Soil-roots Strength Performance of Extensive Green Roof by Using Axonopus Compressus

N A Yusoff[1,3] M N Ramli[1], T N T Chik[1], H Ahmad[2], M F Abdullah[1], H Kasmin[1] and Z Embong[3]

[1] Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

[2] Horticulture Research Centre, MARDI Headquaters, P.O. Box 12301, 50774 Kuala Lumpur, Malaysia

[3] Research Center for Soft Soil, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat Johor, Malaysia

E-mail: azizy@uthm.edu.my

Abstract. Green roof technology has been proven to provide potential environmental benefits including improved building thermal performance, removal of air pollution and reduced storm water runoff. Installation of green roof also involved soil element usage as a plant growth medium which creates several interactions between both strands. This study was carried out to investigate the soil-roots strength performance of green roof at different construction period up to 4 months. Axonopus compressus (pearl grass) was planted in a 1'x1' test plot with a designated suitable soil medium. Direct shear test was conducted for each plot to determine the soil shear strength according to different construction period. In addition, some basic geotechnical testing also been carried out. The results showed that the shear strength of soil sample increased over different construction period of 1st, 2nd, 3rd and 4th month with average result 3.81 kPa, 5.55 kPa, 6.05 kPa and 6.48 kPa respectively. Shear strength of rooted soil samples was higher than the soil samples without roots (control sample). In conclusion, increment of soil-roots shear strength was due to root growth over the time. The soil-roots shear strength development of Axonopus compressus can be expressed in a linear equation as: $y = 0.851x + 3.345$, where y = shear stress and x = time.

Keywords: Green roof, shear strength, soil-root interaction, axonopus compressus.

1. Introduction

Green roof is a roof of a building that is partially or completely covered with vegetation and growing medium. Green roof could serve several purposes in a building, such as absorbing or reducing rainwater, providing insulation layer, hence it could help to reduce urban air temperatures and in larger scale, it could combat the heat island effect. There are two types of modern green roofs which are intensive green roof and extensive green roof. Intensive green roof has a deeper soil medium and could support a wider variety of plants, but it has heavier load structure and requires more in maintenance.In contrast, extensive green roofs normally constructed in a shallower layer of soil, hence lighter vegetation is needed and are lighter than an intensive green roof [1].

   Green roofs provided a number of important environmental benefits. It included improved building thermal performance, urban cooling, removal of air pollution and reduced storm water runoff [2,3]. In addition, green roofs can reduce the hydrological effect of vegetation function applied. It can

withstand the hydrological effect by rainfall interception, surface water runoff, infiltration and evapotranspiration. Moreover, the green roof's vegetation could absorb carbon dioxide and through photosynthesis, oxygen is released, lead to reduction of greenhouse gases in the atmosphere [4].

The direct impact of raindrops on a thin layer of soil and the movement of water over the green roof's soil surface constitutes the major force initiating soil detachment. That case will cause structural bond between soil particles becomes weaker and lead to soil erosion [5]. As a result, the strength performance of green roof may become poorer.

Vegetation could protect soil from erosion of raindrops, runoff, water currents and wind. Plants could decrease an amount of rainfall that directly impacts the ground surface by intercepting and holding a portion of water on the leaves and stems. Vegetation could also influence the stability of soil slope when the roots act as reinforcement to the soil. Study done by [6] stated that the performance of slope stability is dependent on the types of plant, material used, the method of installation and its properties.

In this study, the geotechnical performance of soil-roots was assessed. This is a part of important element which significance in ensuring a longer life expectancy for the green roof. In addition, it is also significant to support its hydrological performance and insulation during the construction stage. This study investigated on the green roof strength performance at different construction period of less than a year. The relationship between shear strength and *Axonopus compressus* root growth of vegetated soil at different construction period was also presented in this study.

2. Method and Methodology

2.1 *Plot Preparation*
Six plots with a dimension of 1' x 1' were used (Fig. 1a) with five plots planted with the Axonopus compressus on a suitable soil medium. Soil medium used is a mixed of the following soil types: lateritic soil: organic soil: sand with a ratio of 5:3:1 respectively [7]. The sixth plot was not planted with any vegetation (bare soil as a control plot) as shown in Fig. 1b. The soil was self-compacted in order to resemble the common situation on-site.

2.2 *Plot Maintenance*
The vegetation was watered evenly with 2 kilograms of water, twice daily, to ensure that the planted grasses will grow well. However, the frequency of the plant watering is normally based on a few factors such as weather condition, the maturity of the plant, plant species and soil condition.

2.3 *Direct Shear Test*
Prior to direct shear test, it is important to ensure that the water content for each plot almost similar. A watering procedure had been set up by using 2 kilograms of water, which equals to half of the volume of the plot. After that, the plot is left under the roof area for 24 hours before the direct shear test can be performed.

2.4 *Soil Sample Preparation*
The mold with size 60 mm x 60 mm which penetrated into the soil in test plot was used to extract soil sample (Fig. 1c). Then, it was transferred into a direct shear apparatus that has the same dimension as previous mold. For the record, the sample thickness taken from the mold was 25 mm.

2.5 *Shear Strength*
Shear strength was measured at 100mm depth from the soil surface by using a Shear Trac II machine (Geocomp Inc. USA) at the Research Centre for Soft Soils (RECESS). This apparatus was fully operational supported by the software installed into a computer for data and results during the test. During consolidation phase, vertical stress used was 5 kPa. Direct shear was carried out with a shearing rate of 1.0 mm/minute and the maximum displacement of 20 mm (33.3% strain) was considered.

2.6 Root profiles
Once the direct shear test completed, the rooted sample was washed to remove soil from the clod leaving only the root specimens. This screening process enabled the root growth to be measured in term of mass at different construction period up to 4 months.

Figure 1. (a) Plot used for the study; (b) View of the six experimental plots; (c) A sampler has been penetrated into the soil.

3. Results and Discussion

3.1 Direct Shear Test Results
Figure 2 and Figure 3 show the shear strength test results for the control sample and rooted soil samples, respectively after a month of planting. For control specimen, three samples tested showed quite similar results of shear stress with an average of 3.72 kPa at 20mm displacement. In contrast, the average shear stress showed slight improvement of 3.81 kPa for the rooted soil sample in the first month.
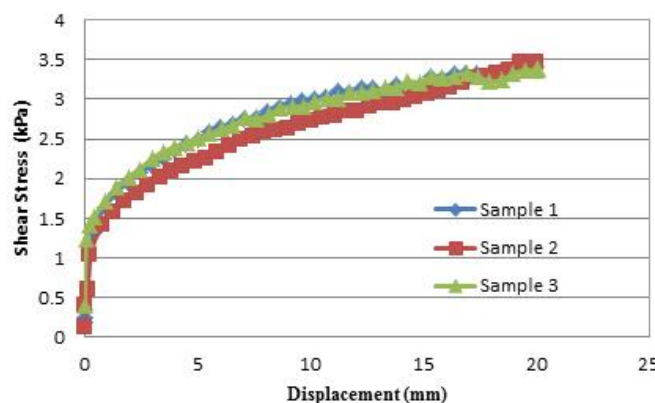

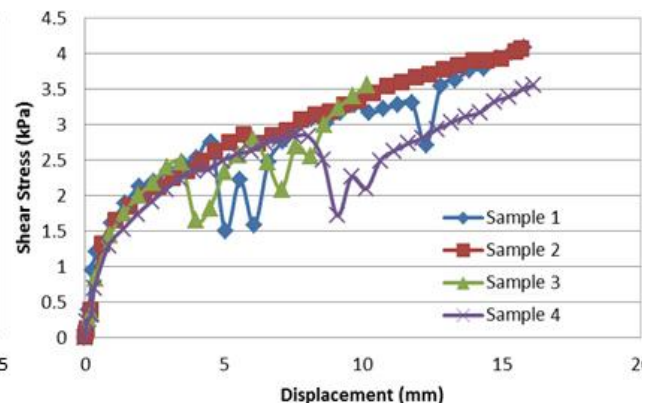**Figure 2**. Shear stress versus displacement of the control sample.

Figure 3. Shear stress versus displacement of month 1 rooted soil.

In addition, the results of the shear strength of rooted soil samples for the different construction period of 2nd, 3rd and 4th month after planting were presented in Fig. 4 to Fig. 6. From the results, the average shear stress for 2nd, 3rd and 4th months were 5.55 kPa, 6.05 kPa and 6.48 kPa respectively. Based on the results obtained for each experiment on different months, it can be noticed there was a gradual increment in shear strength reaching towards the end of the experiment at 20 mm displacement. The peak shear stress and residual shear stress cannot be clearly defined. It was similar to studies done by [8], where direct shear test results for several soil samples found to be continuously increased towards the end of the experiment at maximum displacement of 20 mm. In theory, it is understandable that the low compacted soil will behave as shown by this study.

    Factor that leads to this trend was believed due to the increasing of vertical displacement during shearing phase. This is because the soil particles have been reoriented or dilatation occurred, resulting

in increasing of shear stress. Another factor was due to the development of elongated and root growth beneath the soil. This situation caused the roots managed to hold soil particles in place. The mechanical reinforcement effect of soil-roots matrices prevent slippage of shear plane.

3.2 Comparison of Direct Shear Test Results

The comparisons performed on the results of direct shear tests for different construction time showed a linear increment in the average value of shear stress for different construction time, represented by a linear equation showed in graph Fig. 7.

Although there was a small improvement shown, but the results conformed with the predictions made by earlier studies. These results were parallel to a study conducted by [9], showing an increment of shear stress for different plant species at the age of 6 months and 12 months.
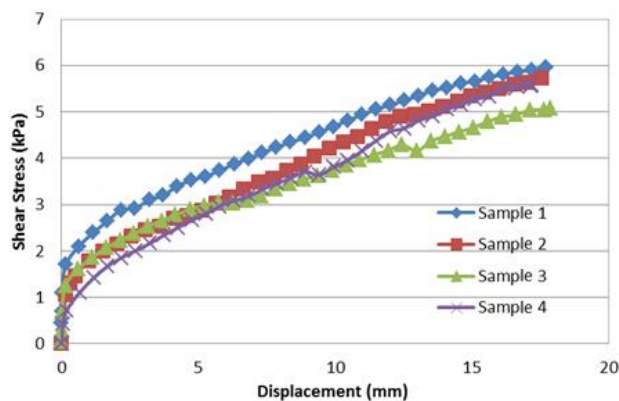

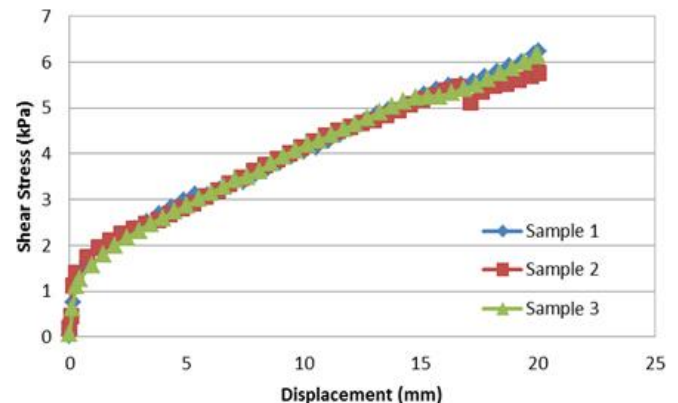**Figure 4**. Shear stress versus displacement of month 2 rooted soil.

Figure 5. Shear stress versus displacement of month 3 rooted soil.
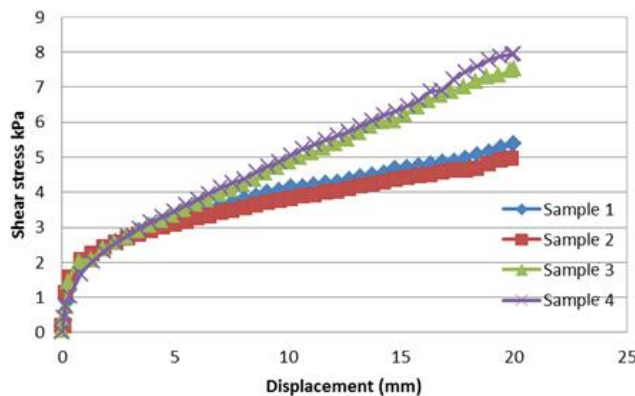

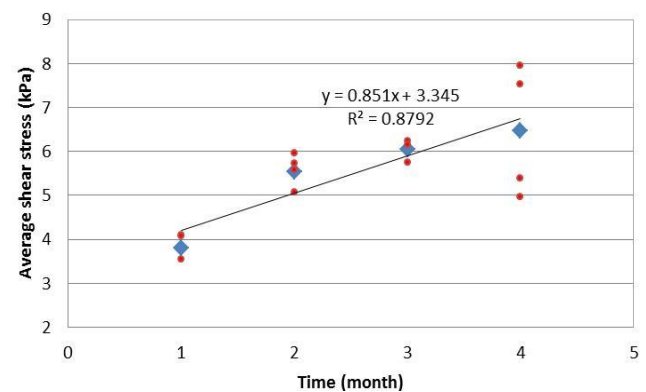**Figure 6**. Shear stress versus displacement of month 4 rooted soil.

Figure 7. Average shear stress versus construction time.

3.3 Percentage of water content in soil samples

It is important to consider water content in soil samples during the direct shear test. Therefore, after completing the test, water content of the samples is recorded. It is observed, with the progression of time, the soil moisture content (%) was slightly difference between months (Fig. 8). This consistency would ensure the validity of shear strength of soil samples.

3.4 Effect of Root Development on Shear Stress

As expected at the beginning of this study, soil shear strength increased with the growth of roots. This was proven by studies [9,10] in which the mechanical effects of root development caused soil anchoring and shear strength increased. A graph of the root weight versus time is shown in Fig. 9. It shows the weight of the growing roots at the different construction time from month 1 to month 4.

Moreover, the increments of root weight also contribute to the increase of soil shear strength as shown in Fig. 10.
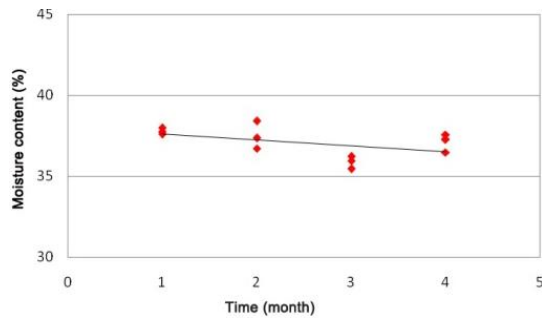

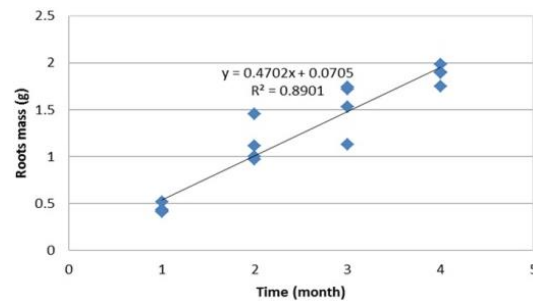**Figure 8.** Percentages of soil moisture contain versus construction period.

Figure 9. Root mass versus different construction period.
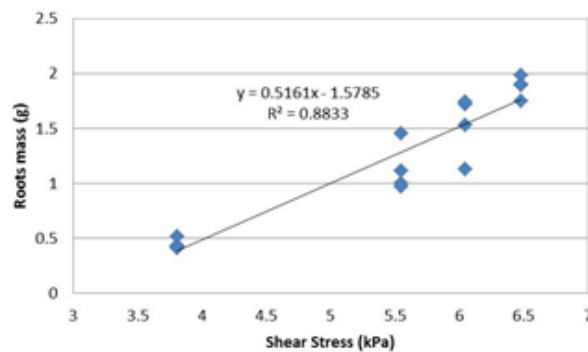

Figure 10. Root mass versus average shear stress.

4. Conclusion

The overall results have proven the shear strength of rooted soil samples is higher than the soil samples without roots (control sample). These results clearly demonstrated by the shear strength performance of soil-roots of Axonopus compressus (pearl grass) used in the study. Results show that shear stress for soil samples without root (3.72 kPa) was lower than shear stress for rooted samples (3.81 kPa). In terms of shear strength and root mass, shear strength of soil showed an increment due to plant growth in the root structure over the time. This is because the roots gripped into the ground resulted in strengthened of soil. This relationship can be expressed in a linear equation of shear stress and time; roots weight and time; and lastly root weight and shear stress are shown in Eq. (1), Eq. (2) and Eq. (3), respectively.

$$y = 0.851x + 3.345 \tag{1}$$

$$y = 0.470x + 0.070 \tag{2}$$

$$y = 0.516x + 1.578 \tag{3}$$

where y = roots weight, x = shear stress

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