THE PERFORMANCE EVALUATION OF SCOUR PROTECTION AROUND BRIDGE PIER USING NATURAL GEOCELL AND GEOTEXTILE

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ABSTRACT

The bridge is the structure that builds for crossing the physical obstacle. There are many designs to support the purpose of use. In civil engineering, the important substructure of the bridge that affects the stability of the bridge is the bridge pier. The bridge piers have problems with the foundation surrounding the pier from the erosion by the streamflow that called scour. This study aims to determine the efficiency of geocell and geotextile to protect the riverbed around the bridge pier from the scour. Since the geocell and geotextile are made from plastic, as time passed, the plastic was decomposed to be microplastic which is the major cause of the environmental problems. Nowadays, Water hyacinth has become a major pest in waterways around the world, so the products that make from water hyacinth are helpful for water hyacinth management. Accordingly, the water hyacinth was made to be the geocell and geotextile to compare the efficiency with the plastic material in this study. The experiments were carried out in the large open channel flume at KMUTT. The scour mechanism, and the effect of scouring on the riverbed was studied. Geocell and geotextile were installed in 4 different cases in order to find the most effective protection and reduction from the scour. Maximum depth and cylindrical coordinate points around the pier were measured and collected. The experimental results show the maximum scouring depth is increasing in the function of Froude Number. The bridge pier without geocell and geotextile was conducted to be the reference. The cases of geocell and geotextile that produce by plastic and water hyacinth for protection were carried out to compare and analyze the protection efficiency. For the results, the case of installing geocell with geotextile in both plastic and water hyacinth materials on the riverbed give the most protection efficiency.

Keywords: *Geocell, Geotextile, Water hyacinth, Bridge Pier, Scour*

1. INTRODUCTION

The bridge is the structure that builds for crossing the physical obstacle. There are many different designs to support the purpose of use. In civil engineering, the important substructure of the bridge that affects the stability of the bridge is the bridge pier. The bridge pier is designed to support the load of the bridge and distribute the load to the soil layer. In general, the bridge piers have problems with the foundation surrounding the pier from the erosion by the streamflow called scour. Scour is the phenomena of the streamflow that removes the sediment surrounding the bridge piers and forms to be a hole caused by the separation of streamflow direction that becomes the vortexes and develops into the scour hole. Normally, the scour can be classified into three main types as general scour, contraction scours, and local scour [1]. The scour type that occurs in the removal of sediment around bridge piers is the local scour. Therefore, the protection around the pier was created to prevent erosion that was the main cause of the bridge collapse.

For scour protection, the design must ensure that the equipment, arrangement pattern, and detail of the scour protection should not cause and increase scour problems. The engineering devices for the protection system of scouring around bridge pier are generally classified into two categories which are bed armoring and flow-altering [2].

Bed armoring (Fig.1a) are the structure that significantly enhanced to resist the streambed. The physical property of devices can withstand the shear stresses that impart by the flow.

The flow-altering devices, the principles of flow-altering devices are changing the flow field, reducing horseshoe vortices. For flow-altering devices, they can be separated into two parts, i.e., pier attachment, and bed attachment.

For pier attachment (Fig.1b), scour is reduced by allowing the approach flow to pass through the openings within the pier or among a smaller group of bridge piers, arresting the sinking of horseshoe vortex by providing a rigid surface. Suitable devices can also be attached to the pier to reduce the strength of downflow and horseshoe vortices for scouring mitigation.

For bed attachment (Fig.1c), the devices that are attached to the bed can shield the riverbed around the pier from scouring. These devices can divert the speeding approach flow and modify the boundary layer separation. Consequently, the strength of downflow and horseshoe vortex will be reduced.

In this research, the flow-altering device in the type of bed attachment was considered to study.

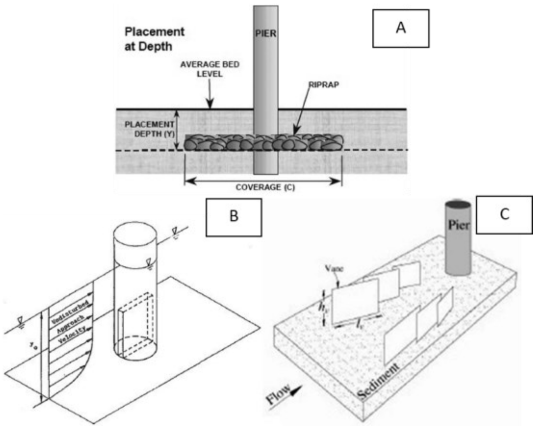


Figure 1 Protection system [2] a) Bed armoring b) pier attachment c) bed attachment

Water hyacinth (Fig.2) has become a major pest in waterways around the world. In Thailand, the department of public works and town & country planning report that 20 million tons of water hyacinths were removed from the waterways from 2014 to 2018 [3]. Water hyacinth is a free-floating perennial aquatic plant native to tropical and sub-tropical South America. Water hyacinth can propagate rapidly. From the rapid propagation of water hyacinth, the water flow in the open channel was obstructed by the density of water hyacinth. The quantity of water hyacinth can be reduced by water hyacinth products. In Thailand, the villagers used the part of water hyacinth to productive, such as the young shoots to make food. The leaves are brought into the machine, forming a food container. The stem is dried to make various handicraft products. Including used to make a cushioning material as well. Therefore, the villagers have the potential to produce the scour protection device from water hyacinth.

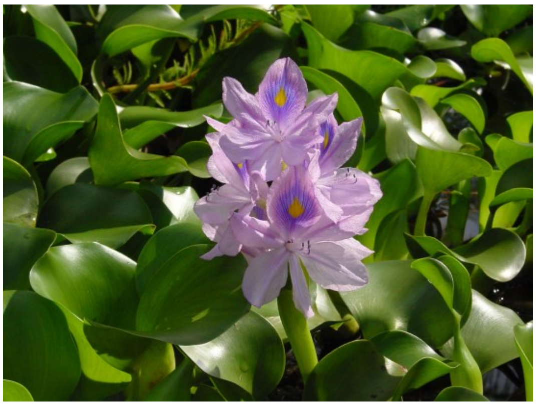


Figure 2 Water Hyacinth

In the previous research, many protection systems were created to solve the scour problem. The products on the market that were geocell and geotextile were claimed that can protect the erosion. Geocell is a three-dimensional structure that was produced from High-Density Polyethylene (HDPE). Geocell has an ability to keep the fill material and protect the sub-surface material from wind and water erosion [4]. Geotextiles are permeable fabrics made from polypropylene or polyester. Geotextile fabrics have three basic forms which are woven, needle punched, and heat bonded. The ability of a geotextile filter is to permit the entry of water however still avoids intermixing of stone and soil. For protection systems, the geotextile is installed at first on the surface after that the geocell is installed and put the fill material in the free space of the geocell. However, there is a lot of previous research study about the protection devices from the scour, and the geocell and geotextile were commonly used as the devices to protect the slope from the landslides. but there is no research using geocell and geotextile to be the protection devices from the scour around the bridge pier. Therefore, the geocell and geotextile were considered to use as the protection devices in this research.

In general, the geocell and geotextile are made from plastic, as time passed, the plastic was decomposed to be microplastic which is the major cause of the environmental problems. In addition, water hyacinth was an important problem for water management, so the products made from water hyacinth will be the solutions for both environmental and water management problems. So, the water hyacinth was produced to be the geocell and geotextile substituted materials from plastic. This can be applied to solve these problems.

For this study, it was of interest to investigate the efficiency of geo-cell and geotextile to protect the scour around the bridge pier and find the substitute materials to reduce the plastic use.

Therefore, this study aims to determine the efficiency of geocell and geotextile to protect the scour around the bridge pier. Moreover, the water hyacinth was produced to be the geocell and geotextile to compare the efficiency with the plastic geocell and geotextile in this study.

2. METHODOLOGY

2.1. MATERIALS

2.1.1. SAND

For the sediment section, the river sand was used to be sediment material in this study. The sand property was presented in Table 1. The grain size distribution curve(Fig.3) was plotted by performing sieve analysis. The sand can be classified as poorly graded sand by the Unified Soil Classification system.

Table 1 Sand property

D10 (mm)	0.158
D30 (mm)	0.209
D50 (mm)	0.278
D60 (mm)	0.325
Uniformity coefficient Cu	2.057
Coefficient of curvature Cc	0.851
Specific gravity	2.65
Unified soil classification system USCS	poorly graded sand

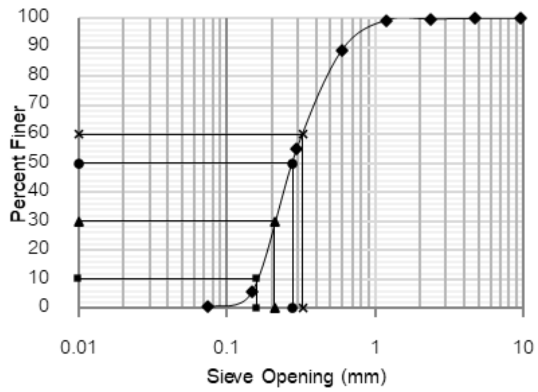


Figure 3 Grain size distribution of sand

2.1.2. PLASTIC GEOCELL

Geocell is one type of geosynthetics. Geocell is formed to honeycomb three-dimensional structure. Geocell can limit the horizontal movement, increase the friction on the soil surface, reduce the surface runoff, and be used for erosion control. In general, geocells have been used for slopes. For installation, the surface can fully fill with the fine aggregate, coarse aggregate, and cover plant. Normally, the geocell was produced from the polyethylene (PE) with a dimension of 0.2 x 0.25 m [5]. In this study, the plastic geocell were produced in the dimension of 0.02 × 0.025 m. with 0.045 m-depth in the shape of a honeycomb by using polyethylene (PE) which means the model was downscale 10 times from the prototype. The plastic geocells were shown in Fig. 4.

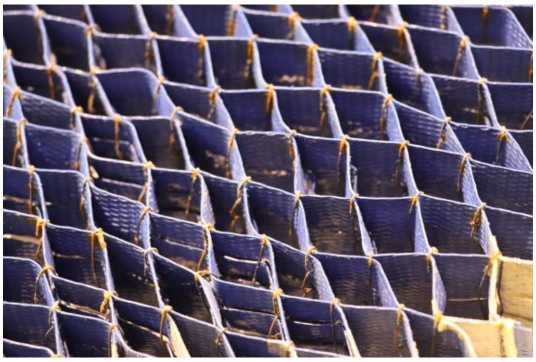


Figure 4 Plastic Geocell

2.1.3. PLASTIC GEOTEXTILE

Geotextile is one type of geosynthetics. Geotextiles have been used as filters for a long time. Geotextile can be classified into two types: woven and non-woven. Geotextile can filtration and drainage, high durability against weather and temperature variations, improve the stabilization of the soft ground, and protect erosion. Therefore, the 3.5 mm woven plastic geotextile in circular shape was used in the experimental test. Figure 5 shows the plastic geotextile.

Figure 5 Plastic Geotextile

2.1.4. WATER HYACINTH GEOCELLS

The properties of water hyacinth fiber have a high ability of absorption and good elongation even in a long time used, but it has low tensile strength, and when time passes the ability to resisting tensile strength decrease [6]. For the water hyacinth geocells (Fig. 6), the dimension was 0.02 × 0.025 m. with 0.045 m-depth in the shape of a honeycomb.

Figure 6 Water hyacinth Geocell

2.1.5. WATER HYACINTH GEOTEXTILE

The water hyacinth geotextile was used to test in the field of soil erosion control. The water hyacinth geotextile has the ability to use in soil erosion control [7]. Therefore, the woven water hyacinth geotextile was considered to use in this study. The 8 mm woven water hyacinth geotextile in circular shape was used in the experimental test. The water hyacinth fiber was produced to be the rope before fabricating into the shape. The circular water hyacinth geotextile is shown in Fig. 7.

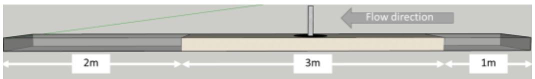
Figure 7 Water hyacinth Geotextile

2.2. EXPERIMENTAL SETUP

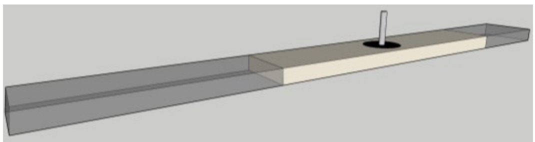
In this research, the rectangular open channel was set up in the Laboratory at the King Mongkut's University of Technology Thonburi. The flume has a working section in a length of 12 m., a width of 0.6 m., and a depth of 0.8 m. A pump can be set the flow to the maximum discharge of water from a water tank with a capacity of 1905 liters. The water flume is shown in Fig 8.

Figure 8 The open channel flume

Raudkivi, et al [8] and Lee, et al [9] recommend that the ratio between pier diameter (D) and the median particle size (D50) should be larger than 25. Melville, et al. [10] have resulted that the maximum scour depth cannot be more than 2.4 times of pier diameter. Therefore, the sand bed height must be higher than 0.144 m. So, the sediment section was installed at 0.15 m. For the study area, the sediment section was set in the middle of the flume with the installing acrylic box at the upper and lower of the sediment section. The diameter of each component is shown in Fig 9. The upstream acrylic box is in width of 0.6 m, length of 2 m, and depth of 0.15 m. The downstream acrylic box is in width of 0.6 m, length of 1 m, and depth of 0.15 m. For the sediment section, the diameter of the section is in width of 0.6 m, length of 3 m, and depth of 0.15 m. The 0.06 m-dimension of the bridge pier model was installed in the middle of the sediment section.



(a)



(b)

Figure 9 SketchUp model of the test section (a) front view (b) isometric view

2.3. EXPERIMENTAL PROCEDURE

In this study, the test can be divided into 5 cases (Fig. 10).

1. Non-protective case (case1)
2. Protective case with plastic geocell (case2)
3. Protective case with plastic geocell and geotextile case (case3)
4. Protective case with water hyacinth geocell (case4)
5. Protective case with water hyacinth geocell and geotextile (case5)

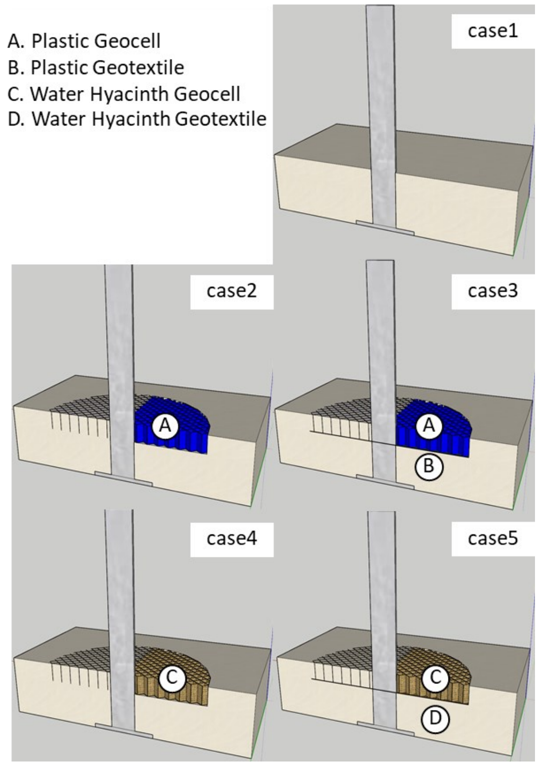


Figure 10 SketchUp model of the experimental cases

In each case, the discharge was varied with the same 5 different Froude numbers. For case 1, the bed around the bridge pier was not protected, and after 2 hours, the scour depths were collected from 8 different points around the bridge pier and collected the 4 different points beside the bridge pier. For case 2, the 0.045m-depth plastic geocell was installed into the sand bed and adjusted to the same level as the bed surface. After 2 hours, the data was collected as same as case 1. For case 3, the plastic geotextile was installed under the geocell and fill the sand to the same level as the bed surface. For cases 4 and 5, the devices were set up like plastic material devices.

In this experiment, there is a comparison of maximum scour depth between the experiment and Colorado State University (CSU) equation. The CSU equation is shown in eq. 1. So, there are 8 points around the pier and 4 points beside the pier were collected to find the maximum scour depth.

The CSU equation, is as follow:

$$\frac{d_{max}}{b} = 2.0K_1K_2K_3K_4\left(\frac{y_1}{b}\right)^{0.35} Fr^{0.43} \quad (1)$$

Where

d_{max} = Maximum scour depth (m)

b = Pier diameter (m)

y_1 = Water depth (m)

Fr = Froude number

K_1 = Correction factor for pier nose shape

K_2 = Correction factor for the angle of attaching of flow

K_3 = Correction factor for bed conditions

K_4 = Correction factor for armoring of bed Material

3. RESULTS

3.1. PERFORMANCE EVALUATION OF SCOUR PROTECTION AROUND THE BRIDGE PIER USING GEOCELL AND GEOTEXTILE

Figure 11 shows the comparison of computed maximum scour depth using the CSU equation to maximum scour depth from experiments by plotting the measuring scour depth in the y-axis and computing scour depth in the x-axis. The computed maximum scour depth is from eq. 1 with correction factors as follows: the correction factor for pier nose shape (K_1) is equal to 1.0

from the cylindrical shape of the pier, the correction factor for the angle of attaching of flow (K_2) is equal to 1.0, the correction factor for bed conditions (K_3) is equal to 1.1 from the clear water scour, and the correction factor for armoring of bed material (K_4) is equal to 0.8. Therefore, the CSU eq. is equal to

$$\frac{d_{max}}{b} = 1.76\left(\frac{y_1}{b}\right)^{0.35} Fr^{0.43} \qquad (2)$$

The line of computing value in both of x and y-axis use to compare the effectiveness of the protection. From Fig.11, the location of the points of case 1 is not on the line of computed maximum scour depth with a performance rate of -3.93 to 16.15 which mean the measured maximum scour depth is lower than the prediction, but case 1 is none-protection, so the cause of different from the prediction is the different some condition. Although the maximum scour depth of case 1 is different from the prediction, but the accuracy of the CSU equation is more accurate than the other formula [11].

The performance rate of scour protection was computed from eq. 3.

The performance rate of scour protection equation, is as follow:

$$\frac{\frac{d_{max,theory}}{b} - \frac{d_{max,measure}}{b}}{\frac{d_{max,theory}}{b}} \times 100 \qquad (3)$$

Where $d_{max,theory}$ = Maximum scour depth from theory (m)

$d_{max,measure}$ = Maximum scour depth from measurement (m)

b = Pier diameter (m)

Table 2 shows performance rate of scour protection of each case. For cases 2 to 5, the location of the points is under the line that means the protection can reduce the scour depth, case 3 is the most performance protection from the lowest scour depth when compared with the computed scour depth in the range of 50.11 to 66.34 percent, case 4 is the least performance protection from the percent range of 1.13 to 45.43 which is the lowest performance effective, case 2 and 5 have the percent range of 48.46 to 58.3 and 42.69 to 50.41. However, the scour depths in cases 2, 3, and 5 are close to each other, indicating that the geocell and geotextile can successfully protect the bed from scour.

Table 2 Performance effective of scour protection

Protection device	performance rate (%)
Case1	-3.93 – 16.15
Case2	48.46 – 58.30
Case3	50.11 – 66.34
Case4	1.13 – 45.43
Case5	42.69 – 50.41

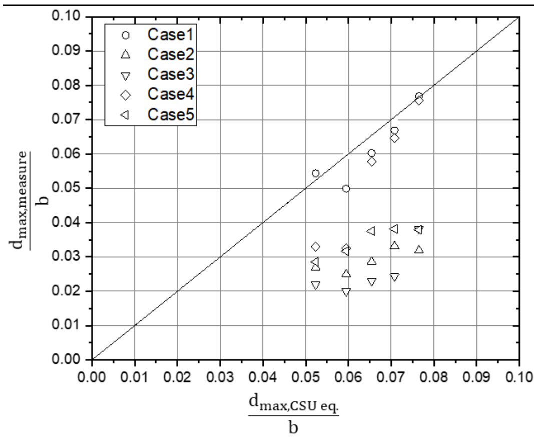


Figure 11 Comparison of computed maximum scour depth using the CSU equation to maximum scour depth from experiments.

3.2. CORRECTION FACTOR FOR GEOCELL AND GEOTEXTILE MATERIAL

The installation of geocell and geotextile has changed the flow direction. Then, the correction factor (K_C) is suggested to adjust the computed maximum scour depth. Figures 12 - 15 show the linear relationship between $\left(\frac{y_1}{b}\right)^{0.35} Fr^{0.43}$ and $\frac{d_{max,\ measure}}{b}$ which is the part of eq.2.

The linear equation is y = mx + c.

From Fig.12, the linear equation is

$$y = 0.4458x \qquad (4)$$

From CSU equation, the $\left(\frac{y_1}{b}\right)^{0.35} Fr^{0.43}$ is x variable, $\frac{d_{max,\ measure}}{b}$ is y variable, and $2.0K_1K_2K_3K_4$ is a slope of graph.

So,

$$y = 1.76K_c x \qquad (5)$$

(4) = (5); $$0.4458x = 1.76K_c x$$

Therefore, the correction factor for case 2 (K_C) is equal to 0.253.

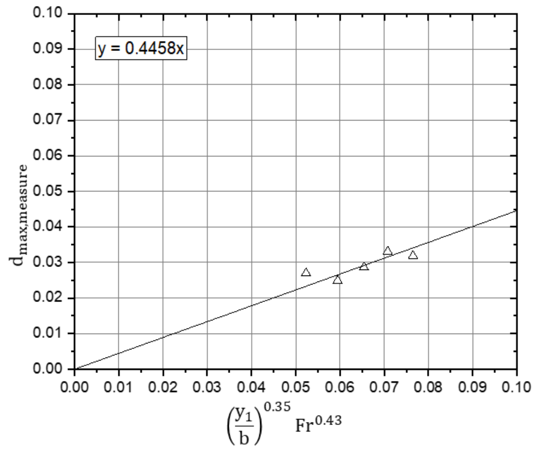


Figure 12 The relationship between $\left(\frac{y_1}{b}\right)^{0.35} Fr^{0.43}$ and $\frac{d_{max,\ measure}}{b}$ of case 2

The linear equation is y = mx + c.

From Fig.13, the linear equation is

$$y = 0.3962x \quad (6)$$

(6) = (5); $$0.3962x = 1.76K_c x$$

Therefore, the correction factor for case 3 (K_C) is equal to 0.225.

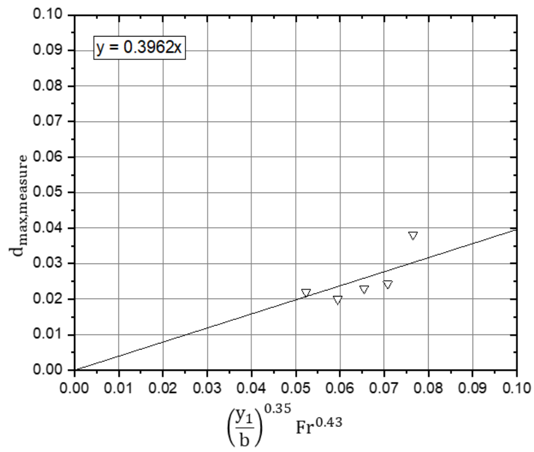


Figure 13 The relationship between $\left(\frac{y_1}{b}\right)^{0.35} Fr^{0.43}$ and $\frac{d_{max,\ measure}}{b}$ of case 3

The linear equation is y = mx + c.

From Fig.14, the linear equation is

$$y = 0.8399x \quad (7)$$

From CSU equation, the $\left(\frac{y_1}{b}\right)^{0.35} Fr^{0.43}$ is x variable, $\frac{d_{max,\ measure}}{b}$ is y variable, and $2.0K_1K_2K_3K_4$ is a slope of graph.

(7) = (5); $$0.8399x = 1.76K_c x$$

Therefore, the correction factor for case 4 (K_C) is equal to 0.477.

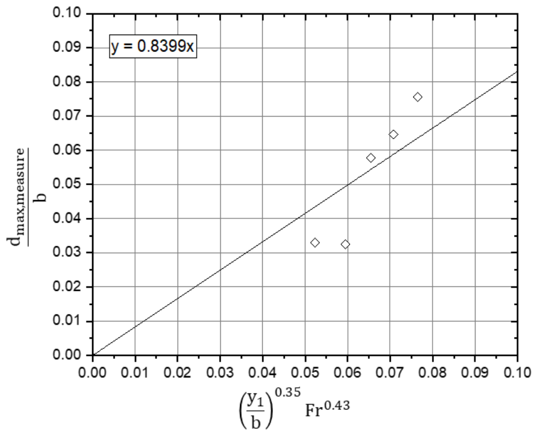


Figure 14 The relationship between $\left(\frac{y_1}{b}\right)^{0.35} Fr^{0.43}$ and $\frac{d_{max,\ measure}}{b}$ of case 4

The linear equation is y = mx + c.

From Fig.15, the linear equation is

$$y = 0.5338x \quad (8)$$

From CSU equation, the $\left(\frac{y_1}{b}\right)^{0.35} Fr^{0.43}$ is x variable, $\frac{d_{max,\ measure}}{b}$ is y variable, and $2.0K_1K_2K_3K_4$ is a slope of graph.

(8) = (5); $$0.5338x = 1.76K_c x$$

Therefore, the correction factor for case 5 (K_C) is equal to 0.303.

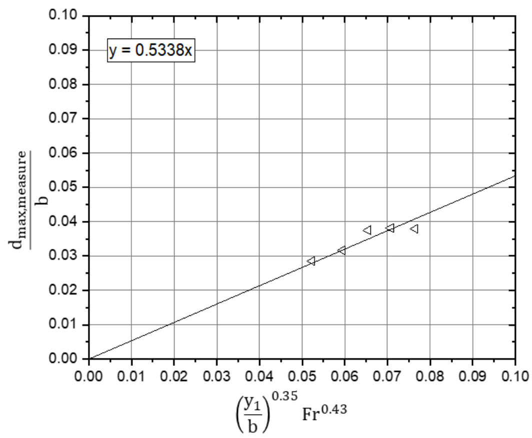


Figure 15 The relationship between $\left(\frac{y_1}{b}\right)^{0.35} Fr^{0.43}$ and $\frac{d_{max,\ measure}}{b}$ of case 5

The correction factor (K_C) for geocell and geotextile was suggested by computed from the slope of the linear equation. The correction factor (K_C) of each case shows in table 4, and the suggested equation is shown in eq.9. The different slope of each graph represents the effect of the device which change the flow direction that affects the sediment transport behavior, therefore, the maximum scour depth design when using the geocell and geotextile must be multiply by the correction factor (K_C) for each device to calculate the correctly predicted maximum score depth. The correction factor (K_C) of each case is different from the different material which affects the flow behavior. In case 4, the K_C is higher than the other case which means case 4 has the lowest performance to protect the bed from the scour, as the property of the water hyacinth absorbs the water into the cell causing the water hyacinth to edema, so the sizing of the water hyacinth is changed and the ability of store the sediment is reduced. However, the installing of water hyacinth geocell with geotextile (case5) has a satisfactory result as the geotextile can reduce the chance that the sediment moves out from the bottom of the geocell, in addition, case 3 is the highest performance of scour protection. Therefore, the installation of geocell with geotextile devices is more performance than the installation of geocell devices in both plastic material and water hyacinth material.

Table 3 Correction Factor

Protection device	K_C
Case2	0.253
Case3	0.225
Case4	0.477
Case5	0.303

The suggested equation, is as follow:

$$\frac{d_{max}}{b} = 2.0K_1K_2K_3K_4K_C\left(\frac{y_1}{b}\right)^{0.35}Fr^{0.43} \quad (9)$$

Where d_{max} = Maximum scour depth (m)

b = Pier diameter (m)

y_1 = Water depth (m)

Fr = Froude number

K_1 = Correction factor for pier nose shape

K_2 = Correction factor for the angle of attaching of flow

K_3 = Correction factor for bed conditions

K_4 = Correction factor for armoring of bed Material

K_C = Correction factor for protection device

4. CONCLUSIONS

The main cause of bridge collapse is the local scour. So, the protection device must be developed to protect the sediment surrounding the bridge pier. In this study, geocell and geotextile were suggested to be the protection device. However, geocell, and geotextile were produced from the plastic which decomposed over time into microplastic, which is the main pollutant of environmental issues. The water hyacinth has become a major invasive species in wetlands all over the world. The density of water hyacinth obstructed the flow in the open channel, which affect the water management in flood season. Although the water hyacinth is an aquatic weed, the strong fiber of water hyacinth can be used. Therefore, the geocell and geotextile produce from the water hyacinth were studied for using to be the protection devices in this research.

Base on the comparison of computed maximum scour depth using the CSU equation to maximum scour depth from experiments. Both geocell protection devices and geocell and geotextile protection devices can obviously reduce the maximum scour depth, besides that water hyacinth material can be used as a replacement material for produce the devices. The installation of geocell and geotextile has changed the flow direction. Therefore, the correction factor to compute the maximum scour depth is suggested.

While plastic geocells and geotextiles can be used as protection devices, water hyacinth is an interesting alternative material for producing environmentally friendly protection devices.

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