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A Study on the Effect of Soil Constraint Filter used in Stone Mattress Revetment for Soil Erosion Prevention

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Abstract: Stone mattress is one of revetment structure installed in the river. This study validate the effects of soil constraint filter which is installed inside of stone mattress. Flood discharge condition was used in the fixed and movable bed hydraulic experiments. Slope and revetment river bed conditions also applicated to the hydraulic experiment model for the various flow conditions. In the movable experiment condition, existence of soil constraint filter were performed for analyzing the effectiveness of soil loss in the stone mattress. In the result, soil constraint filter installed condition shows the residual rate of soil increased more than that were not installed conditions. Constrained rate of soil in the slope and revetment bed conditions showed a dissimilar trend in the experiment at movable bed condition. It is considered that the soil loss in the stone mattress revetment influenced more on the high slope condition than on the supercritical flow with high froude number.

Key words: Soil constraint filter, stone mattress, hydraulic experiment, revetment, froude

INTRODUCTION

Revetment is a structure installed along the embankment to protect it from being eroded by heavy discharge in flood season and many types of revetment blocks have been developed in consideration of structural stabilization as well as plant recruitment in environmental aspect. Many researches on natural vegetation revetment technique are in progress to use eco-friendly revetment blocks on revetment sites (Lee and Lee, 2000).

Among many kinds of revetment techniques, Korean researches adopted the analytic hierarchy process by considering the stability, economic feasibility, construction and environmental performance that are most appropriate for Korean rivers (Lee and Lee, 2008) while applying the evaluation index of revetment developed through field surveys (Kim *et al*., 2007). Of particular note, the cost-benefit analysis showed that vegetation blocks and mattresses were more effective than any other revetment materials in designing close-to-nature rivers in Korea. The quantitative evaluation of environmental effects analyzed that gabion, retaining wall, crib, natural vegetation mattress had great influence on the environment of revetment while indicating the gabion as the most influential material with environmental advantages (Kim and Ahn, 2007).

This study attempted to verify the effects of soil constraint filter by conducting hydraulic experiments on stone mattress revetment which is one of eco-friendly revetment techniques using gabions. Soil constraint filter is a material produced by processing coir and net which is used within the stone mattresses of river revetment for plant recruitment and prevention of soil erosion. In general, the application of stone mattress technique has difficulty in plant survival due to soil loss incurred by the velocity of flood condition. Therefore, soil constraint filter was developed to prevent such soil loss and promote plant recruitment.

Many hydraulic experiments and on-site experiments have been performed on vegetation revetment under circumstances that plant recruitment is already completed. In these days, diverse researches are in progress to evaluate the stabilization of vegetation revetment under flood conditions (Kwon *et al*., 2013; Jang *et al*., 2014; Rhee *et al*., 2007). These researches focused on the stabilization of vegetation revetment while verifying the plant recruitment under supercritical flow conditions with a higher froude number. As plant recruitment requires the prevention of soil erosion from revetment blocks, the researches to decrease the velocity of flood condition in vegetation revetment blocks were conducted as well (Kim, 2006).

The ultimate objective of this study is to identify the soil erosion prevention effect of soil constraint filter used in stone mattresses. The study performed hydraulic model experiments under the same slope and revetment

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conditions as a real river to analyze hydraulic characteristics in relation to the existence of soil constraint filter. The study first established model theories for more accurate hydraulic experiments and then created a detailed model to perform hydraulic experiments on both the fixed and movable bed conditions. The results of hydraulic experiment would quantitatively suggest the expected effect of soil constraint filter when used in practice.

Prior to hydraulic model experiments, the study looked into stone mattress and soil constraint filter to collect data for preliminary experiments. The result of these preliminary experiments did not only determine the size and scale of model but set the conditions of hydraulic model experiments. The study measured the changes in the velocity of flood condition through fixed bed experiment and examined the appropriateness of experimental result while performing sediment analysis through movable bed experiment. To recreate the real flow of water in the fixed bed model, the geometric similarity between the original structure and model should be met and both the froude and reynolds laws of similarity should be met to satisfy dynamic similarity. Applying the froude similarity, the study created a fixed bed model at a ratio of one to four (model to original structure) by downsizing the horizontal and vertical scales of stone mattress and soil constraint structure at the same rate.

During the fixed bed experiment, hydraulic experiment took place under the conditions that soil constraint filter were used in stone mattresses with no sediment filled in the model. Considering the roughness of stone mattress and soil constraint filter installed on the river bed of hydraulic experiment apparatus, detailed analysis was performed on the fluid flow by measuring its depth and velocity. Then the study examined the influence of the gravity and inertial force of fluid flow within the experimental section by analyzing froude number. The result of this experiment revealed the characteristics of fluid flow on the fixed river bed and became basic data for the analysis of movable bed experiment.

During the hydraulic model experiment at movable bed condition, distorted models are often used to realize the tractive force. Therefore, the model should be verified to confirm the model's hydraulic similarity with the original structure. The experiment conditions are divided by use of soil constraint filter and standard sand was laid inside the stone mattresses and soil constraint filter to measure the height of remaining soil after a certain time period of fluid flow. In addition, the study figured out and suggested the amount of sediment loss by applying the data of fixed bed experiment on the depth and velocity of water and the particle size distribution curve of the soil used in the sieving experiment to rottner formula.

MATERIALS AND METHODS

Similarity and experimental setup

Similarity for the models having fixed and movable bed materials: The fixed bed experiment is applied to the case of flowing river if the river bed is stabilized and the influence of sediment transport or changes in the river bed is deemed insignificant. The major issues studied in the fixed bed experiment are the backwater effect caused by obstacles in the waterway or modification of waterway, flood routing, discharge distribution of waterway at the mouth of river. The study's experiment was conducted on open channel with the froude law of similarity applied. The study established a model theory, supposing that Manning's mean velocity formula was applied in both the original structure and model to maintain their similarity (Henderson, 1966):

,F-r.=,,F-p.-,F-m.. = 1 (1)

Where:

m = The model
p = The original structure
r = The ratio of original structure to model

The following Eq. 2 can be obtained if ,g-r. (rate of gravity) is 1:

,,U-r.-,-,g-r.,L-r... = 1 or ,U-r. = ,,L-r.-1/2 (2)

Where:

,,U-r. = The rate of flow velocity
L_r = The rate of standard length

To create a model that corresponds with the similarity such as sediment discharge and the variation of river bed for conducting the model experiment at movable bed condition, horizontal and vertical scales, specific gravity of model material and the scale of particle size should not be decided randomly but determined by certain relations.

Basically, the model experiment on open channel has to satisfy the froude similarity factors which are not satisfied in some cases of model production. Henderson (1966) suggested that the degree of freedom in deciding the scale of model can be increased by having the froude number of 0.3 for original structure and the froude number of 0.4 for model in the case of deep water (i.e., small froude number) (Henderson, 1966). The froude similarity factor can be mitigated as follows (Chow, 1965):

,,U-r.,Y-r.-1/2. = ΔF (3)

Where:

,,U-r. = ,U-p./,U-m
,,Y-r. = ,Y-p./,Y-m

are defined as rates obtained by dividing the quantity of original structure by that of model. $\Delta F = 1$ refers to the accurate similarity and the similarity condition can be mitigated by having a little lower or higher value of ΔF than 1.

To calculate the sediment discharge, it is necessary to set related variables for analyzing the flow characteristics of alluvial river from the current aspect of river maintenance such as flood and irrigation management and determine in what conditions these variables are applied dependently and independently. Rottner defined the discharge of bed load as the ratio of particle size to depth of water, i.e., a function of relative roughness as follows:

$$q_{sb} = r_s\left[(s-1)gd^3\right]^{1/2} \times \left\{ \frac{v}{\sqrt{(s-1)gd}}\left[0.667\left(\frac{D_{50}}{d}\right)^{2/3} + 0.14\right] - 0.778\left(\frac{D_{50}}{d}\right)^{2/3} \right\}^3 \quad (4)$$

Where:

- q_{sb} = The bed load discharge per unit meter
- s = The slope of bed
- g = The gravitational acceleration
- v = The mean velocity
- D_{50} = The central particle diameter
- s = The r_s/r which is the unit weight ratio of soil particle to water

Experimental setup for the effects of soil constraint filter: The study created a waterway model at a ratio of one to four (model to original structure) by downsizing the horizontal and vertical scales of original waterway with stone mattresses installed on both revetment sides at the same rate and carried out the hydraulic model experiment on a straight 4.2 m waterway section (17 m of original waterway). The sizing of model was determined by considering the experimental space and theories for hydraulic model. The study used a 20 m-long, 2 m-wide and 1 m-high open channel apparatus. This hydraulic experiment apparatus can supply water at maximum 0.21 m^3/sec.

Installation of slope device and soil constraint filter: To identify the effect of soil constraint filter under the rapid velocity of water, slope device was installed. Figure 1 shows how the slope device and soil constraint filters were installed. The slope device with an inclination of 1:0.5 were attached to the open channel where revetments were installed on both sides and covered by wire mesh for further installation of cobble stones as mattresses and soil constraint filter. Then, cobble stones and soil constraint filter were installed at certain intervals, covered by wire mesh and non-slip devices were installed on both ends.

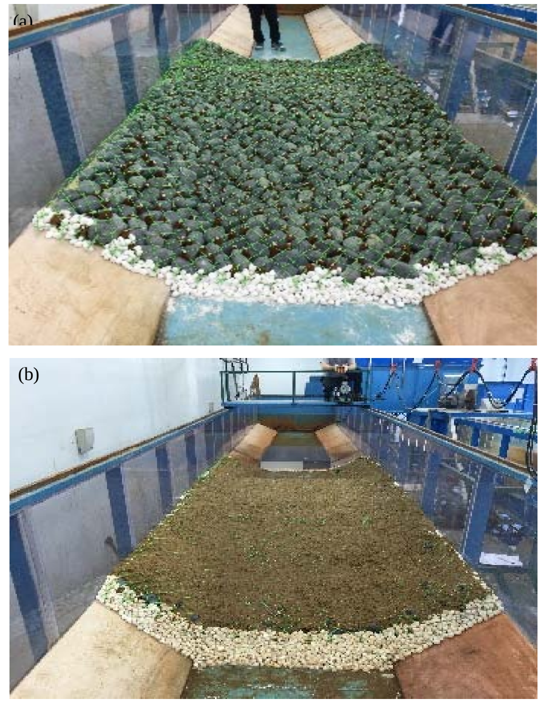

Fig. 1: Installation of slope model for supercritical condition: a) Installation of stone mattress, soil constraint filter and b) View of soil laid on channel

Installation of revetments and soil constraint filter: The revetments with a slope of 1:0.5 was installed on both ends of the waterway with slope device uninstalled condition. Soil constraint filters were installed on both revetment sides and at the center of waterway to analyze the effect of soil constraint filter. Figure 2 shows how revetments and soil constraints filter was installed. The study covered wire mesh on the open channel where revetments with a slope of 1:0.5 are installed on both sides.

Soil constraints were made by processing coir and net into a roll shape. When the stone mattress technique is applied, the velocity of flood condition may cause soil loss between ripraps before plant recruitment starts. Soil constraints does not only control the loss of soil occurring on impingement and erosion parts and any other parts where the width of river is changed but have a drainage function that helps plant recruitment progress smoothly. The shape of soil constraint comprises a cylindrical, empty central part and materials with large gaps. Figure 3 shows the shape of soil constraint installed within stone mattresses.

Fig. 2: Installation of revetment model for subcritical flow condition: a) Installation of stone mattress, soil constraint filter and b) View of soil laid on channel

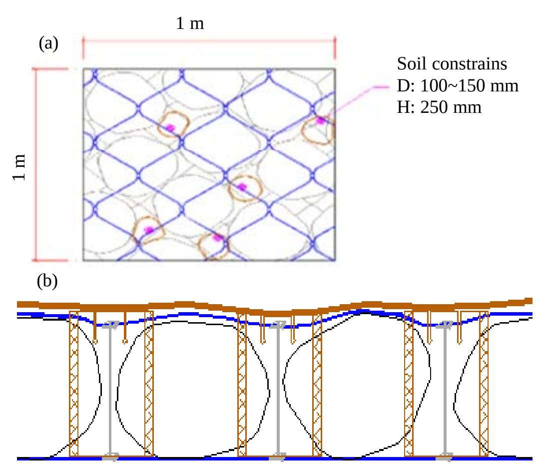

Fig. 3: Specification of soil constraint filter: a) Plane figure and b) Cross section

Analysis of hydraulic characteristics through the experiments having the fixed bed material

Experiment conditions and methods: The experiment was mainly performed under two conditions; installation of within the river with revetments on its both sides and installation of revetment on the plane river bed with no slope installed. Each of these conditions is subdivided into three discharge conditions, making a total of six experiment conditions. The discharge ranges from the slope experiment's maximum discharge to two thirds and one third of maximum discharge. Table 1 shows the conditions of hydraulic experiment at fixed bed.

During the experiment with the slope installed condition, the depth and velocity of water were measured at 45 points. The central part of waterway, left bank and right boundary equally had 15 measuring points (A-O). Figure 4 indicates the measuring points in this experiment.

During the experiment with revetment condition, additional measurements took place along the boundary surface where revetment starts. Therefore, the depth and velocity of water were measured at total 75 points of five sections. Figure 4b indicates the measuring points of this experiment.

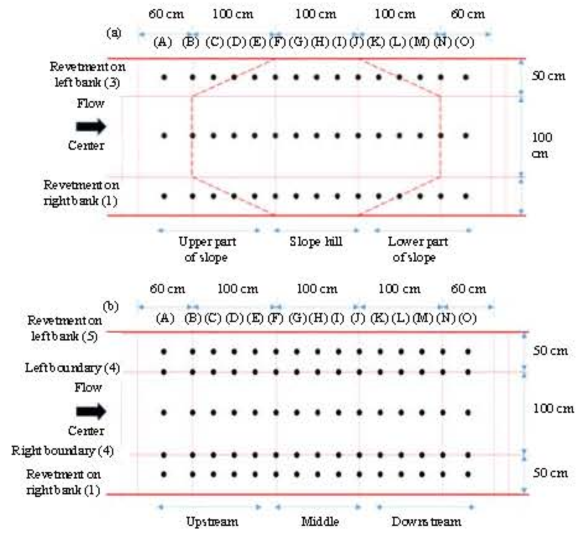

Fig. 4: Measuring points under 'slope' and 'revetment' conditions: a) Slope condition and b) Revetmen (no-slope) condition

Table 1: Conditions of hydraulic experiment at fixed bed

Classifications	Experiment conditions: Condition of stone mattresses	Discharge condition (m/sec)
C1	Slope installed	0.07
C2		0.14
C3		0.21
C4	Slope uninstalled	0.07
C5		0.14
C6		0.21

Comparison of hydraulic characteristics through fixed bed experiment: Figure 5 shows the depth and velocity of water and the distribution chart of froude numbers at the discharge of 0.21 m^3/sec. The measurement showed that

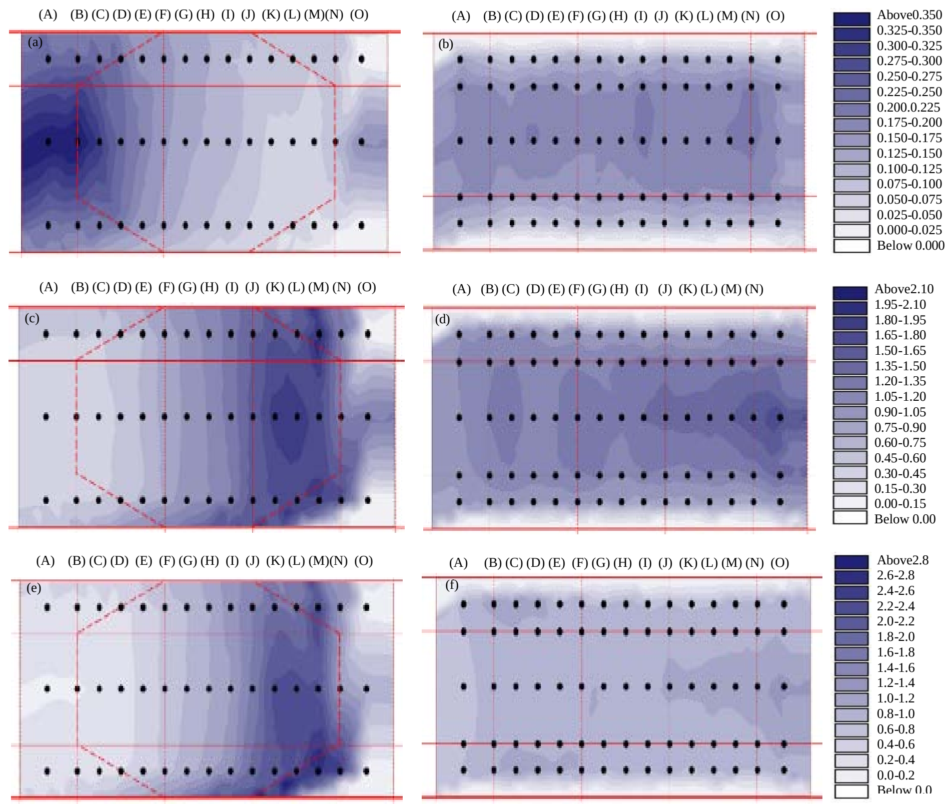

Fig. 5: Result of fixed bed experiment at 0.21 m^3/sce condition: a) Water depth-slope condition; b) Water depth-revetment condition; c) Velocity-slope condition; d) Velocity-revetment condition; e) Froude numbers-slope condition and f) Froude no-revetment condition

the upper part of slope had a higher depth of water due to its inclination while the depth of water was lowered beyond the slope hill. The central part had a higher depth of water due to the revetment sides of right and left banks. The depth of water of the point O appeared higher than any other flow conditions, showing the effect of water conveyance was relatively higher than any other flow conditions.

From J-M sections where the lower part of slope started, the froude numbers were relatively higher, the section M of left and right banks and the point L of central part showed maximum froude numbers. The point L was the center of lower part of slope and it was considered that the overflowing water received maximum acceleration at this point. Especially, the section L on the central part of waterway showed a considerably strong supercritical flow with froude numbers of 2.18-2.62 which was considered the best comparison point to assess the effect of soil constraint filter.

In the experiments with the slope hills removed, measuring points were added on the river bed and along the boundary side of revetment. The depth and velocity of water were measured at five points from each cross section. Compared to slope inclination conditions, the overall waterway showed stable water flow, showing the froude numbers <1, except some sections in which supercritical flow occurred at the maximum discharge condition. Considering the 1:4 ratio of model to original structure, the discharge ratio was 1:2 in the real river and the maximum water velocity was 3.6 m/sec under the maximum discharge condition which could be considered the flood condition with the froude number approximately equal to 1.

The effects of soil constraint filter through movable bed experiment under the conditions of supercritical flow: In the movable bed experiments, the study selected boundary conditions under the supercritical flow conditions (slope installed) and subcritical flow conditions (slope uninstalled) same as fixed bed experiments. Then, the study examined the effect of soil constraint filter by laying the selected sand. The river bed materials used standard sand whose central particle size is 0.91 mm. The time of water supply was 10 mins which can vary with froude similarity up to 20 min in actual situation.

The movable bed experiment was performed under total 12 cases with supercritical and subcritical flow conditions. Table 2 shows the supercritical flow conditions which is slope installed in the stone mattress. New conditions such as installed or unistalled soil constraint filters were added to the previous fixed bed experiment. The sand was laid on the entire section (8.4 m^2 wide and 9 cm deep) where stone mattresses were installed.

Table 2: Conditions of hydraulic experiment at movable bed condition under supercritical flow

	Experimental conditions		
Classification in cases	Stone mattress condition	Conditions of upper mesh, soil constraint filter, fixation pins	Discharge condition (m/sec)
1	Slope installed	Installed	0.07
2	-	-	0.14
3	-	-	0.21
4	-	Uninstalled	0.07
5	-	-	0.14
6	-	-	0.21

RESULTS AND DISCUSSION

Results of experiment on supercritical flow condition: In the experiment with slope conditions, the lower part of slope where the fastest velocity of water was formed showed a distinct difference as to whether soil constraint filter was used or not. The amount of soil loss decreased when soil constraint filter was used compared to when they were not used, implying the effect of soil constraint filter. Figure 6 is the plane figure that indicates the height of sand in cases 1-6 after completion of experiment. Under the condition that soil constraint filter was installed, the experiment showed a tendency that scouring phenomena increased in tandem with the increase of discharge on the slope hills and on their lower parts whereas the soil loss increased on the lower part of slope when the discharge increased under the condition that soil constraint filters were removed. When compared to soil constraint filter installed condition, the loss of soil increased in all sections including slope hill, lower part of slope and bottom part of slope, except the hills on upper river section.

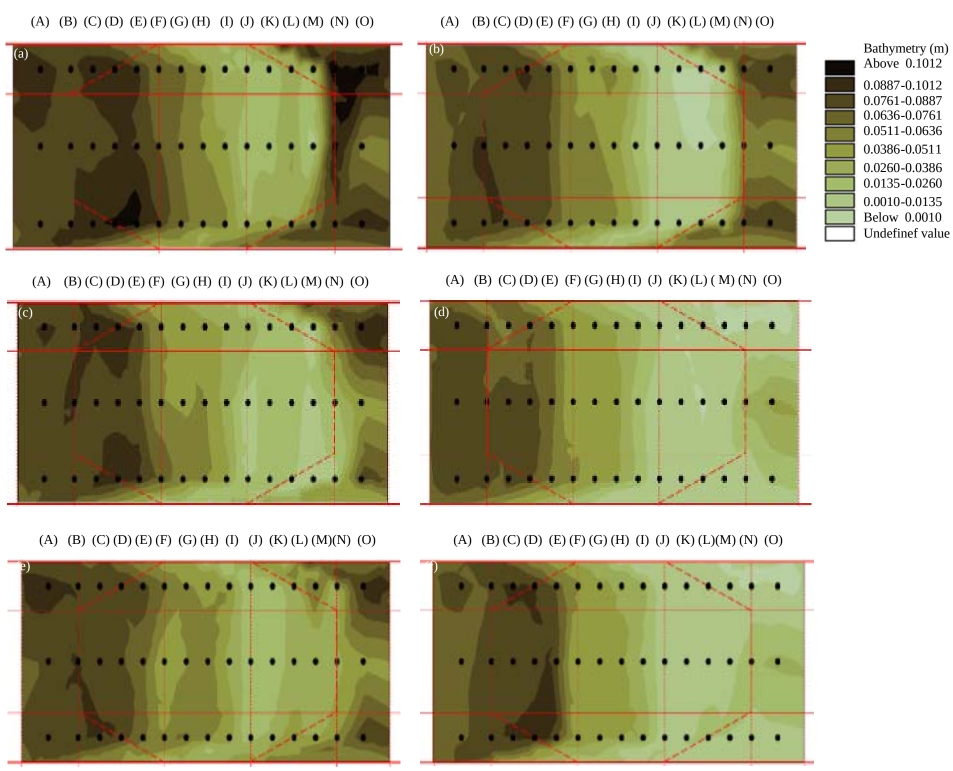

Fig. 6: Comparison of the height of remaining sediment under slope condition: a) 0.07 m^3/sec, soil constraint filter installed condition; b) 0.07 m^3/sec, soil constraint filter uninstalled condition; c) 0.14 m^3/sec, soil constraint filter installed condition; d) 0.14m^3/sec, soil constraint filter uninstalled condition; e) 0.21m^3/sec, soil constraint filter installed condition and f) 0.21 m^3/sec, soil constraint filter uninstalled condition

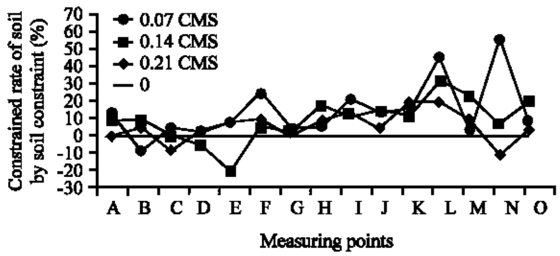

Fig. 7: Comparison of constrained sand moduli at measuring points under slope condition

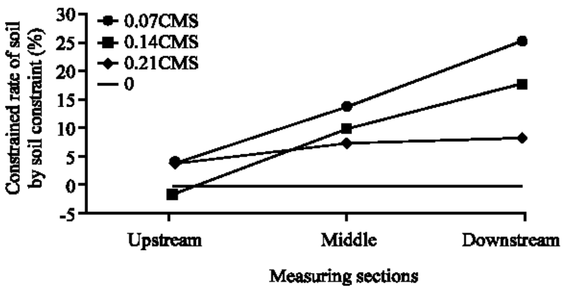

Fig. 8: Comparison of constrained sand moduli at individual sections under slope condition

Analysis of the constrained rate of soil: Figure 7 is the result of comparing constrained rate of soil at the measuring points of central part under individual discharge conditions. The constrained rate of soil would be 100% if there was no soil loss based on the result of measuring the height of remaining sand before and after the experiment. The experiment showed little effect of soil constraint filter in the upper part of slope where the velocity of water was low and almost no scouring phenomena occurred which means the constrained rate of soil increased as soil constraint filters were installed on the hill and lower part of slope. Looking at the effect of soil constraint filters under various discharge conditions, maximum 56.7% of sand was constrained at the point N when the discharge was 0.07 m^3/sec, maximum 32.2% of sand at the point L at the discharge of 0.14 m^3/sec and maximum 20% of sand was conserved by soil constraint filters at the points K and L at the discharge of 0.21 m^3/sec.

Figure 8 is the result of analyzing each experimental section categorized into upper, central or lower river. In the case of upper river with a lower water velocity, the constrained rate of soil was within ±5% which rose at the central and lower river. When the discharge was 0.07 m^3/sec, forming a low water level, the analysis showed a high constrained rate whereas it showed a low constrained rate of soil constraint filter at the maximum flow of 0.21 m^3/sec. The highest constrained rate was shown at the lower part of slope where the fastest of flow was formed.

Table 3: Conditions of hydraulic experiment at movable bed condition under subcritical flow

	Experimental conditions		
Classification in cases	Stone mattress condition	Conditions of soil constraint filter	Discharge condition (m/sec)
7	River bed (revetment) installed	Installed	0.07
8			0.14
9			0.21
10		Uninstalled	0.07
11			0.14
12			0.21

The effects of soil constraint filter through movable bed experiment under the conditions of subcritical flow: The movable bed experiment under condition of subcritical flow was performed under 6 cases. Table 3 shows the subcritical flow conditions which is slope uninstalled in the stone mattress. New conditions such as installed or unistalled soil constraint filters were added to the previous fixed bed experiment.

Results of experiment on subcritical flow condition: Figure 9 is the plane figure that indicates the height of remaining sand in cases 7-12 after completion of experiment. Not a great change was found in all measuring points in cases 7-9, under the condition that soil constraint filters were installed on both sides of revetment and the central part of waterway. The maximum velocity of water being formed at a lower point compared to the revetment condition, little loss of soil occurred which implied that use of soil constraint filter effectively prevented the loss of soil. In cases 10-12 where soil constraint filters were removed from the revetments on both sides of river bed, the amount of scour gradually increased due to the increase of discharge. The heights of remaining sand in cases 7-9 were higher than those in cases 10-12.

Analysis of the constrained rate of soil: Figure 10 is the graph comparing constrained rate of soil from each measuring point of central part with each discharge conditions. The constrained rate of soil by use of soil constraint filter increased when the dischage increased. Looking at the effect of soil constraint filter under individual dischage conditions, maximum 20.9% of soil was constrained at the point N when the discharge was 0.07 m^3/sec, maximum 20.4% of soil at the points D and J at the discharge of 0.14 m^3/sec and maximum 37.3% of soil was conserved by soil constraint filter at the point O at the discharge of 0.21 m^3/sec.

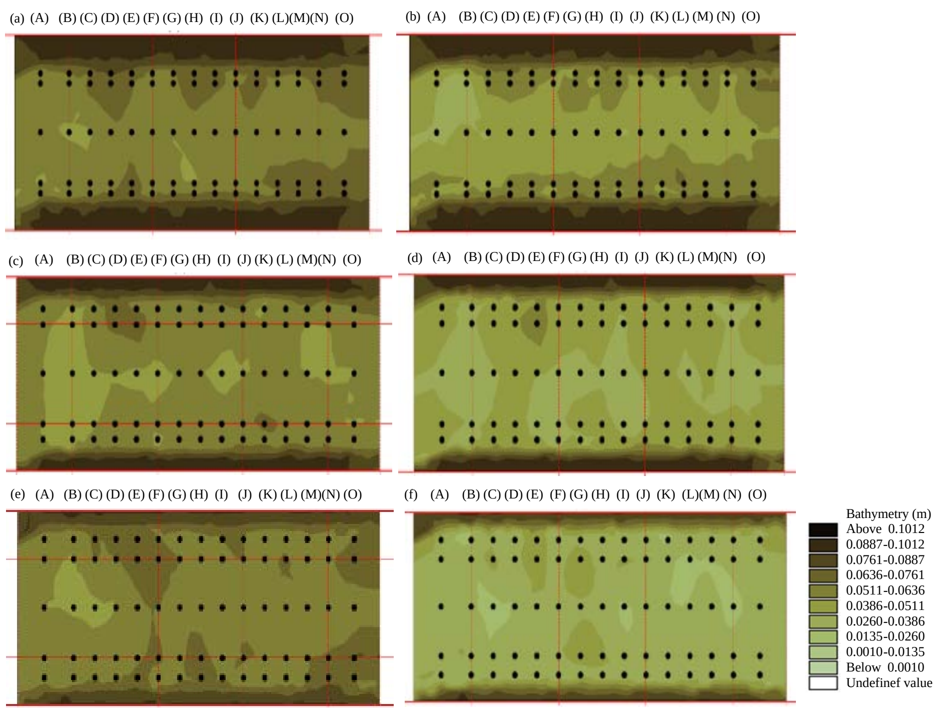

Fig. 9: Comparison of the height of remaining sediment under revetment condition: a) 0.07 m^3/sec, soil constraint filter installed condition; b) 0.07 m^3/sec, soil constraint filter uninstalled condition; c) 0.14 m^3/sec, soil constraint filter installed condition; d) 0.14 m^3/sec, soil constraint filter uninstalled condition; e) 0.21 m^3/sec, soil constraint filter installed condition and f) 0.21 m^3/sec, soil constraint filter uninstalled condition

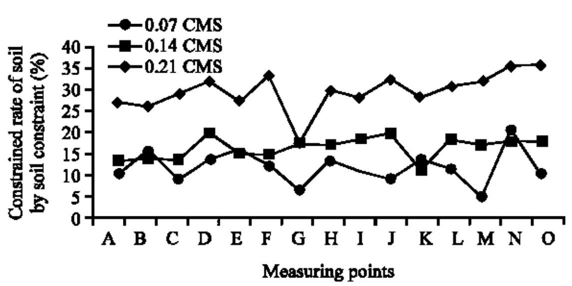

Fig. 10: Comparison of constrained sand moduli at measuring points under revetment condition

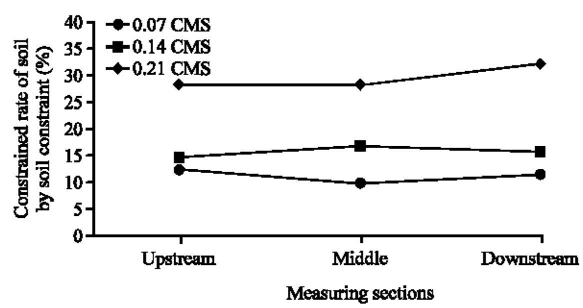

Fig. 11: Comparison of constrained sand moduli at individual sections under revetment condition

Figure 11 is the result of analyzing each experimental section categorized into upper, central or lower river. All cross sections showed a similar range having no much difference between the upper, central and lower parts of river. The constrained rate of soil constraint increased when the discharge was incresed. The experiment showed that soil constraint filter prevented soil loss approximately by 10-34%.

Calculation: Rottner, Schoklitsch, Duboys and Einstein formulas are mainly used as a formula of calculating the sediment transport. The study used the inflow discharge for experimental upstream boundary condition, the the velocity and depth of water calculated through hydraulic experiment at fixed bed, the amount of sand loss calculated through experiment at movable bed condition, the particle diameter of sand grain (D_{50}) used on experiment at movable bed condition and the unit weight of sand particle. Among the above formulas, the study chose the rottner formula to which all the aforementioned factor could be applied and calculated the discharge of bed load by using this formula.

Rottner developed the formula to express the discharge of bed load in terms of the flow parameters based on dimensional and empirical coefficients. Rottner

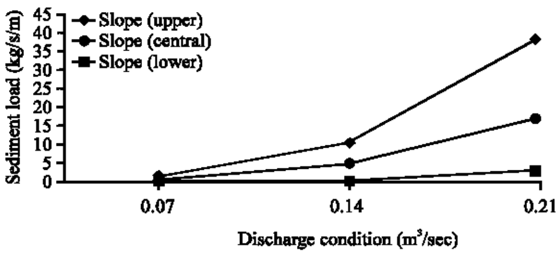

Fig. 12: Calculation of sediment discharge by Rottner formula under slope condition

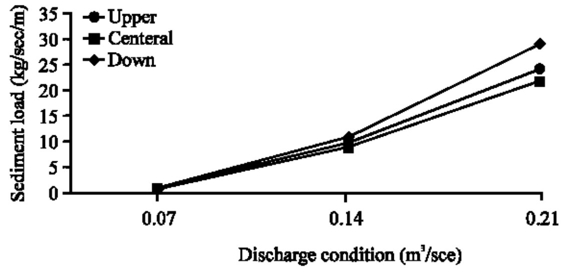

Fig. 13: Calculation of sediment discharge by Rottner formula under revetment condition

applied a regression analysis to determine the effect of a relative roughness parameter D_{50}/d (central particle size/depth of water) as seen in Eq. 4 in Chapter 2. According to this theoretical formula of bed load discharge, the unit of sediment discharge is expressed as kg/sec/m, referring to the sediment discharge of unit width in kg per second. The calculated amount of soil loss was conveyed for 10 min in the experiment, yet the exact period of time for sediment transport could not be obtained as the river bed under both of slope and river bed conditions entered the stabilization phase within 10 mins. Moreover, the formula assumes that a certain discharge of bed load occurs by lapse of time which has different characteristics from the soil loss calculated from the study's experiment at movable bed condition.

Experiment on slope conditions under supercritical flow: Under the slope condition, the sediment load calculated by rottner formula can be seen in Fig. 12. The factors used in the formula were the unit weight of sediment, specific gravity of sediment, acceleration of gravity, depth of water, velocity of water and particle size (D_{50}). For the depth and velocity of water, the study used the values measured from the experiment at fixed bed and applied the value calculated from the sieving experiment to the particle size (D_{50}).

The result of Fig. 12 shows that a big difference is made in sediment load according to the discharge conditions. When the slopes of upper, central and lower parts of river were compared, an increase of discharge by 0.07 m^3/sec expanded the difference of sediment discharges by 14 times at maximum and the soil loss increased nearly 7 times on average. Particularly in the lower part of river, the sediment load increased rapidly according to the discharge conditions.

Experiment on river bed (revetment) conditions under subcritical flow: Figure 13 shows the sediment load calculated by rottner formula under revetment condition.

The result of Fig. 13 shows that the revetment condition also made a big difference in sediment load according to the discharge conditions. When the slopes of upper, central and lower parts of river were compared, an increase of discharge by 0.07 m^3/sec expanded the difference of sediment discharges by 9 times at maximum and the soil loss increased nearly 5 times on average. However, unlike the slope condition, the difference between upper, central and lower parts of river was not that big. The sediment load increased as the discharge increased.

In the case of theoretical formula of calculating the sediment load, the amount of soil loss is calculated by second unit. In the real experiment, it is difficult to measure the amount of soil loss in real time after the water is conveyed. Therefore, the amount of soil loss measured in the initial stage is considered appropriate for comparison with the theoretical formula. There are also some limitation in comparing the result of experiment with the formula which does not take stone mattress and soil constraint filter into account. The formula is based on the assumption that the river bed only consists of soil but it can become an index to analyze the effect of soil constraint filter and stone mattresses.

CONCLUSION

The objective of this study is to identify the soil erosion prevention effect of soil constraint filter used in the river bed. The study performed fixed and movable bed hydraulic experiments for comparison of soil loss in relation to the use of soil constraint filter. Also the soil erosion by theoretical bed load formula was compared with the results by experiments. The following conclusions were obtained based upon the comparison between the experiments using the soil constraint filter used in stone mattress revetment and the experiments without it.

First, the decreasing rate of soil erosion resulting from the experiments having the soil constraints is clearly indicated even though the rate is different depending upon the discharge as well as the froude number. The decreasing rate of the soil erosion is changed from 20-56.7% in the maximum depth depending upon the froude number from 2.18-2.62. However, the points indicating the maximum decreasing rate is indicated at the junction area between the channel bed and the bottom of the inclined slope of revetment.

Second, the decreasing rate of soil erosion is changed. Under the supercritical flow condition, the constrained rate decreased when the discharge increased while the constrained rate increased when the discharge increased under the revetment condition in the subcritical flow. In the experiment at fixed bed, the velocity of water and froude number showed a trend to rise in tandem with the increase of discharge in both of supercritical and subcritical flow condition while the constrained rate of slope and revetment showed a different trend in the experiment at movable bed condition.

Third, maximum froude number is indicated in the points of downstream of slope bed. Bed load calculated from Rottner's theoretical formula on sediment discharge revealed that supercritical flow was more affected from discharge and slope. The results from formula show that bed load in supercritical conditions has variety from discharge conditions but subcritical flow conditions show the similar range of bed load from same discharge as supercritical flow conditions.

In the actual river, complex shape of stone mattress can cause the occurrence of complicated tubulant flow and the result of measurement may have a large margin of error compared to the flat river bed. The following study will investigate on the flow of turbulent flow against the complex shape of stone mattress. It is expected that the study will draw a more precise experimental result if the tractive force of stone mattress is considered in combination with the establishment of a numerical model.

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