A study of the energy reduction of flow through concrete and natural rubber tetrapods

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Abstract

Natural rubber is widely used as a multipurpose material in engineering for several years. Currently, natural rubber in Thailand has been facing with falling price and oversupply problems which extremely damage to a natural rubber industry. Although, Thailand is the world's top producer and exporter of the natural rubber, but it still faces with these problems in many years. Therefore, the propose of this research is to utilize natural rubber for erosion control due to its special properties and also help a natural rubber industry by increasing the value of product. The process of this research is to study and analyze the flow behavior over concrete and natural rubber tetrapods in laboratory. Two-dimensional physical model is carried out in open-channel flume (12 m. long, 0.6 m. wide and 0.8 m. high) at King Mongkut's University of Technology Thonburi. The results are analyzed to compare the ability of energy dissipation between natural rubber and concrete tetrapod. In the conclusion, natural rubber can be applied for erosion control, which has an efficiency of energy dissipation. The maximum ability to dissipate energy by using natural rubber tetrapods is lower than concrete approximately 5%. In addition, based on natural rubber properties, rubber is able to use with sea water condition. Therefore, natural rubber is alternative to use as a substitute material in erosion control field.

Keywords: Natural rubber, Tetrapod, Energy dissipation, Erosion control

1. Introduction

Natural rubber is a versatile material which is widely used around the world. There are several proper properties to be used in engineering such as an excellent tensile, resilience, tear resistance and elongation. Natural rubber obtains from the latex of certain trees and plants. The world's crucial sources of rubber are located in Asia, especially Southeast Asian countries. Hot weather and monsoon climate are significant effect to natural rubber cultivation. Since early 20th century, Thailand has become the world's largest exporter and producer with high quality of rubber. There is around 32,800 km^2 of natural rubber plantation and a full range supply chain of rubber industry. About 1.4 million households are natural rubber agriculturists. Currently, demand of natural rubber is fluctuated. Thailand has been facing with falling price and oversupply problem which extremely damage to a rubber industry in several years. Thai latex association revealed that natural rubber price continuous decrease [1], which is illustrated as a graph in Figure 1. However, due to its special properties, natural rubber can be used extensively in engineering for many applications and products. This research aims to utilize natural rubber in erosion control by using as an energy dissipation material and also increasing the value of rubber product.

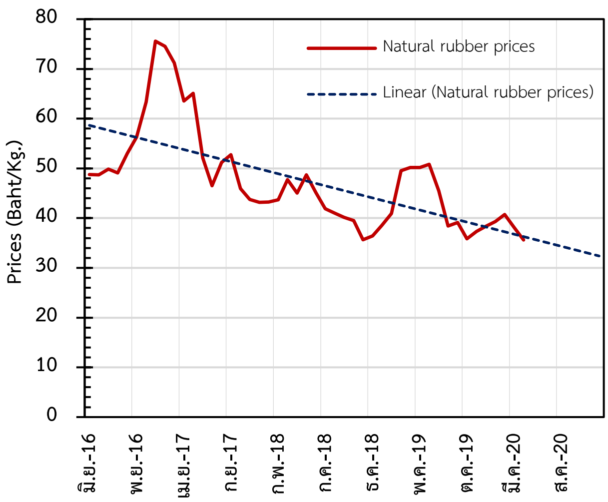

Fig 1. Natural rubber price in Thailand [1]

Thailand is also experiencing coastal erosion almost every year, there are coastline in the gulf of Thailand around 1,878 kilometers and around 937 kilometers facing with Andaman sea. The strong erosion occurs along the coastline with average rate of 5 meters per year [2]. Moreover, river and canal also face with strong erosion problem. In order to protect land from erosion, there are several obstructions that are used to destruct the wave energy or to reflect it. Concrete armor blocks are worldwide obstruction which are used as a revetment and breakwater protection. It not only uses for coastal areas, but concrete armor block is also used in riverside and downstream of dam. During the past years, several shapes of armor block were created. One of the most basic shapes of armor block is tetrapod. There are special legs which can interlock together with the other. However, armor block is normally constructed with concrete. The main problem of concrete armor block is a crack due to cross-section reduction and structural weakness or underweight. Therefore, this research intends to apply natural rubber as a substitute material for erosion control. Tetrapod shape is considered because of easily handled in experiment. The process of research is to analyze flow behavior over tetrapod model and to study the ability of energy reduction between using natural rubber and concrete tetrapod.

2. Literature review

2.1 Artificial armor block

Armor blocks are created for wave dissipation, which are used as a placement of breakwater and revetment. It not only uses for coastal areas, but an armor block also be able to use in riverside such as river bank protection and downstream of dam. Structures such as breakwater and jetty consist of a sloping surface which is exposed directly to the action of water, so an armor block is necessary for the outer layer of the structure to absorb the wave energy and reflect it. A several precast concrete armor unit has invented for a long time. There are many shapes of armor blocks such as a simple cube or the other complex shapes which are shown in Figure 2. Concrete armor units are easily to handle which be able to stand without any steel reinforcement. The tensile capacity and quality of concrete casting are important function for marine structure. Any cracks or large surface defects are used to determine for the performance of armor unit. A Crack is caused by a cross-sectional area reduction of concrete, and a large surface defect may cause of structural weakness or an underweight of the concrete unit. Some units of armor blocks are used in single layer, and some shapes are required in two layers for lump. However, a packed of armor blocks be able to resist the hydraulic loads from the wave impact, but it has never been successful for the very high impact forces of wave [3].

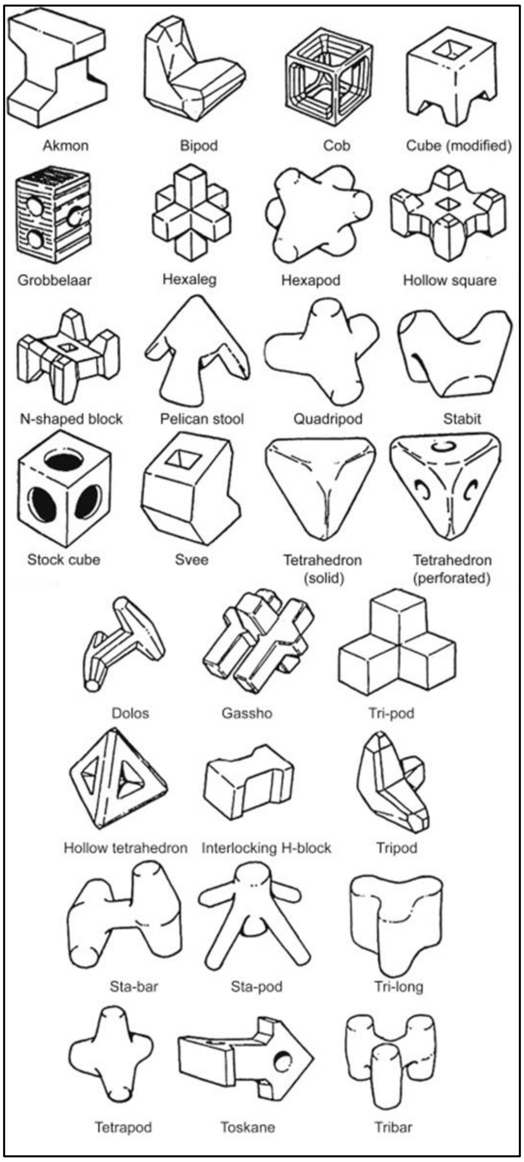

Fig. 2 Shapes of concrete armor block [3]

2.2 Tetrapod

Tetrapod is a type of structure in coastal engineering that used to prevent erosion caused by winds and waves. There were interesting results of the behavior of structure protection. Tetrapod is very stable form in term of hydraulic properties, strength of materials and work site operations. Tetrapods are made of concrete which use a tetrahedral shape to dissipate the force of incoming waves by allowing water to flow around them. The four legs of tetrapod are able to reduce displacement by interlocking. Therefore, the special shape of tetrapod can interlock together to protect the surface of the structure. In term of strength of materials, tetrapod is very easily to handle even concrete still fresh. There were the experiment of breaking test and work site experience of tetrapod. The results showed that steel reinforcement is unnecessary for tetrapod, which is a great advantage for marine construction. Tetrapod is able to handle with a simple equipment for concrete pouring and vibrating operations.

Two layers of tetrapod armor block are normally placed on structure. There was a study about the placement effect on the stability of tetrapod armor unit on breakwaters. Two methods of tetrapod placement pattern were studied which is shown in Figure 3.

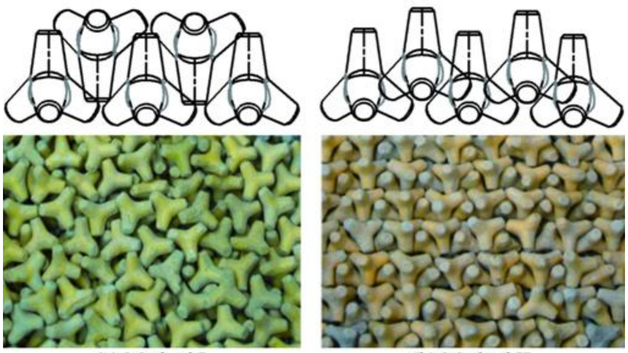

Fig. 3 Tetrapod placement methods [4]

The damage radio versus the stability parameter $H_{1/10}/(\Delta D_n)$ is plotted for both placement methods with all periods in irregular waves in Figure 4. Based on the results, the damage ratio for Method II is larger than Method I. Therefore, tetrapod placement pattern with method I is used in this study. The first layer is placed by three legs down, and the second layer of tetrapod interlock with the one leg of another layers [4].

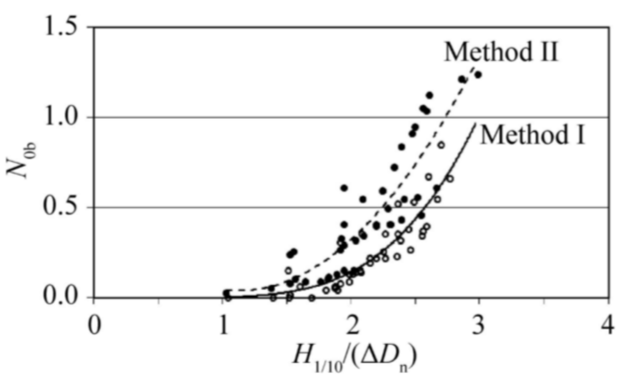

Fig 4. Stability of tetrapod placement methods I and II [4]

2.3 Coastal area

2.3.1 Dynamic equilibrium in the coastal system

A beach consists of sand, gravel or a crushed seashell which have been transported by water flow along a river and stream, carried by waves, and deposited along the coastal area. Beach be able to protect the land from wind and wave, that is the interface area between land and sea. Many factors are related to the beach balance system, such as wave action, wind action, ocean currents and tidal movement. Beach or a shallow coastal area are influenced by wave action, wind action, ocean currents and tidal movement, that have been happening all the time. Sediment transport is the movement of solid particles, which due to fluid motion in rivers, oceans, seas and other bodies of water due to currents and tides. Beach consists of backshore, foreshore and sand bar. Normally, the particles of sand slowly move and arrange to be slope on the beach. In monsoon season, the high wind and wave carry the particles of sand on the beach and place on sand bar in the shallow water area. In normal season, the calm wave transports the heap of sand on sand bar to move back on the beach. The movement of sediment can balance the coastal cycle, which is called “dynamic equilibrium”. Therefore, beach form changes every year because of the fluid motion in coastal zones [5]. The beach cycle is shown in Figure 5.

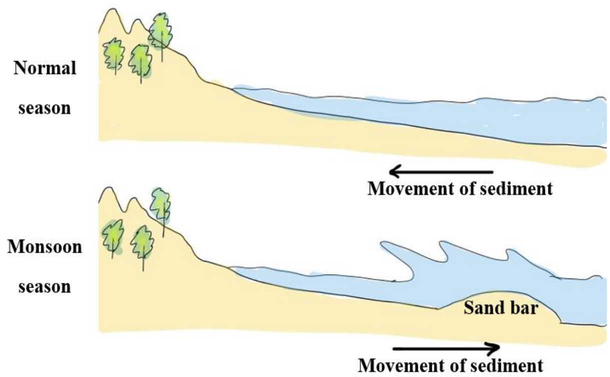

Fig. 5 The balance of dynamic equilibrium [5]

2.3.2 Coastal erosion in Thailand

Thailand is littoral country with the coastal zone including the Gulf of Thailand Coast and the Andaman sea Coast. There are around 2,815 kilometers coastline in Thailand which consist of coastal area in 23 provinces. The coastline in the gulf of Thailand is around 1,878 kilometers that cover in 17 provinces, there are Bangkok, Samutsakorn, Samut Songkhram, Trat, Chanthaburi, Rayong, Chonburi, Chachoengsao, Samut Prakan, Phetchaburi, Prachuap Khiri Khan, Nakornsrithammarat, Chumphon, Surat Thani, Songkhla, Pattani and Narathiwat. 937 kilometers face with Andaman sea which consist of 6 provinces, there are Ranong, Phangnga, Phuket, Krabi, Trang and Satun. The coasts are characterized by geologic nature of landforms as sandy beach and dunes, coastal wetland, rocky coast, cliff coast and islands [2]. Coastal erosion is a main problem for Thailand on both Gulf of Thailand and Andaman Sea. The strong erosion occurs along the coastline with average rate of 5 meters per year. The coastal changes of Thailand were investigated by using satellite image SAR that were compared with topographic map. The comparison of coastline areas showed that there was land loss in every year. There are many causes of coastal erosion in Thailand such as coastal development projects for tourism, the decreasing of upstream sediment supplies due to dams and upland deterioration, climatic change during the dynamic of natural coastal process and improper land-use activities along the coast. Therefore, the degradation of coastal resources such as beach, sand dune, mangrove swamp and lagoon including natural scenery need to be restoration and maintenance for the future.

2.4 Property of natural rubber

Natural rubber is an elastic material which obtained from the latex of certain trees and plants. After latex is processed, natural rubber becomes an elastomer with excellent properties. There are excellent tensile, resilience, tear resistance, elongation, resistance to water and cold flow. Moreover, natural rubber also has good abrasion resistance and excellent low temperature flexibility. Nevertheless, natural rubber has only moderate resistance to damage from heat, light and the ozone in the air. There is poor resistance to solvents, oils, fuels and petroleum derivatives. The range of useful temperature of natural rubber is -60° F to +175° F (-51° C to +80° C), tensile range of natural rubber (P.S.I) is 500 to 3500, the maximum elongation is 700 [6].

To apply natural rubber for coastal field, the properties of natural rubber were investigated. There was study about the effect of 42 years immersion in sea water on natural rubber. The physical tests were taken to determine the hardness, tensile strength, elongation at break, tensile strength and compression set of rubber samples. Moreover, the chemical analysis was also investigated. Finally, this research showed that there was no serious deterioration in rubber condition after 42 years exposure to sea water [7]. Therefore, rubber was found to be a good material that can be used to exposure in sea water.

3. Methodology

3.1 Studying the related researches

The related researches were studied and reviewed for applying into this study. In this research, tetrapod shape is chosen for study. Many researches studied and compared tetrapod with the other shapes of armor block. The four legs of tetrapod are able to compactly stand together with the other units when there is attacked by water wave. Tetrapod is acceptable and popular shape of armor block which is existed seventy years ago. There is perfect shape with 4 legs to interlock with another and excellent property of hydraulic stability. Tetrapod has low center of gravity, so the individual blocks are very stable against to external forces. In addition, tetrapod is easy to install in any places which is fabricated without steel reinforcement. Therefore, based on the supporting of tetrapod properties, this research choses tetrapod armor block for consideration. Moreover, the purpose of this research is to study and apply natural rubber for erosion control which also be applied for seawater. The properties of natural rubber such a strength, chemical resistance and heat resistance are also reviewed from the related researches. Finally, there are support that natural rubber can be used in hydraulic fields.

3.2 Experimental setup

3.2.1 Hydraulic flume

The experiment was carried out in hydraulic flume (12 meters long, 0.6 meters wide and 0.8 meters deep) at the laboratory of King Mongkut's University of Technology Thonburi, that is shown in Figure 6. A pump power can be set from 20-50 Hz, the discharge can be determined by V-notch weir with a capacity of 1905 liters of water tank.

Fig. 6 Hydraulic flume at King Mongkut's University of Technology Thonburi

The model calibration for discharge equation was computed [8]. The discharge formula for weir calibration is shown in equation (1).

$$Q = 1.15H_w^{2.5} \qquad (1)$$

The variable above are mentioned that Q is the discharge of flow (m^3/s) and H_w is depth of water in tank (m).

3.2.2 Model setting

In order to compare the ability of energy dissipation by using natural rubber and concrete tetrapods, two layers of tetrapod are placed on hydraulic flume. The blocks forming of the first layer is placed by three legs down, and the second layer of tetrapod interlock with the one leg of another layers. Moreover, tetrapods model are covered by wire mesh for locking the position of model. The sizes of wire mesh box are 0.08 meters height, 0.55 meters width and 0.145 meters length, which is shown in Figure 7.

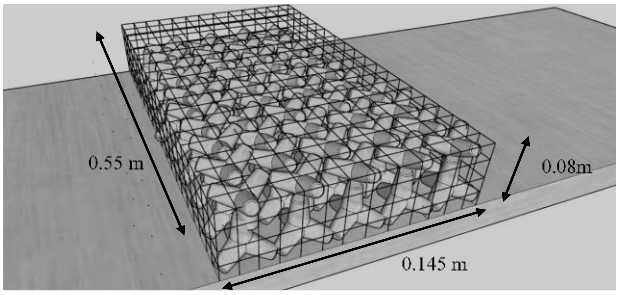

Fig.7 Tetrapod model setup

For the main characteristics of tetrapod model, height of tetrapod is 0.07 meters and volume of model is 66.05 cm3. Weight of concrete and natural rubber tetrapod are 112 g and 60 g, respectively. This tetrapod model is simulated from the actual size of tetrapod, which is 8 tons. There are seven cases study of porosity, which are 22.36%, 27.53%, 37.86%, 43.06%, 48.24%, 63.77% and 74.12%. The model setup of natural rubber and concrete are shown in Figure 8 and 9, respectively.

Fig. 8 Natural rubber artificial tetrapod placement

Fig. 9 Concrete artificial tetrapod placement

3.3 Data collection

In the experiment, there is the comparison of energy reduction between natural rubber and concrete tetrapod. To compare the energy dissipation ($\Delta E\%$) of each materials, specific energy equation and energy dissipation equation are used to compute in experiment which are shown in equations (1) to (3), respectively. Therefore, there are two points of data collecting for water depth in front of and behind the models. The energy dissipation sketch and real experiment in laboratory are shown in Figure 10 (a) and Figure 10 (b), respectively. The water depth in front of the artificial armor blocks is upstream measuring point and downstream measuring point is located behind the models. The water depth in tank is measured by hook measuring, which can be considered for discharge.

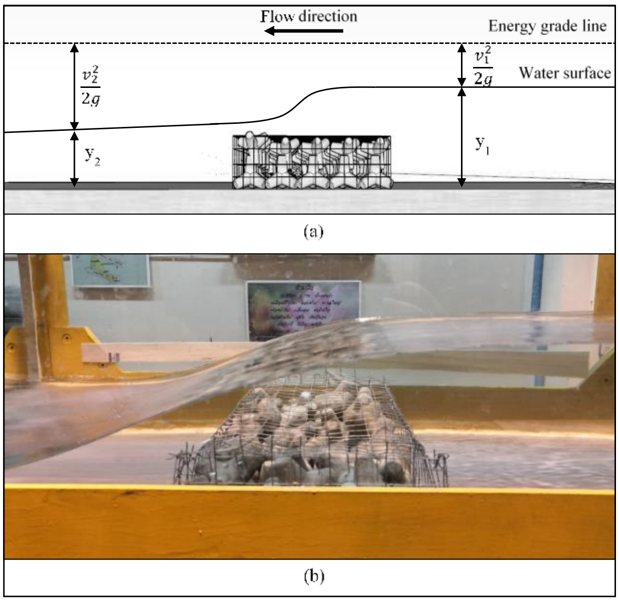

Fig. 10 The energy dissipation (a) sketch (b) real experiment in laboratory

Specific energy for each point is

$$E_1 = z_1 + y_1 + \frac{v_1^2}{2g} \quad (1)$$

$$E_2 = z_2 + y_2 + \frac{v_2^2}{2g} \quad (2)$$

$$\Delta E\% = \frac{E_1 - E_2}{E_1} \times 100\% \quad (3)$$

The variables in the equation mention that E represents energy, z is the elevation of waterbed (m), y is water depth (m), v is velocity of water flow (m/s) and g is gravitational acceleration (m/s^2).

4. Results and discussion

4.1 The comparison of energy dissipation between natural rubber and concrete tetrapods

To compare the ability of energy dissipation, there are two points for measuring the depth of water in hydraulic flume, which are the point in front of and behind the tetrapods model. The study of energy dissipation between natural rubber and concrete tetrapods with 22.36%, 27.53%, 37.89%, 43.06%, 48.24%, 63.77% and 74.12% of tetrapods model porosity are investigated. The relationship between energy dissipation ($\Delta E\%$) and Froude number (Fr) by using natural rubber and concrete tetrapods are shown in Figures 11 to 17. Polynomial trendlines are used in fluctuated data analysis. The results show that the maximum potentiality of energy dissipation between using rubber and concrete are indicated around 50% to 60% reduction for 22% to 74% of model porosity.

The performance of energy dissipation is developed to the maximum point, then continuous decreases with incremental Froude number (*Fr*). Although, the maximum ability to dissipate energy by using natural rubber is not higher than concrete, but trends of rubber can be gradually developed to equivalent with concrete. Based on these comparison, natural rubber has an energy dissipation efficient which can be used as an erosion control material.

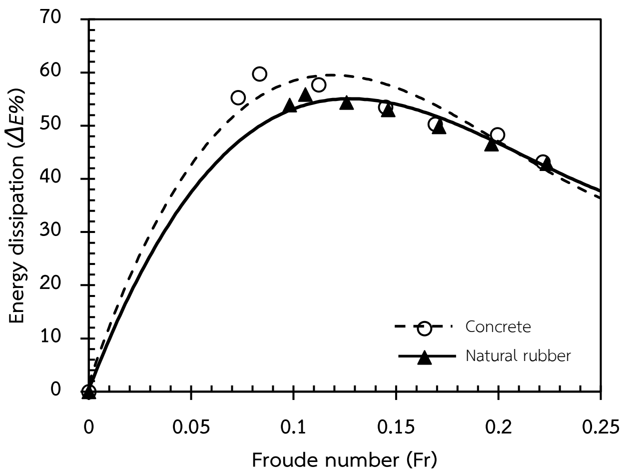

Fig. 11 The relationship between energy dissipation and discharge of natural rubber and concrete tetrapods with 22.36% of porosity.

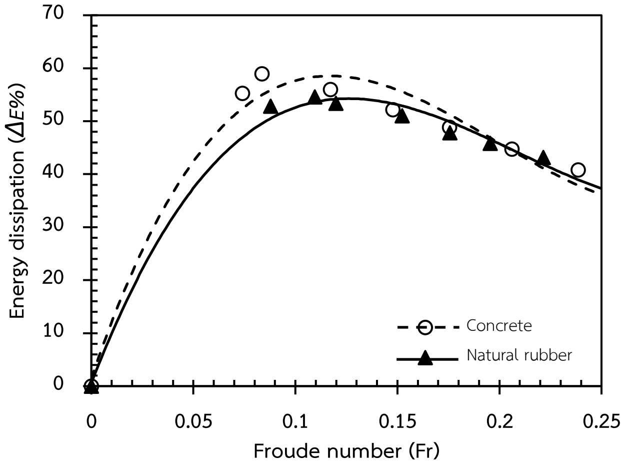

Fig. 12 The relationship between energy dissipation and discharge of natural rubber and concrete tetrapods with 27.53% of porosity

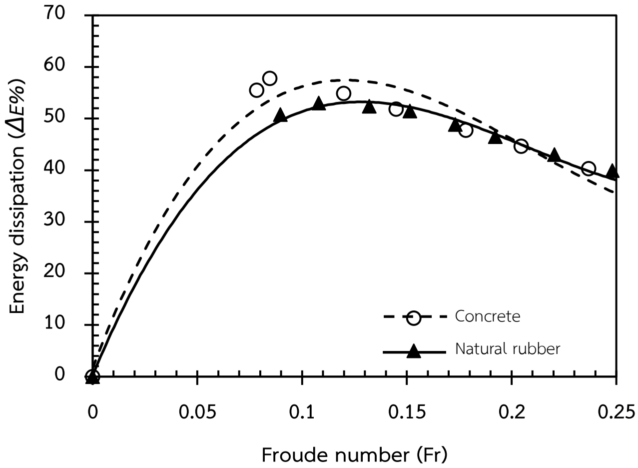

Fig. 13 The relationship between energy dissipation and discharge of natural rubber and concrete tetrapods with 37.89% of porosity

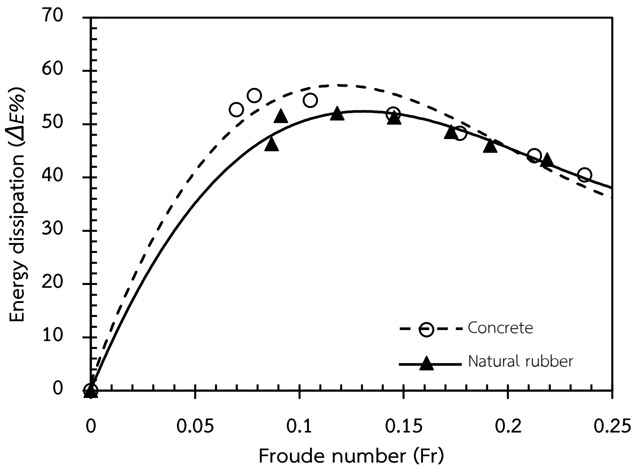

Fig. 14 The relationship between energy dissipation and discharge of natural rubber and concrete tetrapods with 43.06% of porosity

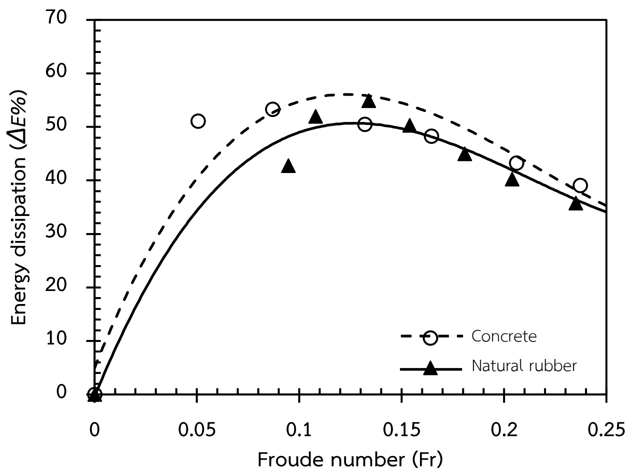

Fig. 15 The relationship between energy dissipation and discharge of natural rubber and concrete tetrapods with 48.24% of porosity

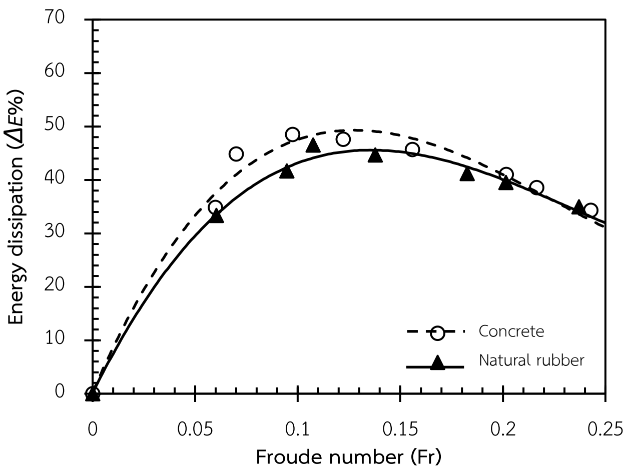

Fig. 16 The relationship between energy dissipation and discharge of natural rubber and concrete tetrapods with 63.77% of porosity

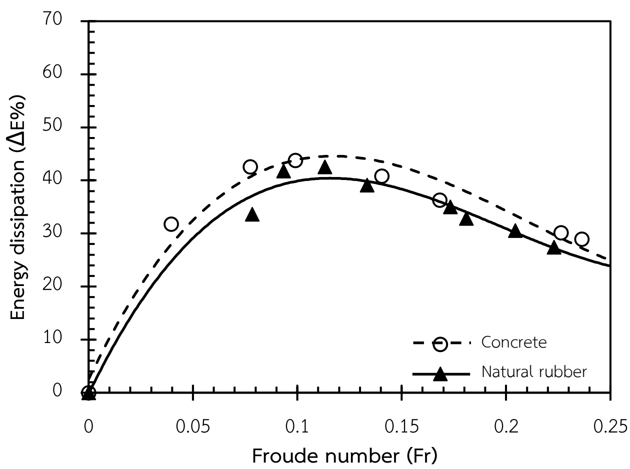

Fig. 17 The relationship between energy dissipation and discharge of natural rubber and concrete tetrapods with 74.12% of porosity

4.2 The porosity of armor block model effects on ability of energy dissipation

The comparison of energy dissipation between different porosities of armor blocks model for using natural rubber and concrete as tetrapods are shown in Figure 18 and 19, respectively. There are seven different cases of model porosities which are 22.36%, 27.53%, 37.89%, 43.06%, 48.24%, 63.77% and 74.12%. Polynomial trendline is also used to analyze the ability of energy dissipation. From the comparison of energy dissipation with different model porosities, void porosity of tetrapod model also effects to the ability of energy dissipation. The maximum ability of energy dissipation by using natural rubber with 22.36%, 27.53%, 37.89%, 43.06%, 48.24%, 63.77% and 74.12% of porosity are 55.06%, 54.27%, 53.23%, 52.42%, 50.70%, 45.58% and 40.42% respectively. It is likewise to concrete case, there are about 59.51%, 58.53%, 57.45%, 57.30%, 56.07%, 49.30% and 44.58% of maximum performance of energy reduction. Therefore, low porosity of armor block has more efficient to dissipate energy.

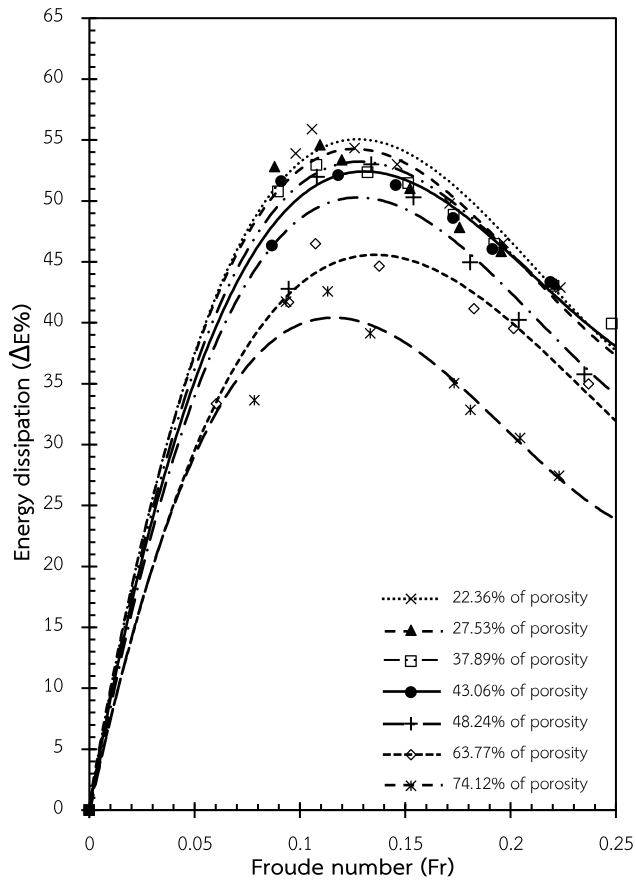

Fig. 18 The comparison of energy dissipation by using natural rubber tetrapods with different porosities

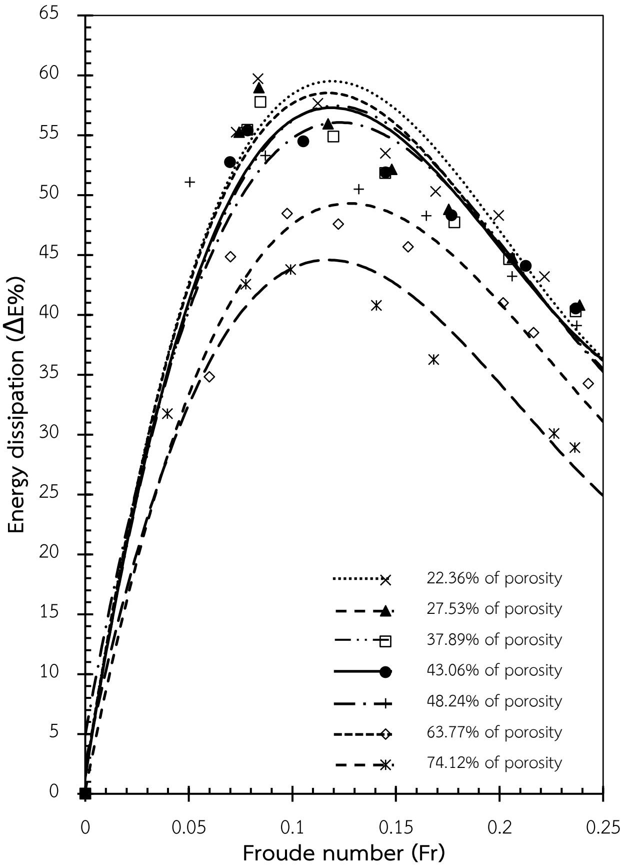

Fig. 19 The comparison of energy dissipation by using concrete tetrapods with different porosities

5. Conclusions

According to Thailand's natural rubber problems, there are falling price and over supply problems which extremely damage to a natural rubber industry in several years. Therefore, the propose of this research is to apply natural rubber for erosion control due to its special properties and also help a natural rubber industry by increase a natural rubber product. The experimental and analytical results can be concluded that natural rubber be able to apply for erosion control.

Based on the comparison of energy dissipation between using natural rubber and concrete tetrapods, natural rubber has ability to dissipate energy. The porous artificial block is also the important factor that impact to the performance of energy reduction. Low porous model has greater efficient to dissipate energy. The maximum ability to dissipate energy by using natural rubber is lower than concrete approximately 5%. Moreover, in order to apply natural rubber in coastal field, the effect of long-term exposure in sea water of natural rubber is searched from many researches. There is determination of the hardness, tensile strength, elongation at break, tensile strength and compression of natural rubber. The chemical and heat resistance are also investigated. However, the results showed that there was no serious deterioration in rubber condition exposure to sea water. Therefore, natural rubber can be applied for erosion control which is used as an energy dissipation material.

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