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Environmental friendly reinforced retaining wall by using traditional stone masonry

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ABSTRACT: The ancient civil structures had been constructed by using natural resources such as soil, stone or timber. In modern structures, those construction materials have been replaced by artificial materials such as concrete, steel or plastic, and such change has contributed to rather speedier and larger scale construction. This paper introduces the newly developed reinforced retaining wall construction method which is expected to harmonize the surrounding ecology and also ensure the stability of structure itself with combination of conventional stone masonry and RC pre-cast reinforcement called Branch Reinforcing Method.

1 INTRODUCTION

We have inherited the ancient civil and architectural structures which had been constructed by natural resources such as soil, stone or timber several hundreds or thousands years ago. In modern structures, the major construction materials have been replaced by artificial materials such as concrete, steel or plastic. Such change has enabled rather speedier and larger scale construction and contributed to the economic development significantly.

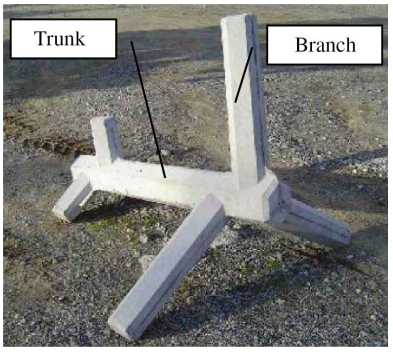


Figure 1. Shape of RC Branch Block (L = 1.5 m).

However, recently, the durability of those modern structures has been put in question and the repairing/rehabilitation method to prolong the serviceability has become the one of social proposition.

This paper introduces the new retaining wall construction method by combining the natural and artificial resources i.e natural stones as major material and RC Branch Block (ref. Figure 1, hereafter called as block) as pre-cast reinforcing members.

Configuration of this method is shown as Figure 2. The concept of design and construction of the method is also discussed.

2 GENERAL

2.1 *Aims of proposed wall method*

Since the applicable construction height by dry masonry is limited to approx. 2 m, the wet masonry has commonly been adopted with using the concrete blocks instead of natural stones due to its advantage in productivity.

Also for the revetment works, the priority has been put into flood control, so that the "Three faces

Figure 2. Configuration of proposed block wall using traditional stone masonry for river revetment in February 2003.

revetment method made by concrete" has commonly been adopted and that has been said as one of major influence factor to the surrounding ecology.

According to the amendment of river law in 1997, "the maintenance and protection of river environment" became the one of the main purpose of public works in addition to the flood control and irrigation, henceforward many kinds of ecology/environment friendly blocks have been developed.

From the environmental point of view, the characteristics of this method are listed as below;

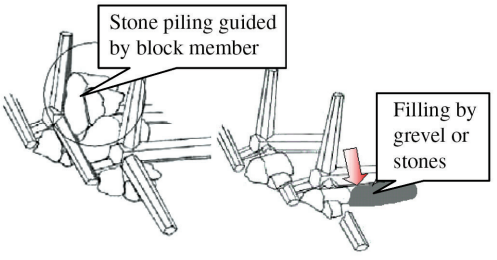
(1) Using natural stones available nearby site,
(2) Not using the concrete which will deteriorate the water quality nearby site,
(3) By applying the dry masonry method, the void between each stone provides the life space for small animals and fishes.
(4) Enabling the sodding and planting works between each stone which contribute the good landscaping and surrounding ecology, and,
(5) Enabling the quick dewatering of excess ground water due to its high permeability of facing.

2.2 *Construction sequences*

Construction sequences are shown as Figure 3. The advantages of this method from the viewpoint of construction sequences are listed as below;

(1) Since the weight of one block is relatively light with 240kg, the big construction equipment is not required,
(2) Utilizing the hexagon shaped by blocks as a guide, the skilled mason is not necessarily required,
(3) Enabling the works in curved alignment (minimum radius = 3 m),
(4) Flexible to the undulation of ground condition. The base ground is not necessarily horizontal.

(a) Piling up blocks for second layer



(b) Piling wall facing with stones and blocks

Figure 3. Construction details of proposed wall.

3 DESIGN CONCEPT

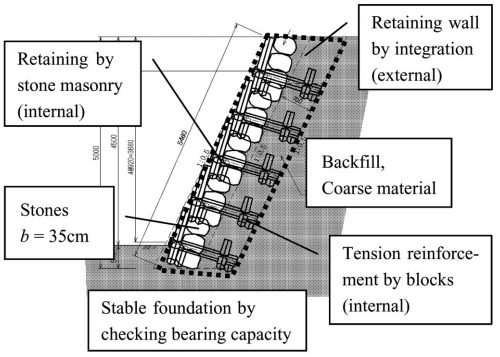
In order to establish the design concept of this method, each function of stones and blocks have to be clearly identified.

Figure 2 showed the photo of river revetment works implemented as a pilot project in Yamaguchi city. In this case study, assuming that only the block structure bears the whole earth pressure, it was calculated that this structure is no longer stable. Therefore, in order to incorporate the function for stones to share certain loading into design, the following model is assumed.

Figure 4 explains the mechanism of resistance against earth pressure as below:

(1) Firstly, the stone masonry (average width $b =$ approx.35 cm) resists against the earth pressure by backfilling material as a leaning type retaining wall. The stability of this phase is calculated by force diagram method.
(2) When the pressure exceeds the resistance capacity of stone masonry, the main member of block starts to resist against tensile force transferred through block member.

As long as the tensile force is within the allowable capacity of main member, this structure is internally stable and able to resist as a mass enveloped by dot line against the earth pressure as externally stable condition. The stability of this phase is calculated same as gravity retaining wall i.e. checking for sliding, overturning and bearing capacity.



* internal, external: mode of stability

Figure 4. Model of load sharing mechanism.

Figure 5. Setup of pull out test of block by hydraulic jacks for 4m-high test wall (Nov. 2004).

Here, it is predicted that the bending moment will occur on two blanch members underneath the block which tend to deflect toward outside, as well as on main member. Therefore, it is important to fill the void by stones laid underneath the blocks during construction. Durability is estimated over 50 years for RC pre-cast reinforcement.

Above design concept has been proved as appropriate by implementing the several monitoring during the trial project with 4m height i.e. monitoring the stress of reinforcement bar, during construction and pullout test of block as shown in Figure 5.

4 INVESTIGATION AND EXPERIMENTATION ON EFFECTIVENESS AS REVETMENT

In order to confirm that this method is effective on ecology and capable for flood control as the revetment,

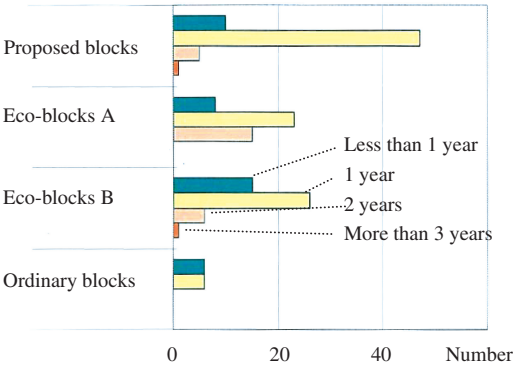


Figure 6. Comparison of number of "Kawamutsu" (*Zacco temminckii*) at each revetment block type.

several investigations and experimentations were carried out at two revetment project sites in Yamaguchi prefecture, i.e. investigation of surrounding ecology, investigation during flood and implementation of hydraulic test in laboratory.

4.1 *Investigation on ecology*

The investigation was implemented on ecology of fishes, aquatic animals and plants nearby site. Nearby the site in Mine-city, the existing revetment had been constructed by using two kinds of environmental friendly blocks (eco-block) and ordinal blocks so that the investigation on those locations was also implemented as a comparison.

Figure 6 shows the number of fish named Kawamutsu (*Zacco temminckii*) as a sample of investigations. It was observed that the number of Kawamutsu living nearby the proposed method site is larger than the other sites. Also, existence of Kawamutsu older than 3 years was observed at proposed block site. Thus, it is confirmed that the void in the proposed block provides the appropriate condition for "Kawamutsu" to grow up.

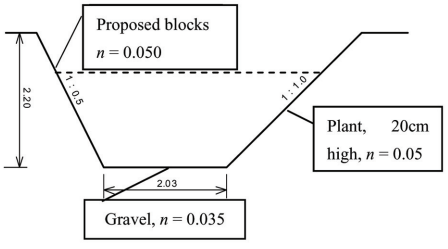
4.2 *Calculation of velocity of flow at flooding*

After the completion of revetment, the investigation was carried out during the flood as shown on Figure 7 (a) and the mean velocity of flow V was back-analyzed by equation (1) and (2) based on the section of river as shown on Figure 7 (b).

$$V = \frac{1}{n} R^{2/3} I^{1/2} \tag{1}$$

$$R = \frac{A}{S} \tag{2}$$

(a) Flood condition of revetment at Yamaguchi City



(b) Estimation of flow velocity during flood by observation

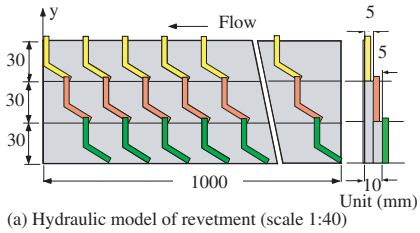
Figure 7. Calculation of velocity of flow during flood.

where n = coefficient of roughness; R = hydraulic radius; I = inclination of river bottom (0.0189); A = water area; and S = wetted perimeter.

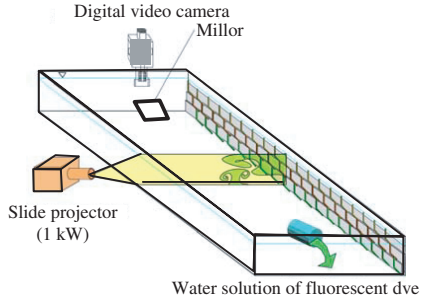
As a result, the velocity of flow was calculated as 3.5 m/s when the flood was 2 m depth. In addition, the strength of this method against hydraulic force was checked by using "Sliding–Unit" model which is based on the Revetment Design Method and also incorporates the result of pull-out test for block. As a result, this structure is confirmed as stable until velocity of flow reaches 10 m/s.

4.3 *Laboratory test by using hydraulic model*

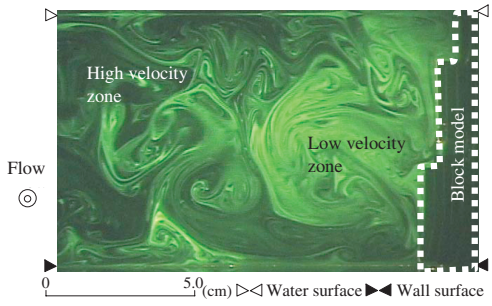
When applying this method as a revetment, it is known that the blanch members of the proposed blocks have the special roughness in repeated geometric pattern on its surface. Flow characteristics of this type revetment have been studying by using the hydraulic model in 1:40 scale. In order to measure the velocity of flow, PTV (Particle Tracking Velocimetry) is utilized. This method is to let the tracer particles with 100μm diameter flow from upstream, and to capture the movement of those particles by digital camera when passing the film of light shaped by radiating through the 2mm slit in horizontal and vertical direction as shown in Figure 8(a), (b). Figure 8(c) shows the example of



(a) Hydraulic model of revetment (scale 1:40)



(b) Setup of hydraulic model test to measure turbulence



(c) Cross sectional turbulence in front of the proposed block revetment model

Figure 8. Laboratory test by using hydraulic model.

experimentation results of turbulence in cross section in front of revetment (Watanabe, K. et al. 2006, 2007).

Through those experimentation results, it was confirmed that the application of this method is able to reduce the velocity of flow near the revetment surface and move the high-speed flow zone toward the centre of river. In other words, this method is able to improve the stability of revetment during the flood.

5 APPLICATION

The proposed wall method was applied to 5 river revetments and 7 embankment walls of reconstruction works after disaster induced by heavy rainfalls in Yamaguchi and Shimane prefectures. Figure 9 introduces the typical example of river revetment adjacent drop structure for reconstruction after flood disaster.

Figure 9. Reconstruction of river revetment after flood disaster.

6 CONCLUSIONS

This method has been developed by Branch Block method study group from June 2005. The proposed method has the following advantages;

- Unnecessary big construction machines.
- Flexible to the undulation of ground condition.
- Friendly for surrounding ecology due to require no curing of concrete, and provide life space for small animals and fishes between void of stones.
- In case the method is adopted as river revetment, it is expected to provide rather stable and durable function than ordinary environmental friendly blocks due to use of natural stones and effect of turbulence by unique roughness of the surface of the structure.

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