Excavation countermeasures utilizing geocell at the foundation ground of the river embankment

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ABSTRACT: The embankment of the Kinugawa River collapsed in 2015, causing serious damage. It is ideal that river embankments are strong enough to resist overflow and washout. However, it is extremely difficult to develop structures that will neither allow overflowing nor break down, due to cost and plots. Therefore, it is necessary to promote the development of a tenacious river embankment, which can be reinforced with a low cost, in order to delay the washout even if the river overflows the embankment. By improving the tenacity of the embankment, we can earn time to evacuate in the event of a disaster. One of the factors that cause the collapse of the embankment after the overflow is excavation of the foundation ground of the slope toe of the embankment reverse side. A plan has been drawn to reinforce the foundation ground with large concrete blocks. However, it is considered that reinforcement of the foundation ground only with concrete blocks is not enough. Under such circumstances, it is considered that reinforcement using geosynthetics materials is effective. In the past studies, it has been confirmed that we can reduce excavation of the foundation ground by using geosynthetics materials. In this study, we conducted a comparative experiment on a reinforced case made of blocks only and a reinforced case combining blocks and geosynthetics materials. As a result, it was confirmed that the tenacity of the slope toe of the embankment reverse side was significantly improved by using the geosynthetics materials.

Keywords: embankment, geocell, measure method of excavation

1 INTRODUCTION

In Japan, due to the recent climate change, there have been a greater number of localized downpours. Because of this type of downpour, the embankment of the Kinugawa River collapsed in 2015. Such disasters can occur not only in the Kinugawa River but also in many rivers throughout the country. In addition, it is expected that the occurrence frequency of such disasters will increase due to climate change in the future, so it is considered necessary to promote improvement of river embankments as soon as possible.

Although it is ideal that the river embankment is absolutely free from overflowing or unbreakable, it is extremely difficult to equip the embankment that absolutely does not allow overflowing or break down from the relation of cost, site etc. Therefore, it is greatly significant to development of tenacious embankment structures that could prolong the time to break down even if the river should overflow it. One of the factors of the collapse of the embankment in the overflow state is the excavation of the foundation ground of the slope toe of the embankment reverse side. At present, a plan has been drawn to reinforce the foundation ground is being carried out using large concrete blocks. However, with only reinforcement using a large concrete block, there is concern that excavation of the foundation ground may occur due to fluid force or the like. The geocell is mainly used as a retaining wall and the foundation of structures etc., but it is seldom used as part of river embankment (Bush et al. 1990, Cowland & Wong 1993, Tatsuoka & Yamauchi 1986, Zhang et al. 2010). In this study, we used the geocell in order to prevent the foundation ground near the slope toe excavated, from being not to reinforce the river embankment itself. We carried out a model hydraulic experiment with the following two countermeasures on the foundation ground of the slope toe of the embankment reverse side. In Case A the foundation ground is reinforced with concrete blocks laid on it, and in Case B the foundation ground is reinforced with geocells and non-woven fabrics in addition to the concrete blocks. Comparing the experimental results, we examined the effect of the excavation countermeasure on the foundation ground of the slope toe of the embankment reverse side.

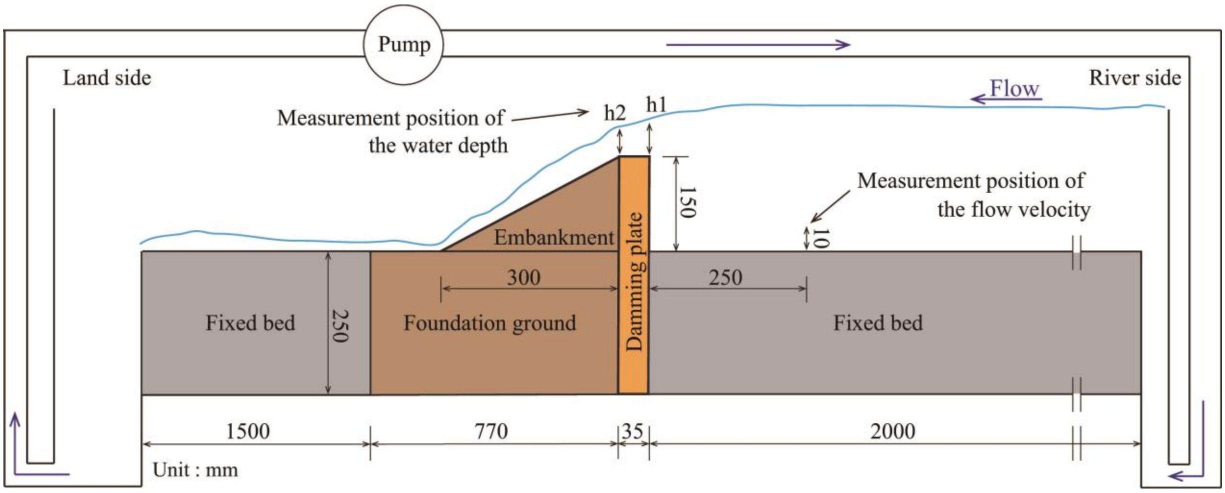


Figure 1. Outline of the open channel

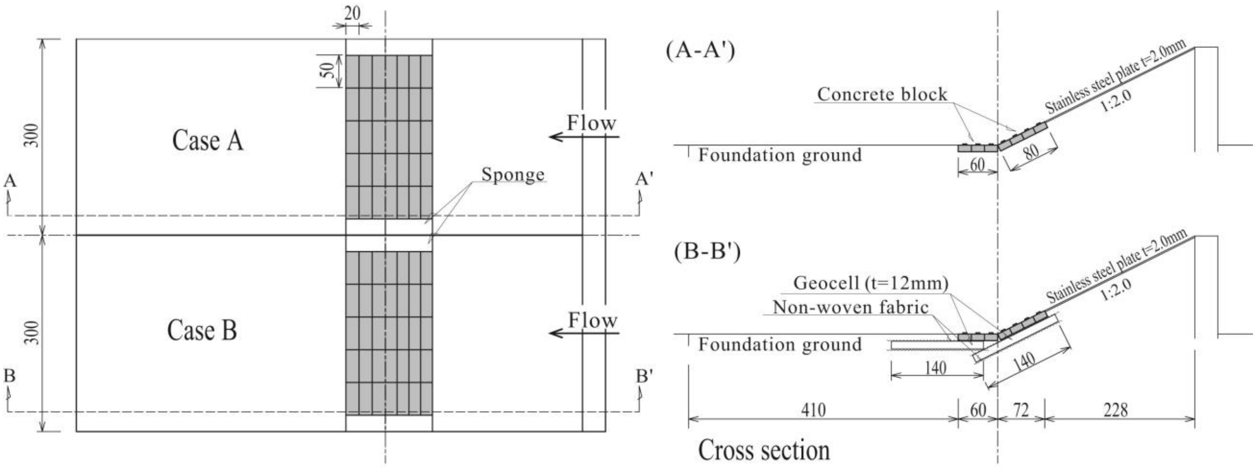


Figure 2. Outline of the experiment case

2 OUTLINE OF EXPERIMENTS

Figure 1 shows the outline of the open channel used in the experiment. The size of the open channel is 0.6 m in width, 11 m in length and 0.8 m in depth. We carried out the experiment by continuously generating a steady flow with a pump. Figure 2 shows the outline of the experiment case. Divided into two from the center part in the width direction of the open channel, and two cases of countermeasures were done at the same time in one experiment. And in consideration of experimental variation, we carried out the same experiment three times.

The model used for the experiment was assumed to be 1/25 scale. The foundation ground and the embankment were built using river sand from Towada City, Aomori Prefecture. The fundamental properties of the river sand used in the experiment are shown in Table 1, the grain size accumulation curve is shown in Figure 3. We build the foundation ground and the embankment that are performed excavation by 96% of target degree of compaction. In this study, in order not to assume the collapse of the embankment itself, the surface of the embankment covered with a stainless steel plate to protect the slope. Also, the friction coefficient of the surface of the embankment was made equal to the stainless steel plate of that of the foundation ground and the embankment by adhering river sand. The foundation ground was divided into two parts, for Case A and B, using a 400 mm high stainless steel plate. And the time spent generating steady flow was 5 minutes. The water depth and the flow velocity in the overflow state were measured using a wave height meter and a flow velocity meter, respectively. As a result, the water depth was 9 mm and the flow velocity was 3 cm/sec. When converting to the actual size from the similarity rule of Froude, the axial water depth is about 23 cm and the flow velocity is about 15 cm/sec. In addition, by measuring the ground height with a laser distance meter at 2 cm intervals before and after the experiment, the volume and the displacement of the foundation ground and the embankment scaled excavated by the overflow was approximately calculated. At that time, we removed the concrete block to measure the foundation ground and the surface of the embankment.

Table 1. Fundamental properties of the river sand

Items	River sand
Soil particle density (g/cm^3)	2.758
Minimum density (g/cm^3)	1.402
Maximum density (g/cm^3)	1.711
Maximum grain size (mm)	4.75
Mean grain size (mm)	0.70
Maximum dry density (g/cm^3)	1.72
Optimum moisture content (%)	17.1

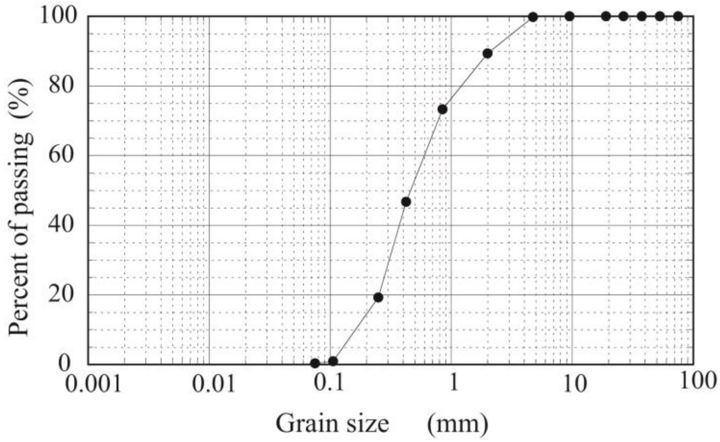
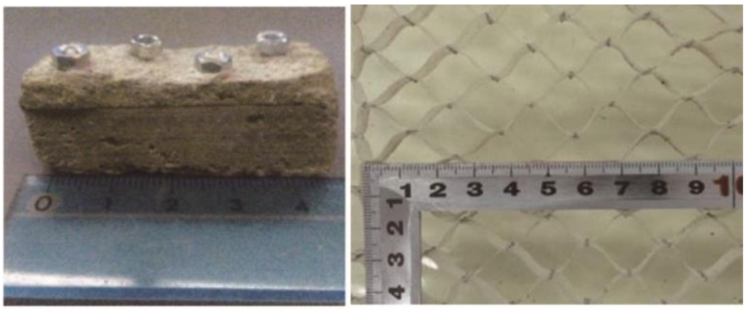


Figure 3. Grain size accumulation curve



a) Concrete block model b) Geocell model

Figure 4. Model of used materials

Figure 4 shows the model of the concrete block and the geocell used in the experiments. We used a model of concrete block with dimensions 20 x 10 x 50 mm with nuts adhered to its upper surface. The model of geocell was made using OHP sheet made of polypropylene with a height of 12 mm and a hole diameter of 20 mm assuming a height of 30 cm and a hole diameter of 50 cm in actual size. Crushed stone having a particle size of 4.75 to 9.5 mm was used for the filling material of the geocell, assuming a cobble stone having a particle size of about 100 to 250 mm. Silica sand No. 8 having a particle diameter of 0.05 to 0.15 mm was filled in the voids. On the boundary between the wall of the open channel and the concrete block, a sponge was installed to prevent arch action. In the case of laying a geocell, geocells were laid on the slope toe of the reverse side area of the embankment, with about 20 mm embedding. In addition, based on past experimental results (Oyama et al. 2015), a non-woven fabric was laid over and under the geocells to prevent the filling material from outflowing by suction. The non-woven fabric was substituted by wiping cloth.

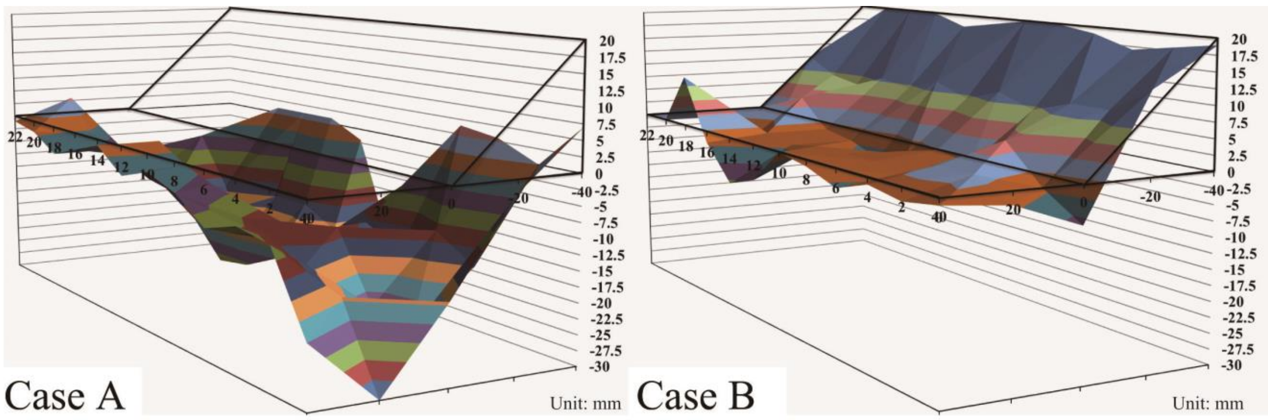


Figure 5. Three-dimensional representation of the foundation ground surface near the slope toe after an experiment

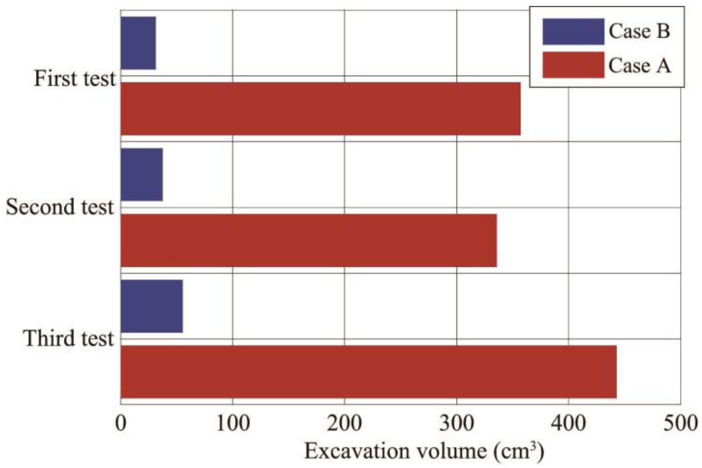


Figure 6. Volume of excavated sand

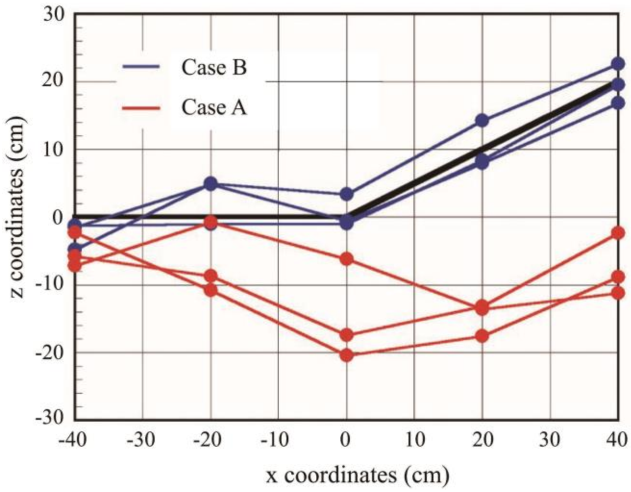


Figure 7. Average sectional view

3 RESULTS OF THE EXPERIMENTS

Figure 5 shows a three-dimensional representation of the foundation ground surface near the slope toe after an experiment. This figure was made based on the coordinates of each 60 points (5 points in the flow direction, 12 points in the width direction of the open channel) measured from the upper part of the open channel with the laser distance meter. In this figure, the left side is a typical example of Case A and the right side is a typical example of Case B. In Case A, the ground of the reinforcement part is largely excavated, whereas in Case B it can be confirmed that the excavation amount is small and keeps the topography before overflowing. In Case B, it is considered that the excavation amount could be reduced by the effect of restraining the soil particles by the geocell and the prevention effect of suction by the non-woven fabric.

Figure 6 shows the approximate calculation and comparison of the volume of excavated sand near the toe of the slope of the embankment reverse side at the time of end of each experiment. First, the vertical displacement of the measurement point was calculated from the vertical coordinates of the ground surface before and after the experiment, and the volume of the rectangular parallelepiped was obtained by assuming that the excavation volume was a typical value of square region with a side of 2 cm around each measurement point. Then, it was calculated by integrating the volume of the rectangular parallelepiped about all measurement points. From this figure, the excavation amount is about 300 cm^3 to 400 cm^3 in the Case A, whereas in the Case B the excavation amount is about 50 cm^3 even when it is excavated the most. It can be said that the excavation volume can be greatly reduced by reinforcing the foundation ground surface of the lower part of the concrete block by using both the geocell and the non-woven fabric.

Figure 7 shows an average sectional view, which is the foundation ground surface near the slope toe. It was obtained by averaging the displacements of measurement points in the width direction of the open channel in each experiment. In this figure, a black line is a sectional view of the ground before the experiment. In Case A, it can be confirmed that not only the part of the slope toe but also the lower part of the embankment was greatly excavated. Therefore, it can be said that when the foundation ground is reinforced by utilizing only the concrete blocks, the embankment is obviously unstable by excavation. On the other hand, in the case where the foundation ground under the concrete blocks was reinforced with the geocell and the non-woven fabric, only a little excavation occurred at the portion of 40 cm on the downstream side from the reinforced range. However, it is considered that it hardly affects the stability of the embankment even if this part is excavated. In conclusion, it can be said that it is possible to greatly reduce the instability of the embankment by reinforcing the foundation ground under the concrete blocks utilizing the geocell and the non-woven fabric.

4 CONCLUSION

In a series of experiments, it was shown that it could greatly reduce that excavation amount of the slope toe of the embankment reverse side, by reinforcing the foundation ground under the concrete blocks utilizing geocell and non-woven fabric when overflowing. As a result, it can be considered that the instability of the embankment can be prevented. It is considered that the excavation amount could be reduced by the effect of restraining the soil particles by the geocell and the effect of preventing suction by the non-woven fabric. In addition, excavation amount can be greatly reduced by combining geocell and non-woven fabric.

In future studies, a design method of river embankment should be established, by quantitatively evaluating the hydraulic conditions such as flow rate and flow velocity during the experiment.

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