Protecting Riverbank’s Environment Towards Scour with Combined Reinforcement of Gabion and Tetrapod: a Laboratory Model Study

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Abstract. The purpose of combined reinforcement installation is to direct the water flow and to reduce the scour process in order to protect the riverbank. The study was conducted by employing a laboratory model using a trapezoidal flume/channel with dimensions of 0.8 m width and 0.5 m height. The length of river bend model was 5 m. Observation was made with a constant flow rate of 7.07 liters/second. Tetrapod and gabion were installed at the angle of 45° and a distance of 51 cm. The running duration of installation variation was 180 minutes each. The results of the test showed that the river model with tetrapod-gabion-tetrapod reinforcement experienced an average scour of 4.16 cm for the beginning, 1.08 cm for the middle and 3.3 cm for the end. The gabion-tetrapod-gabion reinforcement can be considered as more effective reinforcement combination to reduce scour with an average scour of 4.03 cm in the beginning of the channel, 2.64 cm in the middle of the channel and 1.97 in the end of the channel.

Keywords: gabion, reinforcement, tetrapod

1. Introduction
River basin (Indonesian: Daerah Aliran Sungai - DAS) is commonly defined as an area/region that is bounded by a topographic barrier (ridge) that functions to receive and collect rainwater and drain it through a river. A river basin is rich and diverse in natural resources [1], however, the increasing functional shift in land use causing a reduction in green open space and reduces water catchment area, especially in urban area. In consequence, the reduced water catchment area will accelerate the runoff and trigger flood [2]. Large flood discharge and flow direction are very dominant in forming many problems that occur in river such as changing in flow direction, landslide, scour and sedimentation.

Scour is a natural phenomenon caused by erosion of water flow at the base and cliff of alluvial channel. It is also a process of decreasing or deepening of the river bed below the natural surface elevation (datum) due to the interaction between flow and river bed material. Scour that occurs around the pillar is due to the vortex system that arises because the flow is blocked by the pillar. Flow approaches the pillar and the stagnation pressure will decrease and cause a down flow that is flow from high speed to low speed. The strength of down flow will reach its maximum when it is right at the bottom of the channel [3].

River bend scour is defined as the scour process associated with the flow of water around a bend in the river. It can cause the bend to migrate downstream and also possibly laterally [4]. Although river bank erosion is a natural process participating in river morphodynamics and related ecosystems [5], river bank erosion, especially in its bends, can be costly. It can result in losses of productive land and damage to fencing, tracks and other infrastructure. This kind of erosion is a serious problem to river engineers concerned with channel stabilization and navigation [6, 7]. The scour at river bend, if it occurs
continuously, will also result in damage to the cliff so that landslide can occur. Scour at river bend is a complex process involving various parameters. The combined effect of vortex, cross-flow and accelerated flow is responsible for the erosion on the concave bank and deposition on the convex bank [8].

Since scour on a river bends is a detrimental event, there is a need for reinforcement in the place where scour occurs to reduce the effects. Several techniques and strategies have been employed to protect riverbank against scour/erosion either by acting directly on the river bank to increase its stability or indirectly by modifying the flow coming from upstream [9]. Already practiced for long time, soft engineering (i.e. bioengineering) techniques take advantage of the natural properties of plants to stabilise the bank with the combined effects of roots and canopy cover [10]. These techniques have many advantages such as: relatively low-cost treatment [11], very small carbon footprint compared to artificial construction [12], support of biodiversity and ecological functions and create terrestrial habitats [13, 14]. In the other hand, hard engineering methods (i.e. civil engineering approach) such as riprap, stone masonry, sheet piling, concrete slabs or gabion are very effective against erosion, but they have a very strong footprint on the river ecosystem since they cover the river bank for a very long time and prevent the development of river habitats [15].

Scour processes are also frequently observed along Bedog River, a river that flows through Yogyakarta Special Region (as can be seen the brown river flow in Fig. 1.a.). Bedog River has a shape curve so that at its river bends (as can be seen in Fig. 1.b), scour occurs repeatedly causing damage to the cliff and riverbed. The damage that occurs result in changing direction of the river and several damages to the surrounding buildings and environment that causing some losses.

This paper presents the results of laboratory experiments investigating the potential use of gabion-tetrapod reinforcement combination to protect the river bends, particularly river bends at the Bedog River, from scouring. The results will be used for further study to find the best option for river bends protection especially its ecological and economical functions.

A gabion mat or basket is a structure made of zinc coated soft temper steel in a shape of hexagonal double twisted wire mesh filled with stones. Gabion is commonly used to protect earth embankments, to line channels, to protect bridge abutments. A gabion is like a wire mesh cage or basket filled with stones or any other suitable material. Gabions are useful in diverting a river and protecting river banks. The standard gabion basket consists of a single piece of wire mesh that can be assembled to form a rectangular box with a lid [16].
Gabion is often chosen as a reinforcement for riverbanks because it has several advantages as follows [16, 17]:

a. gabion structure is flexible so it can follow the movement of the soil without damaging the construction,
b. water can penetrate gabion structure so it can reduce the pressure of active soil,
c. gabion can be considered as durable since gabions are less susceptible to cold weather cracking or frost action as compared to reinforced concrete,
d. gabion is more sustainable and economically affordable, and
e. the construction is simple that can be done without high-tech machinery and skilled labor.

Tetrapods were employed as co-reinforcement structure for gabion. Tetrapods were chosen because its similarity with gabion in reducing the water flow velocity. Compared to gabion, its resistance to water with high salinity or high acid is higher. However, tetrapod installation needs a help from heavy equipment. Another disadvantage of tetrapod is its more expensive the structure compared to gabion.

2. Materials and Methods

This study employed a method of physical modeling conducted at the Hydraulic Laboratory, Department of Civil Engineering and Planning, Faculty of Engineering, Yogyakarta State University. The experiments were carried out by modeling the river on a laboratory scale in the form of a trapezoid flume channel with a bend length of 5m, high angle of 0.5 m, width of 0.8 m, and turn of 90°. The variation of bend protection placement were: 3 tetrapods – 4 gabions – 3 tetrapods for the formation of installation 1 (code: FP1) and 3 gabions - 4 tetrapods – 3 gabions for the formation of installation 2 (code: FP2).

Data was collected by observing the scour that occurs around the cliff and the river bed until the scour is stable. Each data taken used the same flow rate and stable depth.

The experiment were run according to the following steps:

a. on the edge of the channel, 24 (twenty four) measurement marker stations were placed and assigned as Sta. 0 to Sta. 24,
b. scaled track motor was assembled and marked with a horizontal spacing of 1 cm by 21 points and 5 cm afterwards by 8 points,
c. distometer was mounted on scaled track motor holder,
d. scaled track motor was positioned from Sta. 0 with condition of the right and left wheels must exactly right at the station that will be reviewed,
e. measurement started by pressing the enter button on the laptop for each distance,
f. distometer holder was moved horizontally according to the prepared distance,
g. the processes were done repeatedly for Sta. 0 to Sta. 24, and
h. measuring data process was done twice for each variation, before and after running.

The bend contour of the river model was measured using a distometer and the data was processed to obtain a cross-section graph at each station. The number of station in this test was 25 stations with a distance of ± 24 cm for each station. Station naming started with Sta. 0 on the upstream channel to Sta. 24 on the downstream channel. The depth of the flow measured at a certain point that has not been disturbed by the reinforcement structures of the channel bend. The flow depth was recorded several times in order to get the optimum average of flow depth data. The scour depth (ys) was measured from the beginning of the channel bend to the end of the channel bend. For each combination of tetrapod – gabion installation, maximum scour depth, scour contour and scour length were recorded and analysed in order to evaluate the most effective combination of tetrapods and gabions in reducing scour phenomenon at a river bend. The data were then analyzed with Microsoft Excel and Surfer 14 program.

3. Result and Discussion

In the following discussions, TP represents river bend without protection, FP1 represents river bend with a combination of tetrapods – gabions - tetrapods protection, and FP2 represents river bend with a combination of gabions - tetrapod - tetrapod protection. Reinforcement was installed with a distance of 51 cm and an installation angle for tetrapod and gabion of 45°.
The result of laboratory model testing showed that the contour at the river bend model has been eroded by the flow in all variation of river bend protection. However, the magnitude of the scours were different. The data from station points Sta. 3, Sta. 9, and Sta. 23 are presented in this paper as examples of contour change in the river bend due to scouring phenomenon.

3.1 Typical Cross Section Situation

Figure 2. Comparison of scour magnitude at Sta. 3

Figure 2 depicts a cross-sectional situation from Sta. 3 showing that on the inside edge of the turn at a distance of 18 cm - 28 cm, an average scour of -5 cm occurred that applies to TP (without reinforcement), FP 1 and FP 2. At a distance of 28 cm - 43 cm there was difference result between the combination of reinforcement installation for TP scour occurs on average by 4.24 cm at the bottom and 0.8 at the wall of the river model. It can be seen that after it was given FP1 reinforcement, the scour that occurred decreased by 0.8 cm. After the FP2 installation, a significant effect occurred and a decrease in scour by 0.21 cm is observed.

Figure 3. Comparison of scour magnitude at Sta. 9
From Figure 3 it can be seen that the scour at Sta. 9 differed from Sta. 3 where for Sta. 9 the effect of installing reinforcement begun. The average scour that occurred at Sta. 9 for TP was 2.59 cm. After the installation of FP1, scour that occurred decreased pretty much that was 1.51 cm. However, after FP2 installation, the scour increased by 0.05 cm.

![Figure 3](image_url)

**Figure 3. Comparison of scour magnitude at Sta. 9**

Figure 3 presents the scour magnitude at Sta. 9. It can be seen that TP experienced a fairly large scour of 4.42 cm. After the installation of FP1 reinforcement, the average scour decreased by 1.12 cm, but the biggest decrease was recorded after the installation of FP 2 by 2.43 cm. Table 1 presents the scour comparison among TP (river bend without reinforcement), FP1 (river bend with tetrapods-gabions-tetrapods reinforcement), and FP2 (river bend with gabions-tetrapods-gabions).

### Table 1. The Scour Depth among TP, FP1 and FP 2 at the River Model

| No. | Retaining wall | Scour depth (cm) |
|-----|----------------|------------------|
|     |                | Sta. 3 | Sta. 9 | Sta. 23 |
| 1.  | TP             | 4.24   | 2.59   | 4.42   |
| 2.  | FP1            | 4.16   | 1.08   | 3.30   |
| 3.  | FP2            | 4.03   | 2.64   | 1.97   |

3.2 Scour Pattern of Reinforcement

The shape of contour and scour patterns of the river bend model with terapod and gabion installation are illustrated by Surfer14 and are presented in Figure 5 (A) for FP1 reinforcement and 5 (B) for FP2 reinforcement.

It can be seen that the material at the bottom of the river model is shown in green. The greatest scour that occurs at the beginning and end of a river bend model is shown in white which occurs at the bottom of the river model. From Figure 5 (B) it can be seen that the basic material of the river model is shown in green. The maximum scour that occurs in the channel is shown in white which occurs at the bottom inside of the river model, scour can be seen from the beginning to the middle and middle to the end of the river bend model.
4. Conclusions
The scour that occurs in FP 1 (combination of tetrapod-gabion-tetrapod protection) at the beginning of the river bend showed an average of -4.16 cm, the middle section of the river bend -1.08 cm and the end of the river bend - 3.3 cm. The scour that occurs in FP 2 at the beginning of the river model turn experiences an average scour of -4.03 cm, the middle section of the turn experiences an average scour of -2.64 cm and at the end of the turn experiences an average scour of -1.97 cm. The results of using FP 1 reinforcement decreased the magnitude of scour at Sta. 3 by 0.08 cm, Sta. 9 by 1.51 cm, and Sta. 23 by 1.12 cm. For the using of FP 2 reinforcement there is also a decrease of 0.21 cm for Sta 3, a decrease of 2.44 cm for Sta. 23, and an increase at Sta. 9 by 0.05 cm. From the result obtained, it can be concluded that FP 2 is more effective in reducing scour that occurs in the river model. The FP2 reinforcement is considered as the most effective protection because the average scour experienced is the smallest.

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