Revetment Failure Tests in the River Experiment Center

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Abstract

The River Experiment Center (REC) at Korea Institute of Civil Engineering and Building Technology (KICT) is a real scale river experiment facility conducting R&D for river environments and flood response. Located floodplain of the Nakdong River, one of the largest rivers in Korea, the Center has over the total area of 193,051 m^2 and three prototype channels with 600 m long and 11 m wide. Artificial floods are generated by large capacity pump with flow rate 10 m^3/sec and the maximum velocity generated in the channel is over 5 m/sec. In the study several kinds of environmentally friendly revetments have been tested to find failure patterns and stability limits. Tested revetments are two kinds of concrete blocks with vegetation hole and two kinds of vegetation mats. Test procedure is referred to ASTM (D 7277, D 7276 and D 6460). Real scale revetments are installed in a steep sloped zone of the test channel. Water elevations and velocities are measured in each flow condition to determine the energy slopes. Bed changes in each flow conditions are measured by 3D Lidar and they are used to evaluate the failure condition. From the tests allowable shear stresses and failure patterns of the revetments are suggested. In the concrete blocks with vegetation hole, most damages are happened from the local scour in the vegetation holes. Vegetation mats reinforced by wire mesh show relatively high allowable shear stress.

Keywords: River Experiment Center, Real Scale Test, River Revetments, Vegetation Mats, Allowable Shear Stress

1 Introduction to the REC

The River Experiment Center (REC) is one of the largest river experimentation facilities in the world. The REC was constructed in 2009 and has a total area of 200,000 m^2 (Figure 1). The main facilities are three prototype channels that were designed to study a wide range of stream characteristics with dimension of 600 m long and 11 m wide. Large capacity pump facility supplies a controllable flow rate up to 10 m^3/s and a flow velocity up to 5 m/s.

Channel No. 1 has a steep reach with sharp bends (slope of 1:80) to create super critical flows for stability tests under extreme conditions. The sharp bends also allow a consideration of oblique flow direction. After the steep reach, the channel has a mild slope (slope of 1:1000) with sandy bed. Channel No. 2 is a straight channel with a compound section, which allows for studies representing floodplain interactions. The one-sided floodplain is located in the 150 m long downstream of the channel. The base width of the floodplain is 6.5 times greater than the bed width of the main channel. Channel No. 3 is a meandering channel with various degrees of sinuosity to represent different river dynamics. Along the channels, crossing instrumentation carriages moving over rails are equipped for accurate measurements.

Figure 1. Overview of the REC.

2 River revetments in Korea

River revetments should supply levee and bank protection from erosion and scour in design flood. In Korean river design criteria revetments are selected by experiences considering shear stress, durability and environments.

There are many types of river revetments applied to protect river levees and banks. These can by classified to major five kinds such as natural vegetation, vegetation mats, concrete blocks, stone type, gabion, and, crib type.

By the activation of environment-friendly river works, application of eco-friendly products has increased. Thus damages of these type revetments have also increased recently. Although application of the eco-friendly products in river works have increased, the allowable shear stress or the allowable velocity of the revetments are not usually suggested and there is no standard method to determine the allowable shear stress or the allowable velocity. In ASTM standards (American Society of Testing Materials) determination procedures for the allowable shear stress and velocity are presented through hydraulic tests.

3 Hydraulic stability tests of revetments

3.1 Test reach

In this study several types of revetments are tested and their hydraulic stabilities are presented. The real scale hydraulic tests are conducted in upstream of REC channel No. 1. Total length of the channel is 594 m and the test reach is 100 m long upstream of the channel (Figure 2 and Figure 3). Bottom width of the channel is 3 m, and the test revetments are installed with basis beds. All the test procedures are conducted with ASTM standards.

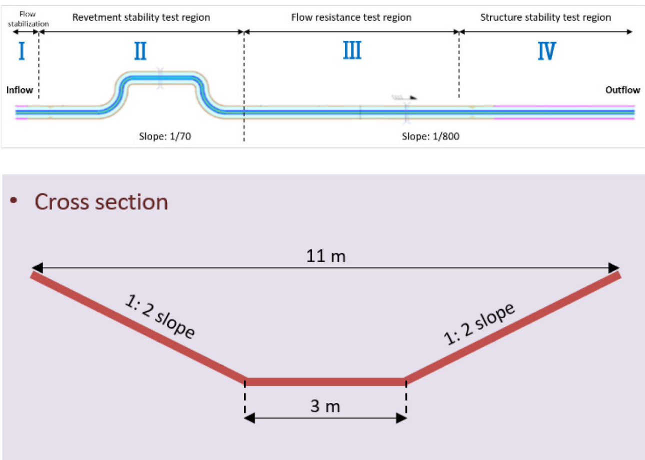


Figure 2. Shape of channel No. 1.

Figure 3. Test reach in channel No. 1.

3.2 Block Revetment Tests

Two types of concrete block revetments and two types of vegetation mat revetments are tested. The block revetments have the opening for vegetation and these types of block revetments are usually used to protect levee from scouring and to make environmentally friendly levee with vegetation. However, these revetments take damages from the sour usually caused in the opening holes. Specifications of the tested blocks are presented in Table 1. Two blocks have similar shapes and differ in the size and weight.

The block revetments are installed in the bed of the test channel and the test reach is 3 m wide and 10 m long. Firstly soil subgrade with 0.3 m depth is constructed with sand and silt then compacted. Geotextile and blocks are installed on the soil subgrade and then the openings of the blocks are filled with gravel and sand. This condition represents usual revetment condition before the vegetation recruitment.

Before the test, bed elevations of the constructed revetments are measured. Flow discharges are measured from the volume change of the inflow reservoir with constant pumping condition and the discharges are compared with measured data from channel water elevation and velocity. The difference of the discharges of the reservoir measuring and channel measuring shows about 10 %.

Hydraulic stability tests of the revetments are conducted with a continuous four-hour flow over the revetments at a uniform discharge. During the tests water elevation and velocity are measured along the center-line of the channel at 1m interval. After each tests, changes of the bed and opening holes are also measured. Installation and test procedures are presented in Figure 4.

Table 1. Specification of the test blocks.

Type	Block A	Block B
Dimension (mm)	500x500x100	1000x1000x200
Weight per unit	45 kg	380 kg
Opening ratio	0.23	0.21
Shape		

Figure 4. Installation and test of block revetments

Hydraulic stability tests for two types of blocks are conducted with discharge conditions of 3.48 m^3/sec and 5.02 m^3/sec. The results of tests are presented in Table 2 and Table 3. Revetment conditions after the tests are presented in Figure 5 and Figure 6. Roughness and shear stresses are calculated from measured water elevation and discharge. In all the tests, filling materials installed in block opening holes at initial condition have been totally lost during the tests as shown in figures.

In same discharge condition, Type B block shows relatively low roughness and this is reasonable considering size and shape of the blocks. Due to low roughness, Block B is exposed to relatively low shear stress in a same flow condition. Mean bed change is the elevation difference of block's concrete part before and after the test and it means the settlement of blocks caused by the loss of the subgrade soil under geotextile. As shown in the Table 2 and Table 3, mean bed changes is proportional to shear stress and higher change is shown in the type B, which is caused by the larger opening although Type B has twice thickness of Type A.

(a) Block A before the test

(b) Block A after the test

Figure 5. Revetment condition (Block A)

(a) Block A before the test

(b) Block A after the test

Figure 6. Revetment condition (Block B).

Table 2. Results of the test (Block A).

Case	Case A01	Case A02
Discharge (m^3/sec)	3.48	5.02
Mean depth (m)	0.33	0.39
Mean velocity (m/sec)	2.11	2.58
Roughness, n	0.016	0.013
Shear stress (N/m^2)	50.0	67.8
Mean bed change (mm)	-16	-37

Table 3. Results of the test (Block B).

Case	Case B01	Case B02
Discharge (m^3/sec)	3.48	5.02
Mean depth (m)	0.32	0.37
Mean velocity (m/sec)	2.21	2.68
Roughness, n	0.015	0.012
Shear stress (N/m^2)	46.4	66.1
Mean bed change (mm)	-25	-55

3.3 Vegetation Mat Tests

Two types of vegetation mats are tested and evaluated. The type A mat is composed of PE net, Coir net, Coated wire mesh and the type B mat is composed of PE net and Coir net as presented in Figure 7. Test bodies with 10 m long and 3 m wide are constructed in the steep channel on the sub soil of sand and silt. Anchors of 0.3 m long are also installed with uniform density as shown in Figure 8.

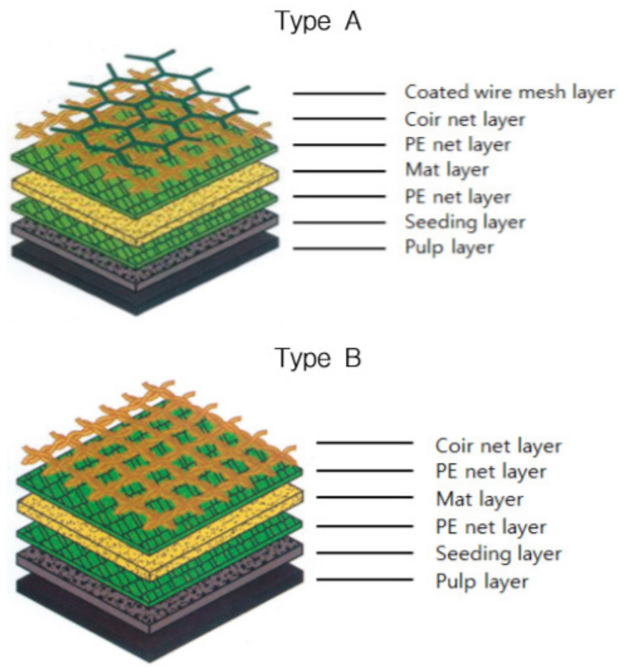


Figure 7. Composition of tested vegetation mats.

Hydraulic stability tests of the vegetation mats are conducted with a continuous 30 minute. During the tests water elevation is measured along the centerline of the channel at 1m interval. Before and after each test, bed elevations are measured with Terrestrial LiDAR (Light Detection And Ranging), Model LMS-Z390i of the RIEGL company.

The tests are conducted with discharge conditions of 4.17 m^3/sec, 3.48 m^3/sec and 5.02 m^3/sec and corresponding average shear stresses on the bed calculated from the measured water elevations are presented in Table 4.

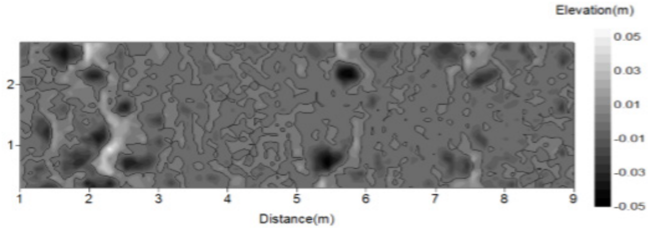
<Type A>

<Type B>

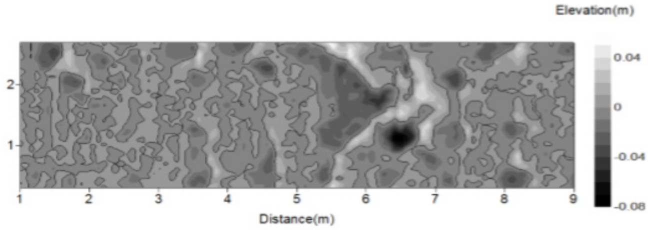
Figure 8. Installation of vegetation mats.

Table 4. Test conditions and shear stresses.

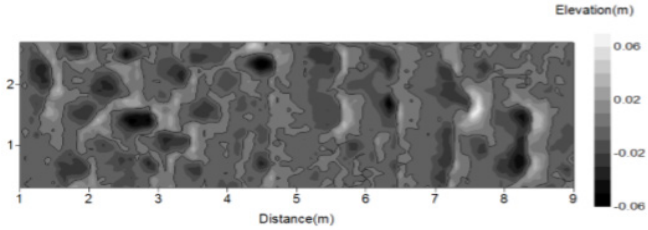
Case No.	Discharge (m3/sec)	Shear stress (N/m2)	
		Type A	Type B
Case1	4.17	21.76	21.58
Case2	5.70	33.73	26.05
Case3	7.56	43.74	50.10



(a) Changes of bed elevation(case 1)

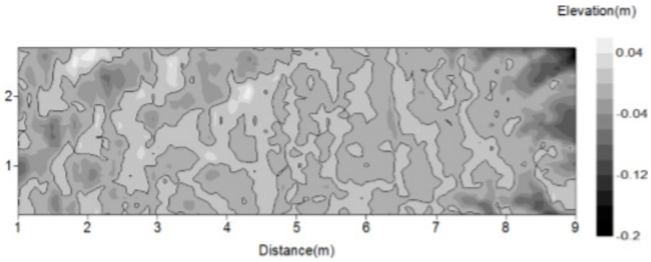


(b) Changes of bed elevation(case 2)

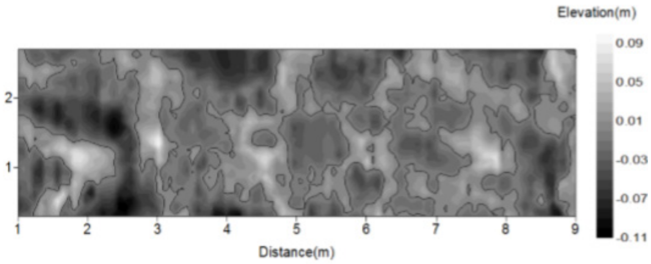


(c) Changes of bed elevation(case 3)

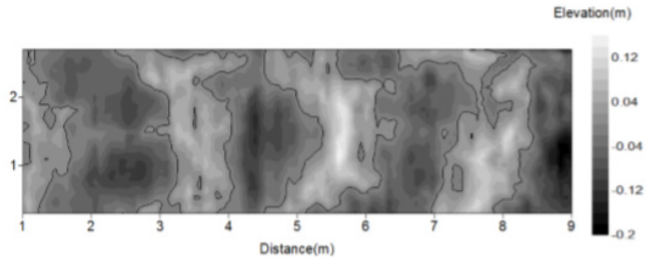
Figure 9. Bed elevation changes (Type A).



(a) Changes of bed elevation(case 1)



(b) Changes of bed elevation(case 2)



(c) Changes of bed elevation(case 3)

Figure 10. Bed elevation changes (Type B).

Stability of vegetation mats can be evaluated by CSLI (Clopper Soil Loss Index) as suggested in ASTM D6460.

$$\text{CSLI} = \frac{C_T}{A_T} \times 100$$

where :

CSLI = Clopper Soil Loss Index, cm,

C_T = total cut volume, m^3, and

A_T = wetted channel area, m^2.

To calculate CSLI, soil subgrade elevations are measured using Terrestrial LiDAR before and after the tests. Changes of bed elevation under the mats in each tests are presented in Figure 9 and Figure 10 and the results are presented in Table 5 and Table 6. Over 20,000 points are measured in each test so detailed aspect of soil scour and deposition under the mats can be shown.

Type A shows relatively smaller patch areas of scour and deposition and Type B shows bigger patch areas. In Type A, movement of sub soil is restricted by hard wire mesh and in high flow condition shape of the wire mesh is maintained. In Type B, larger movement of sub soil is detected and in high flow condition large scale of scour and deposition is observed similar to movement of sand bar.

For quantified analysis, maximum deposit height and scour depth, total volume of soil loss and deposit, area of soil loss and deposit, and CSLI are calculated from the LiDAR measurement as shown in Table 5 and Table 6. In those values, total volumes of soil loss and deposit are proportional to shear stress, and areas of soil loss and deposit show relatively uniform values. Consequently, CSLI calculated from total volume of soil loss shows proportional to shear stress.

Table 5. Results of soil loss evaluation (Type A).

Cases	Case 1	Case 2	Case 3
Shear stress (N/m2)	21.76	33.73	43.74
Max deposit height (mm)	53.1	65.9	50.8
Max scour depth (mm)	47.9	55.9	75.6
Total volume of soil loss (m3)	0.0628	0.0876	0.1221
Total volume of soil deposit(m3)	0.0235	0.0394	0.0473
Area of soil loss (m2)	12.88	11.41	12.70
Area of soil deposit (m2)	6.32	6.49	7.79
CSLI (mm)	3.3	4.6	6.4

Table 6. Results of soil loss evaluation (Type B).

Cases	Case 1	Case 2	Case 3
Shear stress (N/m2)	21.58	26.05	50.10
Max deposit height (mm)	54.3	96.0	158.3
Max scour depth (mm)	183.4	108.8	192.0
Total volume of soil loss (m3)	0.1952	0.2921	0.5306
Total volume of soil deposit(m3)	0.0426	0.1153	0.2562
Area of soil loss (m2)	12.34	11.75	11.34
Area of soil deposit (m2)	6.86	7.45	7.86
CSLI (mm)	10.2	15.2	27.6

4 Summary and Conclusion

The River Experiment Center of KICT has three prototype channels with 600 m long and 11 m wide. Large capacity pump supplies a controllable flow up to 10 m^3/sec and a flow velocity up to 5 m/sec.

By the activation of environment-friendly river works, application of eco-friendly products has increased. Thus damages of these type revetments have also increased recently. Although application of the eco-friendly products in river works have increased, the allowable shear stress or the allowable velocity of the revetments are not usually suggested and there is no standard method to determine the allowable shear stress or the allowable velocity.

In the study real scale tests for hydraulic stability of the revetments are conducted by ASTM standards. Real scale revetments are installed in a steep sloped zone of the test channel. Water elevations and velocities are measured in each flow condition to determine the energy slopes. Bed changes in each flow conditions are measured by 3D Lidar and they are used to evaluate the failure condition. From the tests allowable shear stresses and failure patterns of the revetments are suggested. In the concrete blocks with vegetation hole, most damages are happened from the local scour in the vegetation holes. Vegetation mats reinforced by wire mesh show relatively high allowable shear stress.

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References

ASTM, "ASTM D6460-07 Standard Test Method for Determination of Rolled Erosion Control Product Performance in Protecting Earthen Channels from Stormwater-Induced Erosion", 2007.

ASTM, "ASTM D7276-08 Standard Guide for Analysis and Interpretation of Test Data for Articulating Concrete Block (ACB) Revetment Systems in Open Channel Flow", 2008.

ASTM, "ASTM D7277-08 Standard Test Method for Performance Testing of Articulating Concrete Block (ACB) Revetment Systems for Hydraulic Stability in Open Channel Flow", 2008.