Green revetment solutions for riverbank erosion protection

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ABSTRACT: This paper describes green revetment solutions for riverbank erosion protection together with two case studies in Malaysia. Rivers are subject to the erosion process naturally. If left unattended, riverbank erosion will pose an immediate threat to the structure built alongside the river. A variety of riverbank protection systems are available, with rock-based or concrete-based systems being adopted traditionally. However, a soft and environmentally friendly solution is more often preferable. Two types of green revetment solutions are described, namely geotextile bags and sand filled mattresses. These solutions provide not only instant green colour appearance to the riverbank, but the highly UV stabilized coarse grain fibres also provide excellent UV protection together with the ability of trapping sediments which will promote vegetation. The first case study presented concerns the application of geotextile bags at Rasau River in Sepang, Malaysia. The project utilized green geotextile bags with high tenacity geogrid anchorage tails for erosion protection. The second case study utilized green sand filled mattresses for erosion protection at Jimah River in Negeri Sembilan, Malaysia.

Keywords: Erosion, green revetment, geotextile bags, sand filled mattresses

1 INTRODUCTION

River is a natural stream of fresh water flowing in a definite course and usually into the sea. The first ever recorded civilization, namely Mesopotamia grew up in river valley. Most civilizations tend to have started in a river valley due to the importance of water for drinking and agricultural purpose. In these modern days, cities are developed near the river not only because of the influence from the past, but the function of river as a medium of transport and sources of food are also the driving forces behind.

Rivers are subject to erosion naturally. This poses immediate threat to the structure built alongside the river as it will undermine the foundation of the structure and lead to failure eventually. Besides that, erosion will also lead to river meandering. If left unattended, it might move into a developed area and cause economic loss.

Traditional ways to protect the riverbank are typically rock-based or concrete-based systems. As raw materials become scarce and with the rising concern on the environment, soft and environmental friendly product is preferable. With the introduction of geotextile filter into the market in late 1950s, subsequent development using geotextile in containment systems that are filled with sand are used to replace the rock in hydraulic structures. This paper presents two case studies on the usage of geotextile containment systems for riverbank erosion protection in Malaysia. The first case study concerns the riverbank erosion protection of Rasau River in Sepang using green geotextile bags with geogrid anchorage tail. The second case study relates to the river widening and flood control project of Jimah River in Negeri Sembilan using green sand filled mattresses.

2 EROSION PROCESS AND MECHANISMS

Riverbank erosion is the wearing away of earth material on the riverbank through natural agents such as flowing water or wind. The main driving forces behind this erosion process is the hydrologic cycle. Hydrologic cycle can be defined as the circulation process of water from the earth surface to the atmosphere through evaporation or transpiration and from the atmosphere back to the earth surface through precipitation. This process involved the exchange of energy where the water at the earth surface absorb the solar energy from the sun to evaporate and the water vapor then condenses to form cloud. Later, they will fall back to the earth surface as precipitation. At this stage, most of the precipitation will fall back into the ocean while some of it will fall onto land. For precipitation falling onto land with higher altitude than the sea level, the water will have higher potential energy. Water with higher potential energy will flow through rivers towards area with lower potential energy, which eventually is the ocean. The flow of water in the river can cause the erosion of the riverbank and is discussed in this paper.

Erosion mechanism comprises of three different steps, namely detachment, entrainment and transport (Yee, 2012). Detachment is the process where the soil particle is removed from the earth surface through impact of raindrop, running water scouring action, flowing debris abrasion or wave breaking action. After the soil particle detached from the earth surface, the soil particle is entrapped in the water by fluid drag, this process is called entrainment. If the velocity of the current is high enough, the soil particle will be transported until the velocity is lower than the settling velocity. Figure 1 shows the erosion and settling velocities for different soil particles sizes.

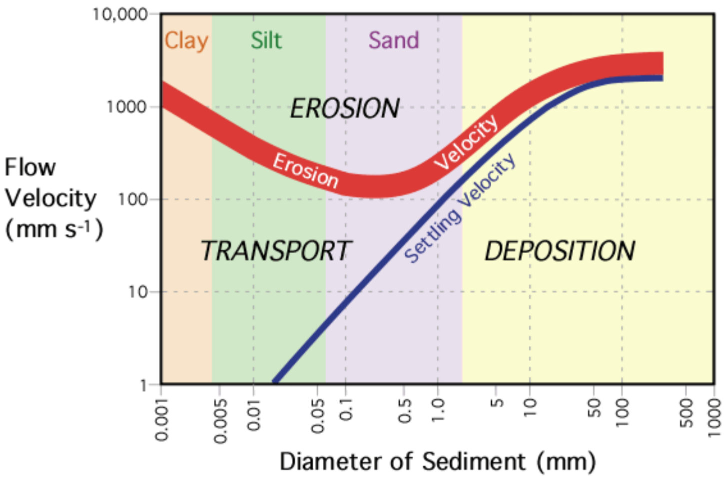


Figure 1. Erosion and settling velocities for different soil particles sizes (Pidwirny, 1999).

3 TRADITIONAL METHODS OF PROTECTION

It is crucial that certain protection measures are to be taken to prevent erosion from occurring especially in places where economical losses can be great. Traditional ways to protect the riverbank are either rock-based system or concrete-based system. The basic idea is to provide a larger and heavier unit as the cover layer of the structure. This larger unit can either be rip-rap, rock armor, precast concrete block or slab unit. When using this kind of systems, often a secondary or tertiary sublayer will be required. This is because not only the outer layer need to be hydraulically stable, the sublayer also need to be design in such a way that it will not be washed out from the cover layer when subjected to hydraulic loading.

In recent developments, it has become a norm that geotextile filter layer is used as a standard component in revetment structure to replace the requirement of multiple granular filter layer (Pilarczyk, 2000). However, the cover layer is still composed of rock or concrete material. The cost of using rock armor has increased over the years which subsequently increases the construction cost. The cost is even higher if rock is not available locally and transportation fees need to be considered to transport the material from a quarry far away. Hence, engineers are always looking for cost effective alternative methods to substitute the usage of rock.

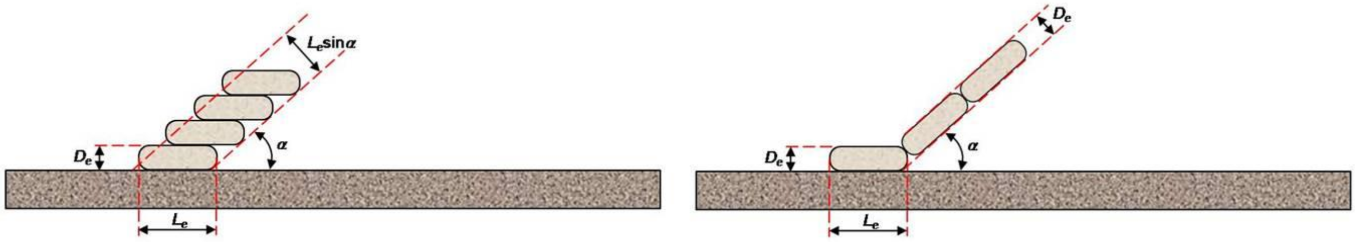
Apart from the cost to construct rock-based and concrete-based revetment, it is also visually unattractive as it has altered the natural appearance of the river.

4 GREEN REVETMENT SOLUTIONS

The earliest recorded usage of sand filled geotextile bags is in The Netherlands and Northern Germany in 1950s (Koerner, 2016). This recorded the usage of geotextile containment system, where geotextile is used to encapsulate the fill material such as sand to form a larger and stable unit. Nowadays, geotextile containment systems have developed progressively and can be categorized into three main categories, namely geotextile bags, geotextile mattresses and geotextile tube. In this paper, only geotextile bags and geotextile mattresses are discussed as geotextile tube is a significantly larger and heavier unit which is normally used in coastal environment subjected to severe hydraulic loadings.

4.1 *Conventional geotextile bags*

Geotextile bags come in different shapes and sizes, with fill volume ranging between 0.3 to 10 m^3 (Bezuijen and Vastenburg, 2013). Typical geotextile bags found in the market today are either pillow-shaped or box-shaped. A pillow-shaped geotextile bag comprises of two overlapping rectangular layers of specially engineered fabric and sealed along three sides. A box-shaped geotextile bag comprises of several pieces of geotextile sealed along the edges to form a box like unit. Basically, geotextile bags can be installed with two types of geometry. Figure 2(a) shows Geometry I where the geotextile bags are placed horizontally with overlap against each other. Figure 2(b) shows Geometry II where the geotextile bags are placed in inclined position following the profile of the slope surface. These two-different installed geometries will result in different effective thickness of the system which will also affect the hydraulic stability of the structure. During the installation of geotextile bags system, a layer of filter geotextile is always required behind the geotextile bags to prevent erosion of the subsoil though the gap formed in between the adjacent geotextile bags.



(a) (b)

Figure 2. Geotextile bags arrangement (a) geometry I (b) geometry II (Yee, 2016).

Although geotextile bags can be filled with varied materials such as sand, earth, gravel or concrete, the preferred fill material is sand. This is due to several reasons such as it is available in copious quantities locally, mechanically and volumetrically stable together with a predictable engineering property. It is also of great importance that the installed geotextile bags will not undergo any significant changes in shape overtime which will affect the overall stability of the structure. Thus, it is crucial to maximize the fill density and volume of the geotextile bags. To achieve this, water can be introduced during filling of geotextile bags to compact the sand fill hydraulically.

Geotextile bags system used for riverbank erosion protection comes with several advantages when compared to the traditional rock-based system. First, the size and shape geotextile bags can be tailored made to fit site requirement such as design hydraulic loading. Besides that, locally available sand is normally used to fill the geotextile bags and this will reduce the overall material and transportation cost. Other than that, geotextile bags system is formed from separate units, it is relatively easier to repair if there are damage found. By using geotextile bags system, a relatively steep slope comparable to rock-based system also can be constructed.

4.2 *Conventional sand filled mattresses*

Sand filled mattresses are formed from two interconnected pieces of geotextile, stitched together at a regular interval to create a tubular filling spaces. The parallel stitches are meant to prevent the movement of sand and to create a definite circumference for the tubular compartment. The filled thickness of sand filled mattresses is controlled by the circumference of each tubular compartment which is restrained by the spacing of the parallel stitches. The effective thickness of sand filled mattresses which is a crucial parameter in withstanding the hydraulic action is determined by a ratio of 0.6 to 0.8 of the whole diameter.

Sand filled mattresses are normally supply in a roll form with the parallel stitches running lengthwise. Some cutting and stitching work need to be done at site to form several strips to fit the slope length. Stitching or lacing can be done on the precut strips of sand filled mattresses to create a continuous piece of sand filled mattresses, thereby reducing the need of overlapping. The sand filled mattresses should be securely anchored to the top of the slope by anchor trench to prevent sliding down of the mattress during and after installation. Sand will be hydraulically filled into the mattress providing maximum density and weight to the structure that will enhance the stability under hydraulic actions.

4.3 *Green geotextile bags and sand filled mattresses*

Conventional geotextile bags and sand filled mattresses are made of woven, nonwoven or combination of both geotextile. Most commonly available type of geotextile bags is made from either polyamide (nylon), polyester (PET) or polypropylene (PP). These types of materials are relatively less expensive but are less robust and may not last for a long time. As the nature of the geotextile which made from polymer, it is subjected to degradation when exposed to ultraviolet (UV) radiation. The geotextile will gradually lose strength when subjected to UV attack until a point where the geotextile will rupture and the fill material will be eroded away and subsequently lost its function as erosion protection system. Normally, for these to be function as permanent solutions, one or more layer of granular materials will be required to cover the geotextile bags. This is to protect the geotextile bags from UV attack while minimizing the risk of geotextile bags being puncture from impact of flowing debris. However, uncontrolled placement of granular material on geotextile bags also tends to damage the geotextile skin.

As conventional geotextile bags and sand filled mattresses are not suitable to be used as permanent solution in exposed environment, a new green material has been developed to be used in this kind of environment. This green material is formed from needle punching highly UV stabilized PP coarse grain fibers into a woven PP geotextile base. The woven PP geotextile base will provide the strength required during installation and throughout the service life of the structure to contain the fill material while coarse grain fibers will shield the woven PP geotextile base from UV attack. The coarse grain fibers layer also acts as a cushioning layer to provide extra protection to the woven base from impact during installation and flowing debris.

Geotextile bags and sand filled mattresses made from this composite geotextile are green in two senses. First, with the green color coarse grain fiber, the completed structure will immediately blend in with the green environment. Secondly, after the needle punching of coarse grain fibers into the woven geotextile, it will form a highly porous surface which will able to trap sediments. This will again provide another layer of protection against UV attack and allow vegetation to growth on it. If the environment is suitable for vegetation growth, it will naturally grow on the surface of geotextile bags or sand filled mattresses without the needs of hydroseeding. Later, the riverbank surface will be fully cover with vegetation and leave no signs of synthetics materials behind.

5 CASE STUDIES

5.1 *Rasau River channel realignment project*

The project site is in the sub-district of Dengkil, Sepang in Malaysia (see Figure 3). The total length of Rasau River is around 6.5 km with a catchment area of about 59.1 km^2. It is one of the tributaries of Klang River. Rapid development and urbanization has cause the natural landscape to be replaced with impervious surface. Consequently, water infiltration into the ground is reduced while increasing surface runoff to river. This increases the peak discharge volume and results in higher flow velocity together with water level rising. The low-lying areas surrounding the river will be prone to flooding due to the increasing of water level during extreme event. A higher riverbank level is needed to counter the effect of increasing water level.

At the same time, the increase in flow velocity increases the severity of the riverbank erosion process. This problem is brought to attention as several numbers of properties located alongside the river are subjected to immediate threat if the erosion process continues.

In this project, a riverbank of up to 4.5 m in height and slope angle of 45° was proposed. Green geotextile bags have been used to provide erosion control for around 1.1 km length of the riverbank. To cater for the slope stability, one-meter length of geogrid is pre-stitched to the green geotextile bags with dimension of 1.2 m x 1.8 m (unfilled) have been used in this project. When filled with sand to a thickness of about 0.3 m, each geotextile bag was estimated to weight around 700 kg. Figure 4 shows the typical section of the proposed riverbank erosion protection.

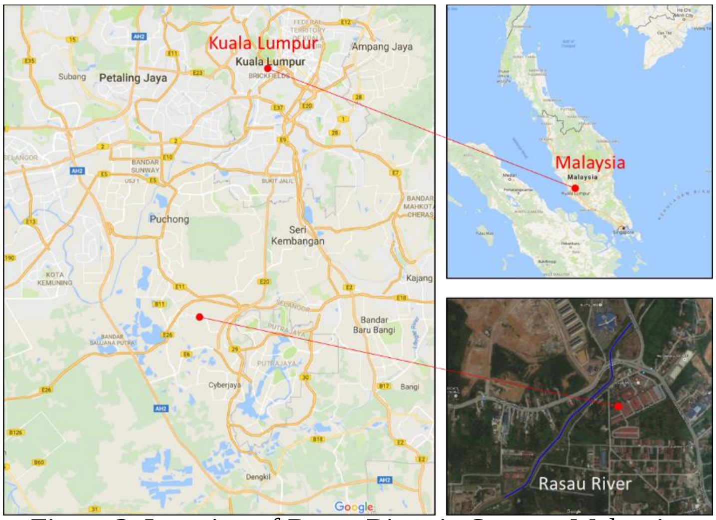


Figure 3. Location of Rasau River in Sepang, Malaysia.

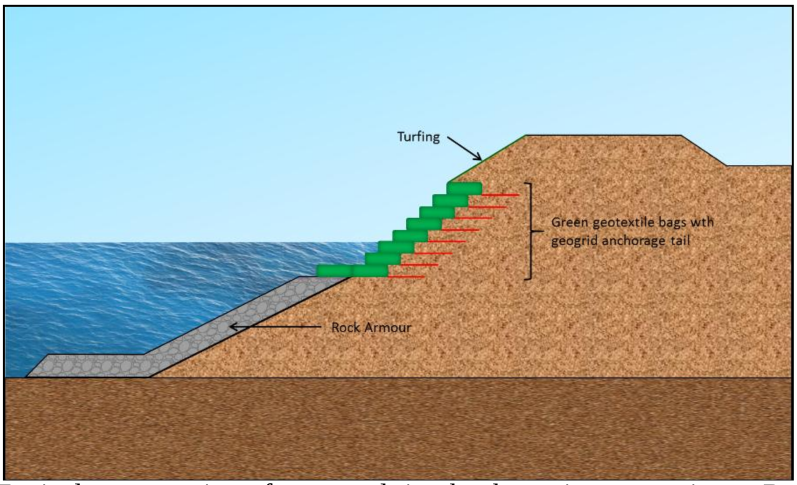


Figure 4. Typical cross section of proposed riverbank erosion protection at Rasau River.

The construction began with the grading and slope preparation of the riverbank. The geotextile bags were filled to the desired volume at site with the help of a supporting frame before closing the geotextile bags with stitching. The filled geotextile bags are then transferred to the installed location using an excavator with heavy duty strap. The geotextile bags are then aligned and compacted along the riverbank profile. A layer of non-woven geotextile has been placed behind the geotextile bags before back filling with sand to prevent the sand from seeping through. Figure 5 show the photos taken after the completion of the construction at different dates.


(a) (b)

Figure 5. Photos taken on Rasau River on (a) 8th June 2016 (b) 24th October 2016.

5.2 *Jimah River channel widening and flood control project*

The project involved Jimah River in Negeri Sembilan, Malaysia (see Figure 6). The riverbank upgrading work was mainly to widen the river and provide erosion protection to the riverbank.

Figure 6. Location of Jimah River in Negeri Sembilan, Malaysia.

In this project, green sand filled mattresses have been used to protect the riverbank. The green sand filled mattresses used are supplied in a roll form with 3.8 m width and 40 m length. Ten tubular compartments are formed through parallel stitchings space 0.35 m apart. After the mattress is filled with sand, it will have an effective thickness of 0.16 m. Figure 7 shows the typical section of the proposed riverbank protection. The mattress was precut to a suitable length to fit the slope length of the riverbank. A trench was excavated above the riverbank and one end of the sand filled mattresses is buried in the trench to avoid the sand filled mattresses from sliding down the slope during installation. Sand is then introduced into the tubular compartments of the mattress hydraulically. Adjacent pieces of sand filled mattresses are then connected using hand lacing to provide continuity to the erosion protection system. Figure 8 shows the photos taken after the completion of the construction at different dates.

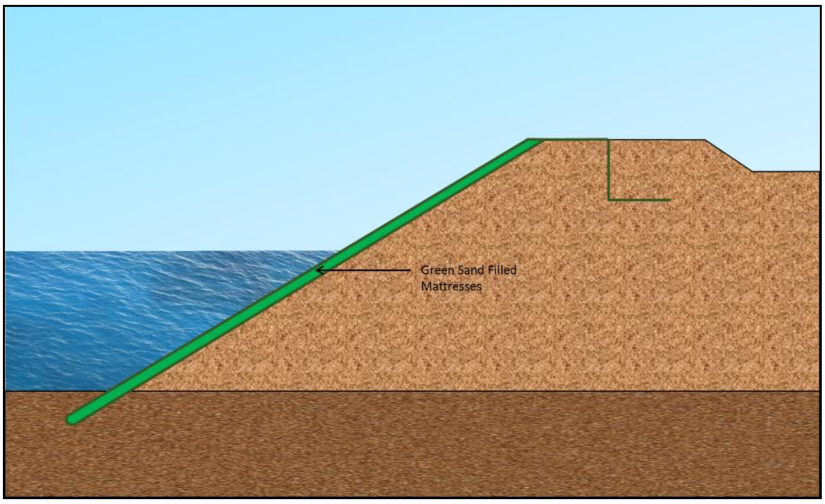


Figure 7. Typical cross section of proposed riverbank erosion protection at Jimah River.

(a) (b)

Figure 8. Photos taken on Jimah River on (a) 23th July 2015 (b) 26th October 2017.

6 DISCUSSION AND CONCLUSIONS

As the result of urbanization, surface runoff has greatly increased over the years. More and more natural rivers are now required to withstand higher water flow velocities and water levels. Riverbank protection needs to be taken into consideration even before any developments to prevent economical losses. Green geotextile bags and sand filled mattresses are suitable to be used as a riverbank erosion protection system due to its ability to promote vegetation to grow on it and also the green color coarse grain fibers allow the systems to blend in with the environment immediately. The differences between geotextile bags and sand filled mattresses are that geotextile bags always used in rivers subject to higher flow velocity while sand filled mattresses generally used in relatively straight section of river with low turbulence and lower flow velocity. The case studies presented here show the successful usage of green geotextile bags and sand filled mattresses as riverbank erosion protection. Vegetations can grow on it after a few months without the needs of human intervention. The vegetations have covered the riverbank and leave no signs of manmade structure behind, returning the river to its most natural state.

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