A STUDY OF BANK SLOPE BEHAVIOR AND EROSION PROTECTION THROUGH NATURAL GEOTEXTILE AND GEOCELL

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Abstract

Bank erosion problem occurs in many areas causing the damages to the resident and properties, hence geotextiles and geocells which normally use for strengthening the soil layer on the road is then introduced to protect the erosion that occurs in the bank slope area. Today, people are turning their attention to more environmentally friendly materials due to the impacts of global warming situation. This situation occurs from the large amount of plastic and microplastic being exposed into the environment. In order to reduce the use of plastic, alternative material should be introduced. According to the research, water hyacinths present in large amounts all around the world causing an obstruction to the source of transportation and drainage system. Therefore, this study aims to find the possibility of using water hyacinth which is abundant in many areas as the alternative resource for geotextile and geocell. The experiment was conducted in the large-sized open-channel flume, with the bank slope ratio of 2:1 which protected by geotextile and geocell on its surface. Different materials of geotextile and geocell were tested. The deformation of the slope from the erosion under different Reynolds number and time was observed and collected in order to see the erosion protection efficiency of each types of material. After the bank slope protection materials was installed, the results show that the erosion protection efficiency of geotextile and geocell for both using water hyacinth fiber and plastic give a remarkably result comparing with the slope without protection. Therefore, water hyacinth fiber can be used as an alternative material which helps in reducing of its large amount and eco-friendly material.

Keywords: *Bank protection, Geocell, Geotextile, Water hyacinth*

1. INTRODUCTION

In the past, Thai people usually settled on the waterfront to facilitate their livelihood, travel or trading. Hence, it was common for many dwellings to be located on the banks or near the waterways. Nowadays, there are many news reports on the bank collapses in many areas that led to the injuries of residents and damage of properties. These problems mostly caused by water erosion. Erosion is the transport of sediments, the causes of erosion include flowing water, wind, wave etc. In this case, when the water flow through the sloping area, water erodes the surface and transfer the sediment to the other area which cause the disappearance of the slope surface and the subsidence of the area. Therefore, geotextiles and geocells are then introduced to protect the erosion that occurs in the bank slope area. Geotextile refers to permeable fabric or synthetic material which can be used to protects soil surfaces from the tractive forces of moving water and stops sediment particles which suspended in the surface of fluid flow while allowing the fluid to pass through [1]. Geocell is a three dimensional geocellular confinement system which generally used to control erosion on slope. It helps by confining soils or aggregates within the cell structure as a prevention of topsoil loss. Within the cells, the infill is based upon the appropriate materials that is suitable for the area. Over the past few years, the term of environmentally friendly materials has played a major role in our society due to the impacts of global warming situation. The idea of manufacture geotextile and geocell using the natural material is then developed. According to the previous research, Urantinon and Pilailar [2] mentioned that water hyacinths is one of the fastest growing plants and present in large amounts all around the world. Because of its ability to adapt and reproduce, an obstruction to the source of transportation and drainage system might be caused. With the abundant amount of water hyacinth, the possibility of using it as the alternative resource for geotextile and geocell manufacturing is then brought into consideration.

Methacanon et al. [3] has investigated several properties of natural fiber. Considered water hyacinth fiber, it can absorb the moisture up to 120% at 23 °C with 97% relative humidity as illustrated in Fig. 1 which mean the water hyacinth fiber can absorb and hold up more water than its body weight which help in keeping the soil surface moist even in low water level conditions. Figure 2 shows the results of tensile strength, and elongation at break value of natural fiber. The tensile strength of water hyacinth fiber is higher at approximately 40 MPa in wet condition while lesser of 30 MPa in dry condition. For elongation break, the water hyacinth fiber shows a significantly different in value between wet and dry condition of approximately 25% and 10% respectively. Hence, water hyacinth fiber has an ability to absorb well and perform better in wet condition.

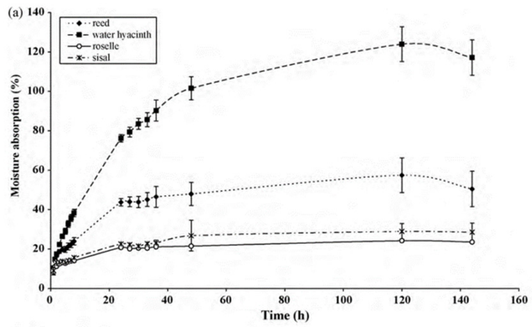


Figure 1 Moisture absorption of natural fibers at 23 °C with 97% relative humidity [3]

In this study, water hyacinth was fabricated as woven geotextile and geocell and installed on the slope to help in stabilization and reduction of sediment loss from the slope. According to the research of Artidteang et al. [4], Fig. 3 has investigated the tensile strength of woven water hyacinth fiber of different pattern. The results show that the plain pattern gives the highest tensile strength, followed by hexagonal and knot-plain, respectively.

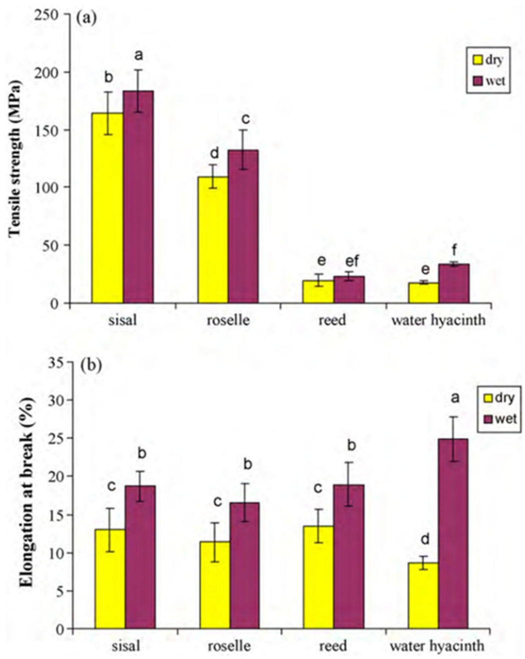


Figure 2 (a) Tensile strength, (b) Elongation at break of natural fibers [3]

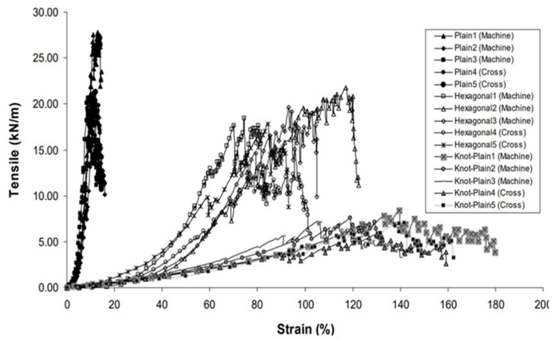


Figure 3 Comparison of tensile strength of woven water hyacinth fiber for all patterns [4]

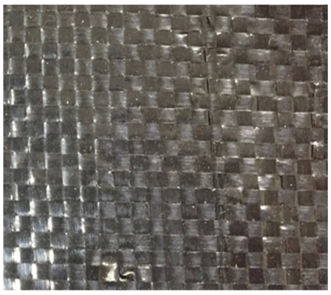
The experiment is conducted physically in the straight open-channel flume. The different material of geocell and geotextile between plastic and natural material will be tested in order to compare the result. This research investigates the effectiveness of erosion protection of the bank slope between plastic and natural geotextile and geocell. The aims of this research are to study and compare the efficiency of erosion protection through natural geotextile and geocell, also, introducing the natural material as the alternative source for the manufacturing of geotextile and geocell.

2. EXPERIMENT DESIGN

As the purpose of this research is to study the behavior of bank slope erosion protection through different materials. Installing the protection devices in the actual area would be difficult and time taking. Therefore, this experiment was conducted in the hydraulic flume to observe the behavior of bank slope erosion protection in order to compare the effectiveness of the materials used for the protection devices.

2.1. MATERIALS

2.1.1. GEOTEXTILE



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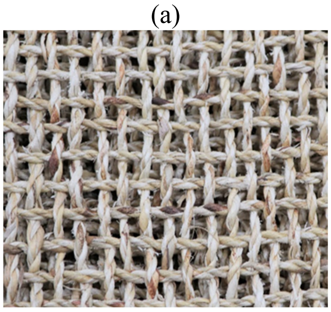


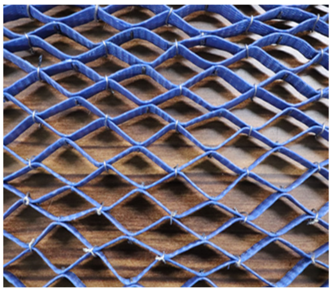
(b)

Figure 4 (a) Plastic geotextile (b) Water hyacinth geotextile with the opening size of 8 mm. x 8 mm.

To compare the effectiveness between different bank slope protection material, plastic geotextile as shown in Fig. 4a which will be using in the experiment as a filter layer between soil and amour layer can be found widely whereas the woven water hyacinth geotextile in Fig. 4b with the opening size dimension of approximately 8 mm. by 8 mm. was crafted by hands. The pattern use for the woven water hyacinth geotextile is plain pattern as it gives the highest tensile strength comparing with the other pattern.

2.1.2. GEOCELL

For both plastic and water hyacinth of honeycomb three dimensional structure geocell will be used as an amour layer to protect the erosion occur at the surface of the bank slope. The dimension of geocell is 0.02 meter wide, 0.025 meters long and 0.015 meters deep of each cell for both plastic and water hyacinth materials. Plastic geocell and water hyacinth geocell are shown in Fig. 5a and Fig. 5b respectively.



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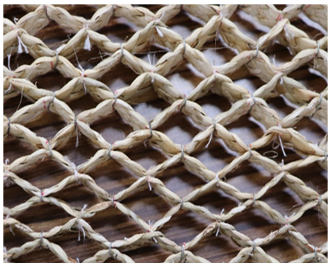


(b)

Figure 5 a) Plastic geocell b) Water hyacinth geocell

2.2. RESEARCH INSTRUMENT

This experiment was conducted in a large open channel flume pictured in Fig. 6 at King Mongkut's University of Technology Thonburi. The dimensions of the flume are 12 meters long, 0.6 meter wide and 0.8 meter high with the acrylic wall. A centrifugal pump is used to create and recirculate the water discharge for the whole system. The maximum capacity of the water tank of this flume is 1.905 cubic meters. The discharge measurement was done by using a sharp crested 60 degree angle V-notch weir.

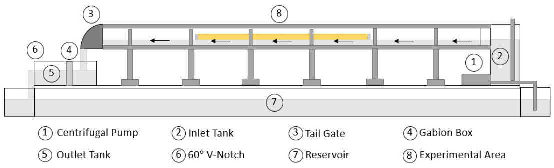


Figure 6 Open-channel flume at King Mongkut's University of Technology Thonburi

2.3. *PARTICLE SIZE DISTRIBUTION*

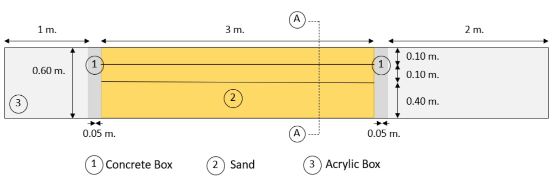
Non-cohesive river sand used in this experiment was tested according to ASTM D 422 to determine the grain size distribution and uniformity of the sand. The importance parameter is summarized in Table 1. The experimental sand is classified as poorly-graded sand.

Table 1 Summary of importance parameter in the grain size distribution

Parameters	Particle size
D_{10}	0.158 mm.
D_{30}	0.209 mm.
D_{50}	0.325 mm.
D_{60}	0.370 mm.
Uniformity coefficient C_u	2.057
Coefficient of curvature C_c	0.851

2.4. *EXPERIMENTAL SETUP*

The experiment was conducted in the large-sized open channel flume, with the bank slope ratio of 2:1 (Vertical: Horizontal) and the length of study area is 3 meters. The bank slope was formed manually with the control volume of 0.36 cubic meter. The dimension of bank slope and its bed are illustrated in Fig. 7.



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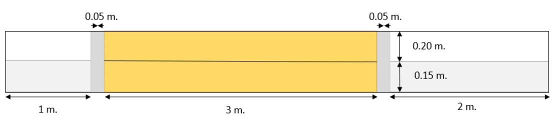

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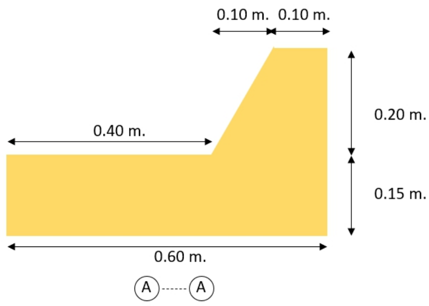

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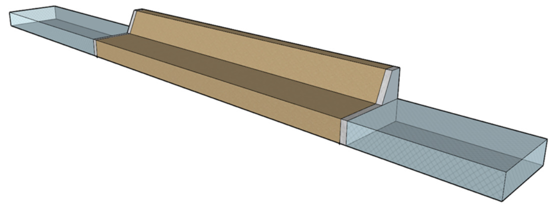


(d)

Figure 7 (a) Top view (b) Side view (c) Front view (d) Isometric view of the installation of bank slope and its bed

There are 5 different cases in this study which are:

Case 1: No Protection (C1)

Case 2: Plastic Geocell (C2)

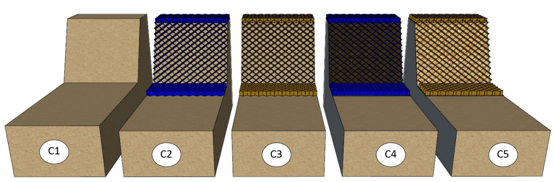
Case 3: Plastic Geotextile and Geocell (C3)

Case 4: Water Hyacinth Geocell (C4)

Case 5: Water Hyacinth Geotextile and Geocell (C5)

The installation of each cases are shown in Fig. 8.

(a)



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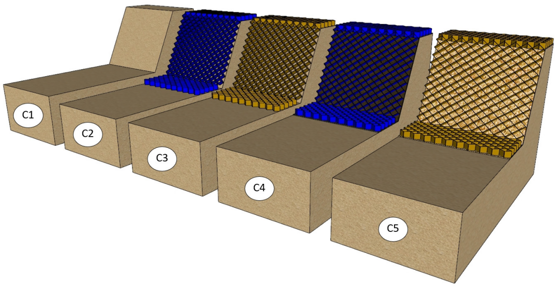


(c)

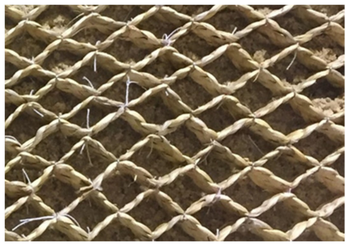
Figure 8 (a) Initial bank slope without protection, (b) Side view (c) Isometric view of each cases before infilling the sand on the surface of geocell

To calculate and analyse the effectiveness of the erosion protection of the bank slope between plastic and natural material of geotextile and geocell, the deformation of the slope from the erosion under different Reynolds number and time was observed and collected. The 6 different discharge will be tested in this experiment for each material. The surface erosion depth of the bank slope is considered for all cases. The results are compared and analyzed for each case.

3. RESULT AND DISCUSSION

3.1. PHYSICAL APPEARANCE OF NATURAL MATERIAL

During the experiment, the physical appearances of water hyacinth fiber that has been observed. Figure 9a shows the original state of water hyacinth fiber geocell before installing into the soil surface. At the condition where water hyacinth fiber soaked in the water, the fiber absorbed the water causing the expansion of its fiber shown in Fig. 9b, this might help in increasing the compaction of the soil in between the cell during the experiment. The fiber is then left to dry under the sun causing a bit of deformation in its shape and become flatten as shown in Fig. 9c. Figure 9d, the geocell is left in the soil in damp condition with poor ventilation and lack of sunlight for 3 days. The fungi are then produced on the surface of geocell as it is common for fungi to grow in this condition. The fungi normally will be decomposed organic matter, in this case, water hyacinth geocell. By the observation at the same condition where fungi happened, water hyacinth fiber that fully submerge in the water was not appeared to have any fungi.



(a)

(b)

(c)

(d)

Figure 9 Water hyacinth fiber (a) before soaking in water (b) after soaking in water (c) after left to dry (d) when left in the soil in damp condition, poor ventilation and lack of sunlight for 3 days

3.2. THE EFFECTIVENESS OF EROSION PROTECTION OF THE BANK SLOPE BETWEEN PLASTIC AND NATURAL GEOTEXTILE AND GEOCELL

To compare the effectiveness of erosion protection of the bank slope between different materials, 6 different flow rates had been choosing to observe the trend of the maximum depth of the surface loss at the bank slope.

Time taken in each experiment is exactly two hours. The six discharge values were calculated as Reynolds number (Re). Re of these discharges are 1655, 4569, 10293, 17371 and 58312. Only one case is in laminar and other five cases are turbulent. During the experiment Re of 58312 is found to be the minimum Re that cause the no protection case to totally collapse. To get the accurate results of each different discharge, the experiment is carried out at least thrice. The erosion depth of the bank slope (D) with the protection devices are collect by selecting at least 20 cells to measure and calculate the average erosion depth of the surface slope. In this experiment depth of the bank slope (D_0) is 0.2 m. Figure 10 shows the position of the depth and erosion depth of the bank slope.

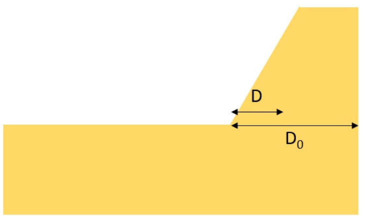


Figure 10 Position of the depth and erosion depth of the bank slope

The erosion protection efficiency was calculated by the equation given in Eq. (1)

$$(\%)\text{Protection Efficiency} = \frac{D_0 - D}{D_0} \times 100 \quad (1)$$

where D_0 = Depth of the bank slope (m)

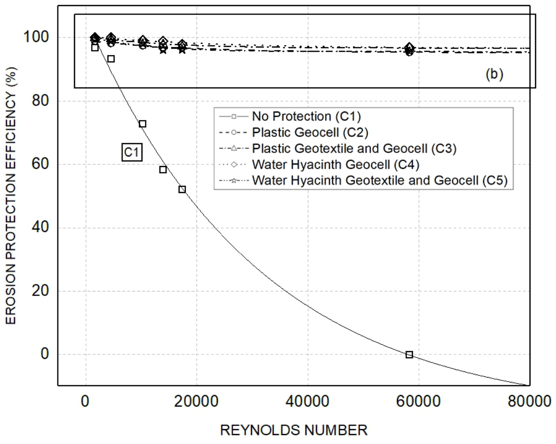
D = Erosion depth of the bank slope (m)

The experimental results and the trend of the percent erosion protection efficiency of the bank slope between plastic and natural geotextile and geocell at different Re are shown in Table 2 and Fig. 11, respectively.

The graphs in these figures are determined using exponential trendline. According to Fig 11a, the results show the drastically different between bank slope with and without protection. Bank slope with the protection shows the better result for all the values and the efficiency of the protection is at least 90% for all cases comparing with its original state. As mentioned earlier, only one case is in laminar and other five cases are turbulent. The case with laminar of 1655 of Re which is almost becoming the transition state give the efficiency at approximately 99% for all cases with protection. Hence, at laminar with the protection will protect the bank slope surface up to 100%. For all the cases, the trends are similar as the protection efficiency is decreasing with the increasing value of Re due to the stronger turbulence flow acting at the slope surface. Figure 11b shows the graph extension of the bank slope with protection of each cases. The Re of this figure is also extended to see a clearer crossover between the trendline. At the beginning C4 tends to give the best result of protection at the same Re comparing with the other cases. However, around Re of 80000, there is a crossover between C4 and C3 where the protection efficiency of C4 fell more rapidly than C3. For Re less than 80000, the cases of C4 gives the best protection efficiency followed by C3, C5 and C2 respectively while Re more than 80000, C3 is better than C4.

Table 2 Experimental results of the percent protection efficiency of maximum erosion depth of the bank slope between plastic and natural geotextile and geocell at different Reynolds number

Re	Protection Efficiency of Erosion Depth (%)				
	C1	C2	C3	C4	C5
9079	96.8	98.9	99.9	100.0	99.5
13173	93.3	98.2	99.5	100.0	99.0
17230	72.8	97.5	99.2	99.2	98.2
21726	58.3	96.9	97.8	98.9	96.2
27642	52.2	97.0	97.1	97.9	96.2
32727	0.0	95.4	96.9	96.9	95.7



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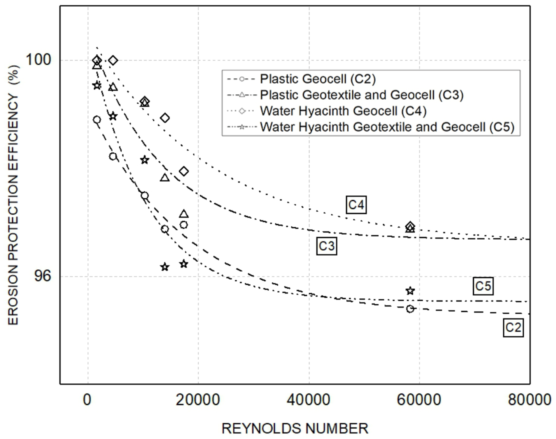
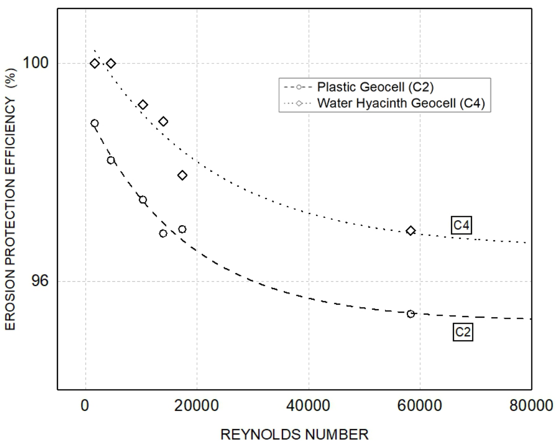


(b)

Figure 11 (a) Overall erosion protection efficiency of the bank slope compared with control case (b) The erosion protection efficiency of the bank slope of different materials



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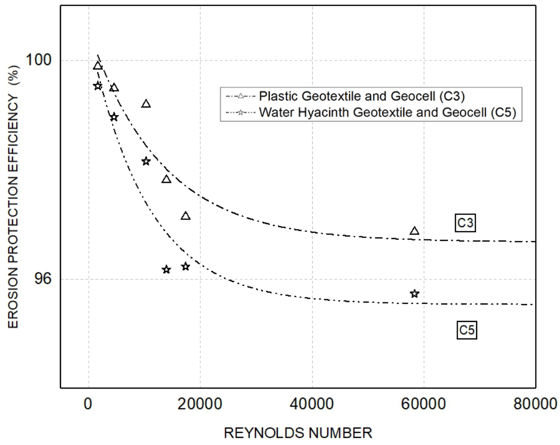

(b)

Figure 12 The erosion protection efficiency of the bank slope using (a) geocell (b) combination of geotextile and geocell as protection devices of different materials

There is a similarity of the trendline in cases of installing the geocell alone and the combination of geotextile and geocell of both materials. The trendline of the installation of geocell in the cases of C2 and C4 as shown in Fig.12a show a lower rate of decreasing comparing with those that have geotextile and decrease continuously as the Re increase. Unlike C2 and C4, the trendline of C3 and C5 with installation of geotextile and geocell in Fig.12b show that the trend decreases greatly at first but the rates of decay become lesser at Re approximate of 40000 onwards and tend to remain stable. Hence, with the same protection devices of geocell and the combination of geotextile and geocell, the results still give the similar trendline regardless of the different materials used.

In the cases where only geocell is installed on the slope, geocell protects the slope surface as the geocell resisted the direct flow acting on the surface. By observing the difference between plastic and water hyacinth fiber, for the cases of plastic the water cannot pass through the plastic surface causing the water to collide with the plastic geocell and change the water direction which avoid the direct shear stress on the surface. Wang et al. [5] investigated the hydrodynamic characteristics using plastic geocell. The result stated that plastic geocell disturbed the flow direction, the water moves along geocell edge and formed a preferential flow. Also, geocell consumed a part of the kinetic energy of the flow causing in the kinetic energy dissipation and the reduction of the slope erosion. Correspondingly, water hyacinth geocell can absorb the water to its saturate point causing the expansion on each cell as shown in Fig. 9b which make sand in the cell become more compacted, water hyacinth fiber allows some of the water to pass through itself which helps in absorbing the energy as well as reducing shear stress acting directly on the bank slope surface similar with plastic geocell.

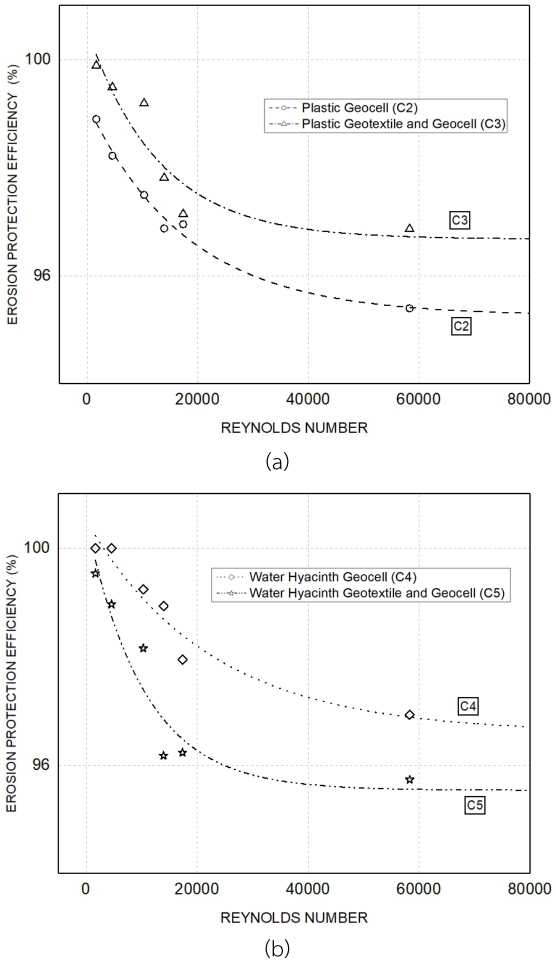

Figure 13 The erosion protection efficiency of the bank slope using (a) plastic (b) water hyacinth as a material

With the combination of plastic geotextile and geocell which help in protecting the soil surfaces and confining the top soil, the case of C3 gives a higher protection efficiency than C2 as shown in Fig.13a. Unexpectedly in Fig.13b, the case of C5 gives the erosion efficiency less than C4 where no geotextile is applied which is different from the cases with plastic material. The cause is likely to come from its ability to absorb well. As stated in Methacanon et al. [3], water hyacinth fiber has a high water holding capacity due to its high hemicelluloses content and the amounts of hollow cavity in water hyacinth fiber greatly contributed to its high water absorption. For the low water level, this ability helps in keeping the soil surface moist. On the other hand, this ability causing the geotextile to swell and expand until reaching its saturation. This high amount of absorption causes the weight of water hyacinth fiber to increase greatly. The installation of geocell alone is already weight contributing, the combination of geotextile will definitely cause the weight acting on the soil surface to become much heavier which could result in the deterioration of the soil surface. Also, the opening size of geotextile become smaller protecting the sand surface under the geotextile. However, the swelling of geotextile push the sand in geocell to come out causing the erosion depth to be higher than C4, hence, reduction in efficiency. Therefore, the erosion protection efficiency of water hyacinth case with geotextile is then become lower than the case without geotextile.

In overall, the cases of bank slope with protection using plastic and water hyacinth give the erosion efficiency of at least 95% at high Re. Therefore, water hyacinth fiber can be used as an alternative material for geotextile and geocell manufacturing due to its high protection efficiency comparing with plastic material.

4. CONCLUSIONS

Water hyacinth causes many problems in the waterways such as obstructing in both transportation and weir drainage causing in the reduction of water flow. This study would not only help in reducing of its large amount but also, enable us to maximize the use of water hyacinth. By applying water hyacinth as an erosion protection material, the study found that the erosion efficiency of both plastic material which is use generally and water hyacinth material give an insignificantly between these materials different. Reynolds number is one of the importance factors impacting the erosion efficiency. The higher the Reynolds number, the lower erosion protection efficiency due to the severity of turbulence flow acting on the slope surface. Despite the strong and turbulence flow, the erosion protection efficiency still gives the minimum of 95% comparing with no protection case.

According to the research, water hyacinth as an environmental-friendly and biodegradable material, products made from water hyacinth fiber could be used up to 5-6 years. However, in contacting with soil the lifespan of water hyacinth products depended on many external factors such as temperature, humidity, radiation, etc. Therefore, water hyacinth can be used as a material in manufacturing of geotextile and geocell in term of eco-friendly material for bank slope erosion protection.

5. REFERENCES

[1] Ferdous, E. N., & Kabir, E. R. B. (2013). The Roles of Geotextile in Erosion & Sediment Control. *International Journal of Clothing Science 2013*, **2**(1), 1-8. DOI: 10.5923/j.clothing.20130201.01

[2] Urantinon, A., & Pilailar, S. (2015). Effect of Water Hyacinth on Open-Channel Water Flow Behavior: Laboratory Scale. *Agriculture and Natural Resources*, **49**(6), 913-923.

[3] Methacanon, P., Weerawatsophon, U., Sumransin, N., Prahsarn, C., & Bergado, D. T. (2010). Properties and potential application of the selected natural fibers as limited life geotextiles. *Carbohydrate Polymers*, **82**(4), 1090-1096.

[4] Artidteang, S., DT, B., Chaiyaput, S., Tanchaisawat, T., & L.G., L. (2016). Performance of Ruzi Grass Combined with Woven Limited Life Geotextiles (LLGS) for Soil Erosion Control. *Lowland Technology International*,**18**(1),1-8.

[5] Wang, G.Y., Liu, Y.H., & Wang, X.H. (2012). Experimental investigation of hydrodynamic characteristics of overland flow with geocell. *Journal of Hydrodynamics*, **24**(5), 737-743.