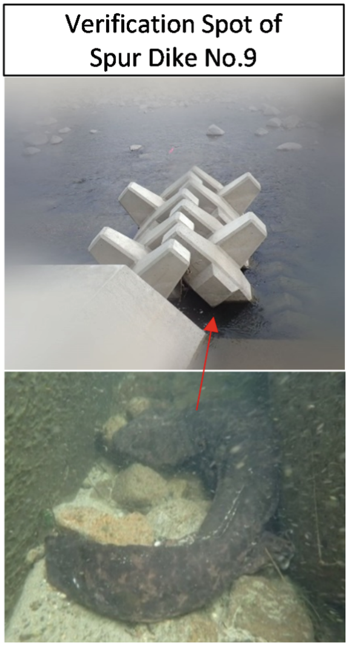

Photo 11. A Japanese giant salamander resting in the void part of 4-ton

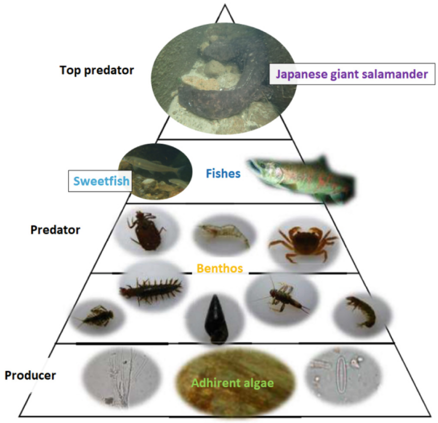

Fig. 9. Ecosystem pyramid in the Waragawa

5 Conclusions

This paper introduced the effectiveness of EAC and its application examples for river structures such as riverbed protection works and spur dikes. Among them, EAC contributed to promoting the growth of attached algae and was also confirmed to be effective in habitat conservation for various organisms such as sweetfish, Japanese eel and Japanese giant salamander.

Concrete is demanded to play an ever more important role in the development of river structures for disaster prevention and mitigation, as there is concern that the increase in floods due to climate change will cause extensive erosion in the future. Under these circumstances, adding environmental functions to concrete, such as EAC introduced in this paper, will make it possible to achieve river structures with both disaster prevention and environmental conservation functions. Hereafter, we hope that EAC will be widely used all over the world beyond Japan.

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