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Potential of Tyre Derived Geomaterial as Alternative Material in Gabion Type Retaining Wall

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Abstract: The disposal of scrap tyre is a major problem in developing countries. Material recycling is adopted in order to promote safer disposal (beside conventional dump and thermal recycling). Tyre derived geomaterial (TDGM) are proposed to be used in construction of gabion type retaining wall to prevent slope failure that has been a serious geotechnical threat in many countries. The reason of choosing tyre is not only to help in reducing the stockpiling of scrap tyre generated in environmentally friendly way but also to reduce the dependency of gravel as the material to filled current gabion wall. In this study, various mixtures were considered in laboratory scale retaining wall namely, 100% gravel, 100% tyre and 50% of both materials. The retaining wall was functioned to retain a 60º of sand slope. The slope was then subjected to 0.8 mm/hour of artificial rainfall. The soil movement from commencement of the test until the slope failed was recorded. Several tests were carried out to determine basic characteristics (grains size distribution and standard Proctor test) of materials used in the study were conducted beforehand. The results showed that TDGM was able to mitigate slope failure as effective as using gravel. No significant horizontal movements were recorded compared to the slope without any countermeasure. However, slight settlement of gabion wall was recorded and need further testing for clarification.

Keywords: Tyre derived geomaterial, gravel, gabion wall, slope stability, laboratory model

1. Introduction

The generation of scrap its disposal is a major problem, especially in developing countries. The conventional open dumping method will lead to the easily spread of diseases as well as it creates an unpleasant view. In developed countries, thermal recycling of scrap tyres has been practiced reducing the amount of scrap tyres generated each year. However, thermal recycling also can cause a problem from the environment point of view because it contributes to the carbon dioxide generation. On that account, material recycling which is more environmentally friendly way of waste utilization was explored.

In the past few years, studies regarding the utilization of tyres in construction projects have gained popularity. These studies include laboratory testing, numerical simulation, and physical modelling as well as field investigation. Due to its advantageous physical and mechanical characteristics, tyre derived geomaterial (TDGM) either in the form of shreds, chips or crumbs has been used as filler material for embankments [1], as backfill material behind retaining walls and abutments [2], [3], as base isolation for buildings [4] and as lining in tunneling works [5]. The effectiveness of TDGM to mitigate soil's liquefaction behind retaining wall and under shallow foundation have also been studied [6]-

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[11]. In addition, research on the potential of TDGM has also covered wide range of waste tyre utilization, either as a whole (i.e. uncut) in conjunction with granular materials [12] or being cut into pieces [13]-[17]. The results of these studies showed improvement in soil characteristics and engineering behaviors when TDGM were utilized on temporary or permanent soil structures as full or partial substitute material.

2. Background of Study

Slope failure is a worldwide geotechnical hazard that can caused losses of lives and damages of structures and infrastructures. Huge amount of money was needed to restore all the damages due to slope failure. Slope failure occurred when slope collapses abruptly due to weakened self-retainability of the soil under the influence of a prolonged rainfall or earthquake. Preventive measures were often taken to prevent slopes from failure. One of the most common method is by constructing retaining wall (i.e. gabion wall) at the toe of the slope. A gabion wall is a retaining wall which made of stacked stone-filled gabions placed within a wire mesh. Gabion walls are usually angled back towards the slope, or stepped back with the slope, rather than stacked vertically. It has been used widely to protect soil slopes along roads and highways especially in Malaysia. Fig. 1 shows a cross section of a gabion type retaining wall that normally been used in Malaysia.

Fig. 1 - Cross section of soil slope with gabion type retaining wall [18].

Since the gabion type retaining wall requires a lot of gravel to be used to fill up all the gabion cages, the demand of this material tends to be increased. Gravel can easily be obtained from blasting and quarrying activities in mountainous area. However, these activities will affect the environment due to land clearing works as well as the excessive dust resulted from the blasting processes. In addition, gravel is a non-renewable material and the supply of the material will be depleted in the future. Therefore, study to minimize the usage of gravel in gabion type retaining wall by substituting it with other material is very crucial.

In this study, the potential of TDGM in preventing slope failure was investigated. TDGM were used to partly substitute the gravel which made up gabion type retaining wall. Current gabion walls use only granular materials that were insert in a wire mesh. Several meshes were tied together horizontally and vertically to perform a retaining wall. The gabion type retaining wall was placed near the toe of the slope to increase the resisting force of the slope which helps to increase the slope's factor of safety. The effectiveness of the TDGM in preventing slope failure were assessed at the end of this study.

3. Methodology

In the present study, two small scale slope models were developed and constructed. The first model consists of sandy soil slope without any support from retaining wall as shown in Fig. 2. whereas, a second model consists of sandy soil slope (as shown in Fig. 3) was constructed with the support of gabion wall.

Fig. 4 shows the side view of the sandy slope with two layers of gabion cages stacked on top of each other to made a gabion type retaining wall. The first model (sandy slope without any support from retaining wall) was constructed so that the performance of the the new material (TDGM) as the material that made gabion type retaining wall (which was used to protect sandy slope in the second model) can be assessed.

Both models were subjected to an artificial rainfall at a constant rate until the slope fails. It is expected that, the sandy slope without any support from retaining wall will fails after been subjected to artificial rainfall for a specific time. The rainfall rate was selected based on the highest rainfall precipitation in Kuantan [19]. The variation of rainfall precipitations in Kuantan throughout the year 2017 is presented in Fig. 5.

As can be seen in Fig. 5, Kuantan area (in general) experienced a gradually increment in rainfall precipitation starting from month of September to November before it drastically rose up in the month of December. In this month, the total amount of precipitation of 570 mm/month was recorded in Kuantan. Therefore, as the highest precipitation value and assumed to be the most critical, precipitation rate of 570 mm/month was selected to be used in this study. However, for the laboratory test purposes, the monthly precipitation rate was converted to hourly basis. After conversion, the precipitation rate of approximately 0.8 mm/hour was obtained. Therefore, an average rainfall value of 0.8 mm/hour is used in this study.

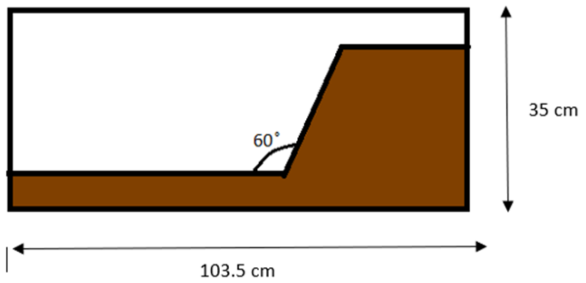

Fig. 2 Cross section of soil slope without countermeasure against failure.

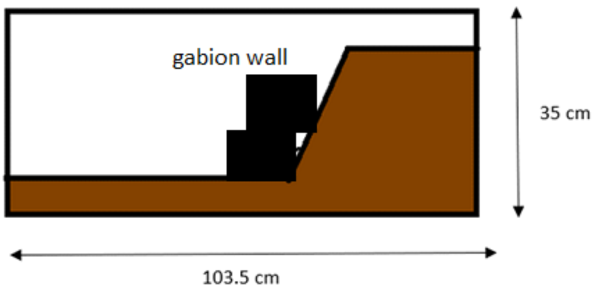

Fig. 3 - Cross section of soil slope with countermeasure against failure (gabion type retaining wall).

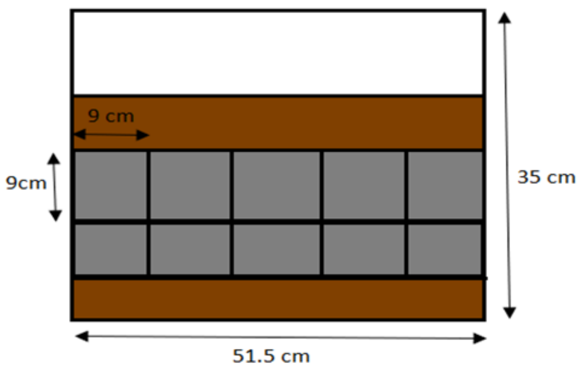

Fig. 4 - Side view of soil slope with gabion type retaining wall.

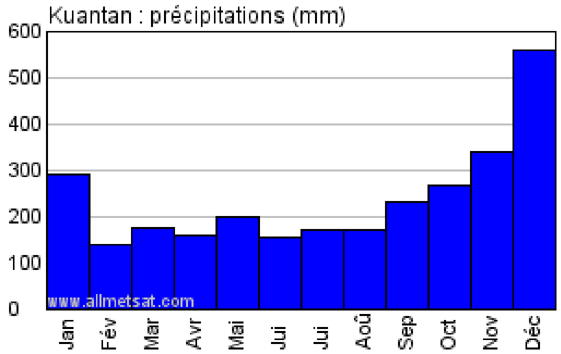

Fig. 5 Rainfall precipitations in Kuantan [18].

For the second model (sandy slope protected with gabion type retaining wall), the gabion mesh cages were filled with different materials (i.e. gravel, tyre and mixtures of both gravel and tyre) for each of the test. Therefore, testing for the second model are repeated three times.

For the first time of the testing, the gabion mesh cages are filled with 100% of gravel. This will reflect the current practice which used only gravel as the material of gabion type retaining wall. On the other hand, 100% of tyres are used to fill the gabion mesh cages for the second time of the testing. Whereas, mixture (by volume) of 50% of gravel and 50% of tyre was used for the third testing. This percentage ratio was assumed to be the optimum mixture that can give the best results in improving slope resistance against rainfall. Table 1 summarizes the series of tests that had been conducted onto the slope model.

As the slope models have been subjected to an artificial rainfall, any movements of the slope were recorded. The measurement was made by using a linear transducer. Two sets of transducers were placed at top left and right of the slope to record any movements of soil and wall. The data was recorded from the beginning of the rainfall until the slope collapse or until the movement of the gabion type retaining wall ceased. Fig. 6 shows the position of the displacement transducer.

The displacement variations against time were graphically presented to show the movement trends. The movement trends for the second model (sandy slope protected with gabion type retaining wall made of either gravel, tyre or combination of gravel and tyre) were compared with the first model (conventional sandy slope without any support) so that the improving trends can be easily observed.

Table 1 - Series of different types of material made up gabion type retaining wall subjected to an artificial rainfall at a rate of 0.8 mm/hour.

Model	Description of slope's countermeasure against failure
1	No countermeasure
2	Gabion type retaining wall made of 100:0 ratio of gravel to TDGM
3	Gabion type retaining wall made of 0:100 ratio of gravel to TDGM
4	Gabion type retaining wall made of 50:50 ratio of gravel to TDGM

Fig. 6 - Position of the displacement transducer.

3.1 Preparation of Materials

Both of the slopes (with and without countermeasure against failure) were made in clear acrylic box (103.5 cm x 51.5 cm x 50 cm). The sandy soil slope with 60° inclination to horizontal was constructed with the assumption that this would be the critical angle of the slope. A marking line was drawn outside the acrylic box as the guidance in making the slope. Dry sand was poured into the box at a constant height of approximately 30cm to ensure that the density of the sand was almost the same for all the slope models. Sand were poured until it reached the marking line drawn.

Then, gabion walls were placed parallel to slopes. The dimension of the gabion wall's cage was simplified as 9 cm x 9 cm which was approximately 10 times smaller than the actual dimension. The cages were made from wire meshes that have been tied together by using wires. The wire meshes were bought from a local store. Initially, these wires came in a roll before it been cut and made into a cube shape. However, the properties of the wire mesh were not yet to be tested. This is because these meshes were only to be used as material to confine either gravel, tyre or combination of gravel and tyre.

Each of the cages were filled with either gravel, tyre or the combination of gravel and tyre. These cages were lined up along the toe of the soil slope and stacked in two levels. Fig. 7 shows the picture of wire meshes inserted with gravel and placed at the toe of the sandy slope.

Fig. 7 - Wire meshes inserted with gravel.

Gravel and sand used in this study were locally obtained from Kuantan area while tyres are purchased from a tyre retread company in Kuantan, Pahang. Fig. 8 shows the picture of gravel, tyre and sand used in the study. Prior to rainfall tests, all the materials (sand, gravel and tyre) has been tested for particle size identification as well as standard Proctor test. The purpose of conducting these tests is to determine the specific sizes of the material and to determine the unit weight of each material. Finally, all elements (soil, wire meshes and transducer) used in the study were arranged and placed in its location as shown in Fig. 9.

The completed slope model was placed on top of hydrology and rainfall apparatus which can be found in the Hydraulic and Hydrology Laboratory of Universiti Malaysia Pahang. This apparatus consists of a metal frame which holds spray nozzles that can simulate rainfall. Source of water are coming from the reservoir attached under the apparatus. Water was pumped from the reservoir to the overhead nozzles. The amount of water that came out from the nozzle can be controlled by using flow valve which located at the middle of the apparatus. Therefore, for this study, a rainfall rate of 0.8 mm/hour was subjected to all the slope models. The hydrology apparatus that used in this study is shown in Fig. 10.

Fig. 8 - Materials used in the study.

Fig. 9 - Arrangement of test's element in the study.

Fig. 10 - Hydrology apparatus.

4. Results and Discussion

Fig. 11 shows the particle size distribution of sand, gravel and tyre used in this study. Coefficient of uniformity, C_u and coefficient of gradation, C_c can be calculated by Eq. (1) and Eq. (2) respectively. Values of the coefficient of uniformity and coefficient of gradation of sand, gravel and tyre used in this study are tabulated in Table 2.

$$C_u = \frac{D_{60}}{D_{10}} \tag{1}$$

$$C_c = \frac{D^2{}_{30}}{D_{60} \times D_{10}} \tag{2}$$

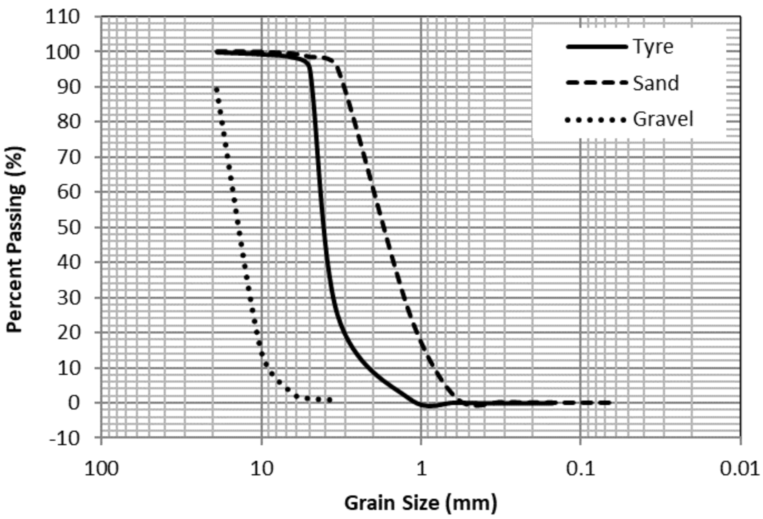

Fig. 11 - Results of particle size distribution test conducted on tyre, sand and gravel samples.

Coefficient of uniformity, C_u and coefficient of gradation, C_c for sand is reported to be 2.5 and 1.41 respectively. Gravel is found to have greater value of C_u and C_c (C_u=17.7 and C_c=10) due to the bigger size of the particle itself. In addition to that, tyre derived geomaterial (TDGM) is expected to have smaller value of C_u and C_c. The coefficient of uniformity and the coefficient of gradation for TDGM is found to be 1.87 and 1.24 respectively. The value of C_u and C_c are use to classify the distribution of the material. Based on that, according to Unified Soil Classification System (USCS), sand which has been used in this study can be classified as SW, well graded sand. Beside that, the results of particle size distribution test as shown in Fig. 11 also shows that uniformly graded gravel and tyre were used in the present study.

Table 2 - Coefficient of uniformity and coefficient of gradation of sand, gravel and TDGM.

Material	Coefficient of uniformity, C_u	Coefficient of gradation, C_c
Sand	2.5	1.41
Gravel	17.7	10
TDGM	1.87	1.24

TDGM are commonly categorized into three different types according to its size. The largest in size is named as tyre shreds which has particle size range from 76 mm to 305 mm. Smaller than that with the particle size varies from 12 mm to 76 mm is tyre chips. While the smallest in size which varies from 0.3 mm to 12 mm is referred as granulated rubber. Fig. 12 to Fig. 14 show the picture of tyre shreds, tyre chips and granulated rubber [13]-[15].

Based on that classification, in this study, granulated rubber was identified as the specific TDGM which to be further utilized as substitution materials in gabion type retaining wall. In addition to that, granulated rubber (size range between 0.3mm to 12mm) also can be further categorized into two different types which are tyre crumbs and tyre buffings [20]. The shape of tyre crumb is more granular whereas tyre buffings has fiber-shape material. Tyre buffings is a product from tyre retread industry.

Fig. 12 - Tyre shreds (size range between 76mm to 305mm) [13-15].

Fig. 13 - Tyre chips (size range between 12mm to 76mm) [13-15].

Fig. 14 - Granulated rubber (size range between 0.3mm to 12mm) [13-15].

Fig. 15 shows the comparisons of the dry unit weight value of TDGM with sand and gravel. The results shows that the dry unit weight of TDGM is found to be approximately 9.91 kN/m^3. This value is in a good agreement with the value obtained by Edincliler et. al [20]. Their results showed that, rubber in the form of buffings (range size from 0.425 mm to 2 mm) has a density value between 3.18 kN/m^3 to 5.22 kN/m^3.

The present study also compared the dry unit weight of different proportion of gravel and granulated rubber mixture as shown in Fig. 16. Based on Fig. 16, samples which have ratio of gravel to rubber mixture of 50:50, 60:40 and 80:20 shows similar dry unit weight value compared to sample of purely gravel. Due to this, ratio of gravel to tyre mixture of 50:50 was used in constructing gabion type retaining wall which functioned to retain soil slope from failure. Gravel and tyre are mixed by volume and the proportion ratio mixture with its dry unit weight are listed in Table 3.

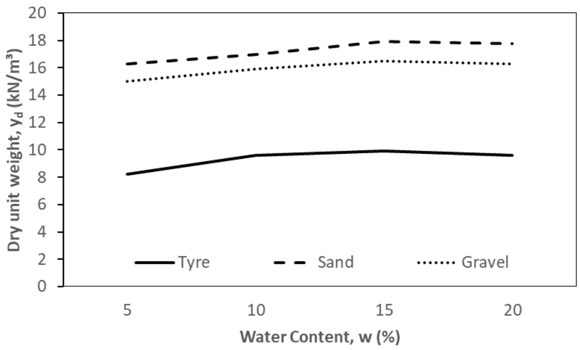

Fig. 15 - Variations of dry unit weight and water content for tyre, sand and gravel.

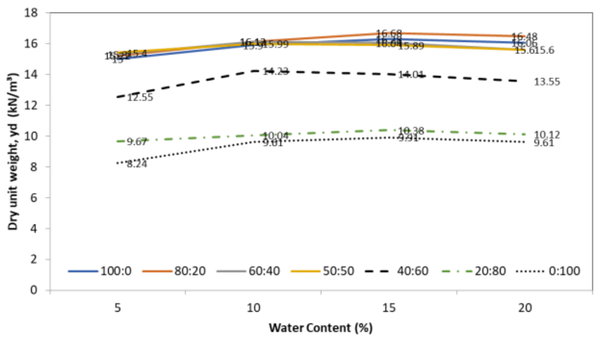

Fig. 16 - Comparison of dry unit weight for different percentage of gravel and tyre mixture.

Table 3 - Ratio of gravel and tyre mixture.

Sample	Gravel : Tyre Ratio	Dry Unit Weight, γ (kN/m^3)
1	100 : 0	16.48
2	80 : 20	16.68
3	60 : 40	16.04
4	50 : 50	15.99
5	40 : 60	14.23
6	20 : 80	10.38
7	0 : 100	9.91

Fig. 17 shows the variations of soil's displacement for different materials (gravel, gravel and tyre mixture and tyre) that made up gabion wall. The displacement of soil in each of the test was compared with the displacement of soil in the case of no gabion wall placed at the toe of the slope. Based on the results, slope without any countermeasure experienced significant movement 50 seconds after rainfall was induced. It was noted that, the movement drastically increased after 100 seconds and the slope collapsed at 120 seconds. Fig. 18 shows the condition of slope without any support from retaining wall at the end of rainfall test.

On the other hand, in the case of slope supported by by gabion filled with gravel at the toe of slope, soil's displacement was significantly reduced. Interestingly, no sudden movement of soil was recorded throughout the rainfall test. Significant trend of improvement was also noted when different materials were used to filled up gabions.

Approximately 90% of soil displacement was reduced by constructing gabion type retaining wall filled with either gravel, tyre or mixtures of gravel and tyre chips.

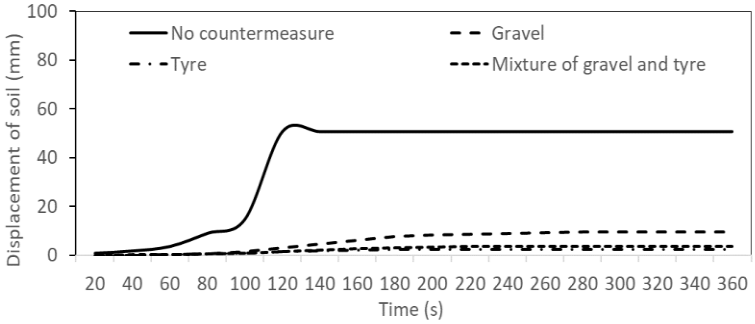

Fig. 17 - Variation of soil's displacement for different types of material that made gabion type retaining wall.

Fig. 18 - Failure of soil slope without any countermeasure.

In addition, although that there was no significant horizontal movement recorded in either of the slope models with countermeasure against failure, slight settlement of gabion wall was observed at the end of the test as shown in Fig. 19. Gabion wall filled with 100% gravel was found to settle approximately 9 mm, followed by gabion cages filled with mixture of gravel and tyre (3.5 mm). Gabion cages filled with only TDGM was found to experience the least settlement of about 2.5 mm. The differences in the settlement behavior of each slopes were found to be directly related to the density of the filler material used within the gabions and also the thickness of the sand soil underneath the gabion. In future study, the thickness of the underlying soil need to be increased to ensure that the sand is able to provide sufficient support to the retaining wall.

Fig. 19 - Settlement of gabion wall at the end of the rainfall test.

5. Summary

Experimental studies on sand slope protected with gabion type retaining wall containing different filler material have been conducted. The results have been compared to the slope without any protection from retaining wall. Horizontal displacement of soil was found to be significantly reduced in the case where gabion wall made of 100% gravel installed at the toe of the slope. Significant improvements in term of displacement and settlement of slope was observed in the case of slope containing tyre derived geomaterial, TDGM in the size of tyre buffings, as partial substitution material. However, in all cases considered, slight settlement of the gabion wall occurred probably due to the density of the material or due to insufficient support from the underlying sand. As conclusion, tyre derived geomaterial is found to be able to use as partial substitution material in constructing gabion type retaining wall. This finding is very important so that the dependency to the current material (gravel) can be reduced. In future study, the potential of TDGM to protect slope failure can be tested by using different intensity of rainfall (low, medium and high intensity) so that the effectiveness can be further evaluated. Moreover, full scale study may also be conducted in order to confirm the small-scale experimental results.

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