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Evaluation of Environmental and Hydraulic Performance of Bio-Composite Revetment Blocks

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Abstract: It is necessary to develop a concrete revetment block which can cater for environment and at the same time it will be effective in protecting river banks (stabilize the slope of banks) from scouring during flood. In the present study, the environmental and hydraulic performance of the proposed revetment block was evaluated through laboratory and field tests. The tested revetment block is called bio-composite because it is composed of concrete, plastic mesh and biological material (coconut husk). The dimensions of the bio-composite revetment block are 400 mm x 400 mm x 100 mm (length x width x thickness) and has a central opening with a dimensions of 280 mm x 140 mm that has a 10 mm layer of coconut husks protected by two layers of plastic mesh. The coconut husk was selected based on laboratory experiments. The experiments showed that the coconut husk is a good media for grass growth and it allows faster growth of grass compared with other tested types of biological wastes (sugar cane husk and oil palm husk). Field tests were conducted on a selected stream which is located at the Universiti Putra Malaysia, Selangor, Malaysia. The stream banks were protected from scouring by using the bio-composite blocks and monitoring after installation revealed that rate of grass growth was 15% per week. However, it was found that the rate of grass growth is depends on the slope of stream banks. This confirms that the proposed bio-composite block is friendly to the environment and can give a good aesthetic appearance. For a given water depth, hydraulic tests showed that the value of Manning coefficient of roughness for the bio-composite revetment blocks depends mainly on the rate of grass growth. The values of Manning coefficient roughness for the stream were found to range from 0.031 to 0.055.

Key words: Bio-composite block, river protection, field-testing, environment, hydraulic roughness

INTRODUCTION

Natural streams and rivers are subjected to scouring particularly during the flood. In tropical river systems, the velocity of water in these rivers (during the flood) is very high and may result in severe scouring that cause damage to the river banks and affect its stability. This will endanger the safety of the infrastructures located near river banks. Also, the scour has environmental impact. This problem can be tackled by protecting riverbanks using suitable material. Usually, concrete masses are used to cover river banks in order to protect the banks from scouring. However, these concepts are not suitable nowadays because of the growing concerns to conserve the environment, river ecology and aesthetic appearance of rivers. Recently, protection methods used for controlling river scouring are more environmentally friendly than before and the use of revetment systems which can promote grass growth beside maintaining the designed configuration and hydraulic capacity of the river is generally encouraged. They are many types of revetment system which are designed to protect and stabilize river banks from erosion. However, they can be categorised into three main types. And these types are bio-engineering (vegetation), structural and bio-technical engineering[1]. The bio-engineering and bio-technical engineering revetment systems will help to restore rivers. River restoration is an integral part of sustainable development in river basin systems and has multifunctional objectives. It can be implemented by using environmentally friendly materials which will maintain the capacity of a river to pass design flood. The objectives of river restoration are to reduce the physical degradation and bring back river aesthetic value, to control all types of pollution of river water, to create a good condition for aquatic life with biodiversity, and to ensure the interaction of river ecosystem. River restoration concept is thus a good tool for conserving the river environment.

In last decades, Malaysia is subjected to rapid development and as a result severe flooding has occurred particularly in urban areas. Flood mitigation measures were taken to reduce the flood damage and channel improvement is mainly used for this purpose. In the past, consultant engineers normally proposed a rectangular concrete section for improving the channel of the flooded river. So, it often happens that the

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undersized natural section of a river is changed to a wider and deeper rectangular concrete channel to reduce flood impact. This solution is proposed by the designer because of the limited available river reserve and possibly the lack of environmental awareness. The consequences of replacing the natural river section with a concrete section are reduction of aesthetic and recreational values of rivers and increase physical degradation. In Malaysia, there is a great emphasis nowadays to consider the environmental impact in canalizing rivers. In this study, the environmental and hydraulic performance of a new proposed pre-cast environmentally friendly block called bio-composite revetment block were tested in both laboratory and site.

CATEGORIZATION OF REVETMENT SYSTEMS

Escarameia[1] categorised the revetment systems into three main types namely, bio-engineering (vegetation), structural and bio-technical engineering. Bioengineering revetment system is a technique that works to stabilize many, but not all of erosion problems. The challenge in bioengineering is protecting the bank from erosion until the vegetation becomes established and it takes more than a year. Gray[2] and Allen[3] discussed five mechanisms through which vegetation can aid erosion control: reinforce soil through roots; dampen waves or dissipate wave energy; intercept water; enhance water infiltration; and deplete soil water by uptake and transpiration. However, from the engineering perspective, the use of vegetation alone on streambanks is not always ideal. Excessive foliage can lead to the reduction in channel capacity and a greater flood potential upstream. Trees planted on certain parts of levees may have roots undermining the levee stability[4]. Researchers analyzed vegetation's engineering functions and found that its effects are both adverse and beneficial, depending on the circumstances. Therefore, it is important not to solve a streambank problem by employing a single measure. The structural revetment system was widely used in 1950 to 1980[5]. Various protective structural linings have been used to face the erosion problems. These hard-armoring methods, such as stone riprap, concrete pavement, rock gabions, concrete or aluminum, sack revetments and asphalt mixes reinforced streambank shear strength[6]. Many governmental agencies favored stone or concrete riprap because over time, a high degree of precision and confidence in construction has developed from research and analysis. In engineering viewpoints, these methods have been successful for their immediate protection. Combining different bioengineering techniques even with structural components is actually more effective than using any specific one alone[7]. Bio-technical is a technique for bank stabilization that incorporates the use of vegetation and engineering structures to increase slope stability[8]. The vegetation increases the soil strength through their root structure while the bio-engineered structure provides additional support.

DESCRIPTION OF THE BIO-COMPOSITE REVETMENT BLOCK

The proposed bio-composite revetment block is a concrete block which is designed to be used for protecting the river banks from scouring and also to keep the design dimensions of the improved river section in flood mitigation projects. The block is square in shape and its dimensions are 400 mm x 400 mm (length x width) while the block thickness is 100 mm. The block is designed to have central opening with dimensions of 280 mm x 140 mm (length x width) and interlocking system which consists of tongue and groove (dovetail arrangement). The central opening of the block contains a layer of coconut husk protected by two layers of plastic mesh (above and below the coconut layer). The mesh is embedded in concrete in order to fix the layer of the coconut husk in its place. The thickness of the coconut husk layer is 10 mm. The configuration of the block is shown in Fig. 1.

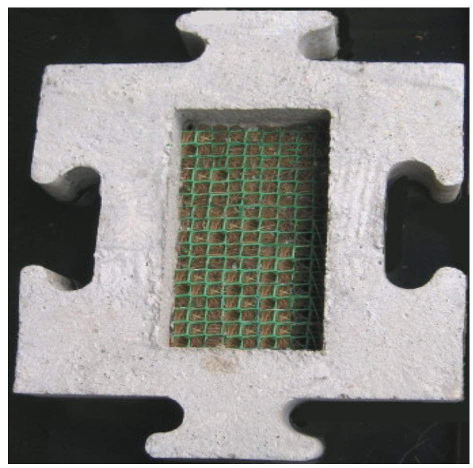


Fig. 1: The bio-composite revetment block

SELECTION OF SUITABLE BIOLOGICAL MATERIAL AS A MEDIA FOR GRASS GROWTH

As mentioned above the coconut husk is used in the central opening of the bio-composite revetment block for promoting the grass growth. It was selected among many available types of biological materials. These materials are considered as biological waste. In this study, only three different biological materials are tested and these materials were coconut husk, sugar cane husk, and oil palm husk. Fig. 2 shows the three types of tested husks. The laboratory test includes monitoring the performance of each type of husk to allow vegetation growth. The effectiveness of the tested husks for growing vegetation was carried out by constructing an overshadow area as shown in Fig. 3. The experiments showed that the coconut husk is the best biological material that can be used in the opening area of the bio-composite block since it showed the fastest rate of grass growth compared with the other tested types of husk (sugar cane husk and oil palm husk). The laboratory experiments showed that the maximum rate of grass growth per week were 5 cm, 3 cm and 2 cm for coconut husk, sugar cane husk, and oil palm husk respectively. Figure 4 shows the rate of grass growth using various biological wastes as growing media.

a) Coconut husk b) Oil palm husk and c) Sugar cane husk

Fig. 2: Biological material used to promote vegetation growth

Fig. 3: Monitoring the effectiveness of various types of husks for promoting grass growth

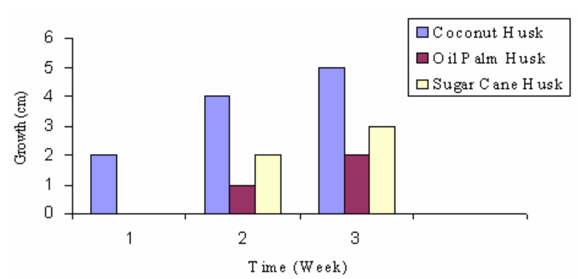


Fig. 4: Rate of growth of three different biological materials

This is attributed to the fact that the coconut husk is composed of millions of capillary micro-sponges that absorb and hold water up to eight times its own weight and has very high water holding capacity and good air porosity[9]. The coconut husk contained about 80 to 85% moisture on oven drying[10]. As an organic material, the coconut husk could be used as organic fertilizer material and has been tested on several crops[11]. This supported the use of coconut husk as a suitable media for grass growth in bio-composite revetment block. Most of the produced blocks of similar function were definitely not subjected to any environmental evaluation and monitoring after construction[8]. As the vegetation matures, root systems will bind soils, inert materials and vegetation altogether on the streambank. This will increase the safety factor of banks stability and its resistance to scouring. Fig. 5 shows the relation between the rate of bank vegetation and soil loss as given by Coppin and Richard[12]. The monitoring for grass growth was done weekly by measuring the percentage of the area covered with grass to the total surface area of the stream banks lined with the bio-composite revetment blocks. Result obtained from the monitoring of grass growth is shown in Fig. 6. An average percentage growth of 15% was recorded per week. The rate was nearly equal to growth rate in commercial grass production, which were estimated to be no more than 2.6% per day as reported by Busey[13]. The monitoring period was extended to 6 months after the date of construction. The plant growth through the block opening will provide armoring to the block since it will anchor it with the underneath soil. Vikaneshwaran[14] categorized the revetment blocks according to it capability for growing grass. The capability is affected by the size of the opening in the block as shown in Table 1. For example, the rate of vegetation growth is fast for blocks with opening size between 18 to 30 % from the block gross area. The bio-composite revetment block has a central opening which forms 25% from the total block area and this place it under the category of blocks with fast grass growth rate.

Table 1: Rate of vegetation growth for various opening size[14]

Rectangular opening size (%)	Rate of growth
<10	Slow
10 – 18	Moderate
18 – 30	Fast

ENVIRONMENTAL PERFORMANCE

A 10 m stretch of a selected stream was used to conduct field tests after the banks of the stretch were lined with bio-composite revetment blocks. The stream was located at Universiti Putra Malaysia, Serdang, Selangor, Malaysia. The main objective of the field test is to monitor the performance of the bio-composite revetment blocks after installation. During the monitoring period, the effectiveness of the bio-composite block to promote grass growth or any vegetation was evaluated.

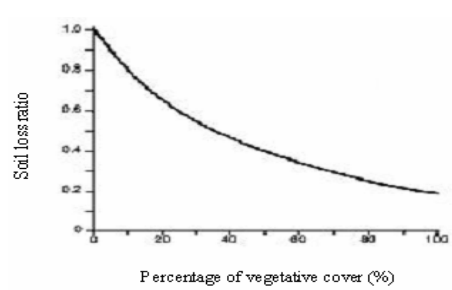


Fig. 5: Effect of vegetation cover on scouring of river banks[12]

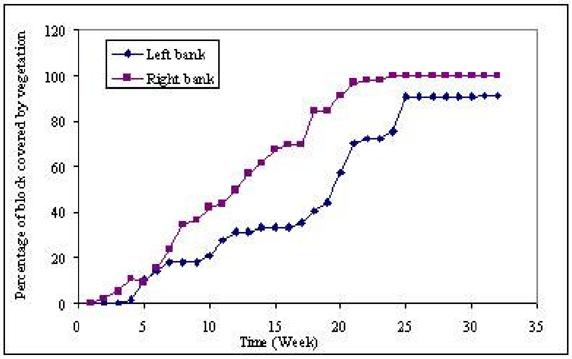


Fig. 6: Variation of the percentage of grass growth with time for stream banks lined with bio-composite blocks

a. Left bank with 1 (V): 1 (H) side slope

b. Right bank with side slope of 1 (V) : 1.5 (H)

Fig. 7: variation of grass growth at banks with different side slope

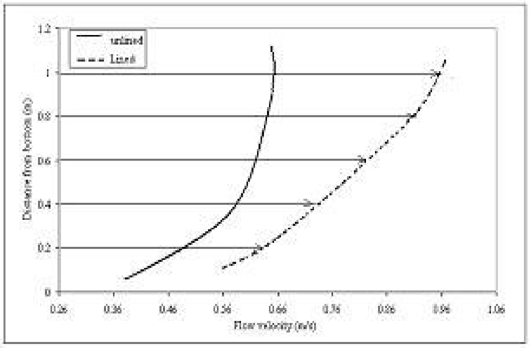
Busey[13] reported that grass growth rates for various periods was not strictly exponential but sigmoidal. From the recorded data, it is found that the rate of grass growth for the bio-composite revetment blocks is in agreement with the finding of Busey[13].
The different growth areas on left bank and right bank of the stream can be attributed to their different side slopes. Bank with mild side slope gave faster rate of grass growth compared with bank of steeper side slope. The milder side slopes will be more moist and sediments carried by water can be deposited on it and this allows vegetation to re-establish and gives better environment for grass growth. In this study, the side slope of the right bank for the selected stream is 1:1.5 while the side slope for the left bank is 1:1. Fig. 7 shows the grass growth at both right and left banks which are lined with the bio-composite blocks.

Long term monitoring was conducted to check the environmental performance of the bio-composite blocks. The monitoring period was 6 months started from beginning of September 2005 up to the end of February 2006. The blocks showed good environmental performance since the grass grew on both side of the lined stretch of the stream as shown in Fig. 8.

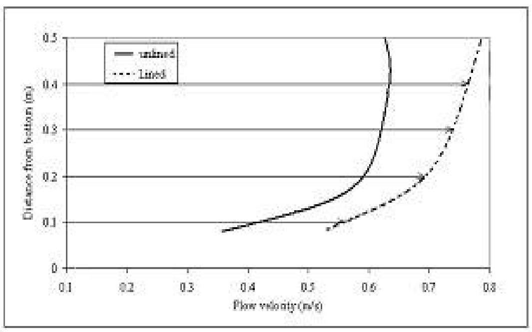
Fig. 8: Condition of protected stream at a given period

HYDRAULIC MEASUREMENTS AND COMPUTATIONS

Most of the revetment blocks used for protection of rivers from scouring are not subjected to field hydraulic tests. So, hydraulic properties of these revetment are not known including the Manning coefficient of roughness and designers usually estimate the value of the Manning coefficient of roughness for many types of revetment blocks based on their experience. But for the proposed bio-composite block, field hydraulic tests were made to determine the Manning coefficient of roughness. A field survey was conducted to determine the cross section and longitudinal slope of the stream. Digital current meter was used to measure the velocity at various points along a cross section of the stream and also vertically at various depths of the stream. Knowing the average velocity of flow, slope and depth, the Manning roughness coefficient can be easily computed using the Manning's formula. The Manning coefficient of roughness was also computed for the unlined stream section for comparing the hydraulic performance with and without lining with bio-composite revetment blocks. Fig. 9 shows the vertical velocity profiles for the steam section before and after using bio-composite blocks to protect its banks. An increase in the velocity was observed when the banks were protected using bio-composite revetment blocks.



a. Vertical flow profile at 0.9 m flow depth



b. Vertical flow profile at 0.5 m flow depth

Fig. 9: velocity profile for the selected stream

The increase in the velocity after using the bio-composite revetment blocks may be attributed to the reduction in the shear stresses at the stream banks. Variation of Manning coefficient of roughness (n) with flow depths for the stream with and without the bio-composite blocks and also with and without vegetations were measured. Fig. 10 and Fig. 11 show the variation of Manning coefficient of roughness for various conditions. The value of the Manning coefficient of roughness was computed at various stages of grass growth and with various flow depths. It was found that the value of the Manning coefficient of roughness were changed from 0.039 to 0.038 when the grass growth increased from 5% to 20%. Also for 30% grass growth, the value of the Manning coefficient of roughness is not much different from the above range. This showed that the effect of vegetation on Manning coefficient of roughness is negligible when the bio-composite blocks were covered with vegetation by less than 30% from total lined area. However, the effect of vegetation on Manning coefficient of roughness is considerable when the percentage grass covered the lined banks with bio-composite blocks is more than 30%. For example, a difference of 32% in the value of Manning coefficient of roughness was obtained between the case of the stream without grass and that with 40% of grass growth.

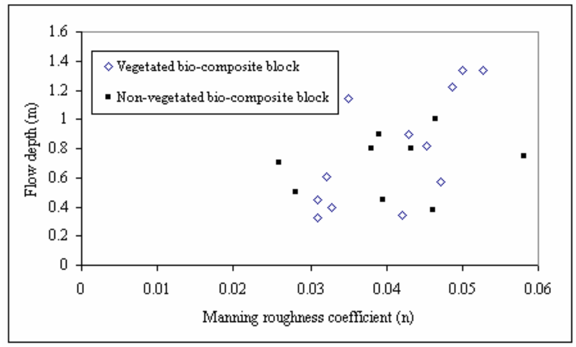


Fig. 10: Effect of grass growth on of Manning coefficient for channel lined with bio-composite blocks

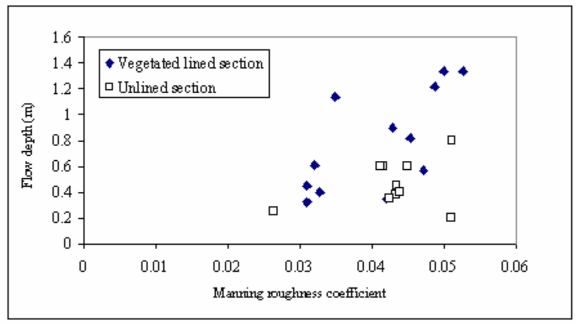


Fig. 11: Variation of Manning roughness coefficient at various flow depth before and after installation

In this study, the roughness coefficient was found to be changed due to the flow depth and percentage of the bio-composite block covered by vegetation. Harun[15] conducted a sensitivity analysis and found that about ±3% and ±5% changes in the value of Manning coefficient of roughness (n) occurred for a change of ±10% and ±20% in water depth. Other aspect that influenced the Manning coefficient roughness is the percentage of open area of the revetment system. A channel lined with a good stand of vegetation cannot be described by a single n value. It is observed that for vegetated lined section, there is significant variation in the value of Manning coefficient of roughness (n) as shown in Table 2. The average maximum percentage of reduction in Manning roughness coefficient was found to be 15%. The Manning roughness coefficient for vegetative linings varies significantly depending on the amount of submergence of vegetation. An increase in hydraulic radius may either increase or decrease the value of Manning coefficient of roughness depending on the condition of the channel[16]. For some case on vegetated lined section, the roughness was found to decrease as the depth increased. This was due to the percentage of grass growth. The roughness of vegetative channel linings depends on physical characteristics of the grass. With grasses, the roughness then will vary depending on the bending of the vegetation.

Table 2: Variation in values of Manning coefficient of roughness for various stream conditions

Condition of the Stream	Range of Manning Coefficient of Roughness (n)	Average Value of (n)
Natural section covered with grass	0.0435 – 0.511	0.0473
Lined section with bio-composite blocks but without grass growth	0.0396-0.412	0.0404
Lined section with bio-composite blocks but with grass growth	0.031-0.0548	0.0429

CONCLUSION

In this study, bio-composite revetment system which is proposed to be used for protecting riverbanks from scouring are subjected to field tests in order to evaluate their environmental and hydraulic performances. The environmental performance includes the ability of the block to promote grass growth in order to increase the aesthetic appearance and the stability of river banks. The hydraulic performance mainly includes the determination of Manning coefficient of roughness after measuring the hydraulic characteristics of a river. A 10 m stretch of a stream is selected to conduct the field tests. The tests showed that the average recorded rate of grass growth was 15% per week for the stream banks protected using bio-composite blocks. This make the bio-composite block environmentally friendly and gives esthetic value for rivers after installation. On the other hand, the Manning roughness coefficient for the blocks was found to range from 0.031 to 0.055. The values of the Manning roughness for river banks protected using bio-composite revetment blocks are affected by the percentage of grass coverage, grass height, and the flow depth.

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