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# Performance-Based Evaluation of Geotextile-Reinforced Expansive Subgrade Soil: A Case Study on the Pavement Road along Mangima Bukidnon

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## Abstract

*The subgrade is an essential component of road pavement systems. It must provide adequate strength to support the complete pavement structure. A weak, clayey subgrade poses challenges because it can lead to the failure of the overlying pavement. A deficient subgrade necessitates treatment and stabilization. This study primarily aimed to do a laboratory assessment of Adtuyon clay subgrade soil reinforced with geotextiles. The soil samples were subjected to the Atterberg limit tests, compaction tests, and the California Bearing Ratio (CBR) test. Three geotextile-reinforced soil samples, with geotextile placed at 1/4, 1/2, and 3/4 of the mold height measured from the top, were compacted and tested for CBR. A plate load test was performed in the field. The resilient modulus (Mr) of the soil samples was estimated utilizing a prediction model. The laboratory results indicated that the reinforced soil samples exhibited higher CBR values than the unreinforced samples. A rising CBR value was noted as the geotextile was positioned from the top to the bottom of the CBR mold. The reinforced sample positioned at 3/4 of the geotextile had the greatest CBR value. Furthermore, the incorporation of geotextiles enhanced the settlement behavior of the reinforcement and elevated the anticipated Mr values. Consequently, it was determined that geotextile reinforcement enhanced the engineering properties of the Adtuyon clay subgrade. It is advisable to conduct studies employing multi-layer geotextiles as reinforcement and to perform quality assessments of geotextiles to further investigate the interaction between geotextiles and the Adtuyon subgrade soil.*

***Keywords**:* compaction, geotextile, pavement, settlement, soil subgrade

## 1. Introduction

The subgrade is an important component of road pavement structures. It must be adequately robust and capable of sustaining the entire pavement structure above it. Soft subgrade pavements are susceptible to premature deformations, cracking, and rutting, which can require repair or reconstruction and result in additional costs. Road performance depends on its subgrade properties (Sangeetha *et al.*, 2018). Hence, improving the properties of problematic subgrade soil through treatment and stabilization is required to withstand and support the stresses generated by traffic loads.

Soil stabilization procedures were used to reinforce the weak subgrade soils. These are commonly employed in areas with soft subgrades, including excavation substitution, chemical additive stabilization, and geosynthetic mechanical reinforcement. Recently, the use of geosynthetic reinforcement among soil improvement techniques has significantly increased due to its rapid construction and low cost (Pancar & Akpinar, 2016). The function of geosynthetics that contributes to the performance of roadways is to separate, filter, reinforce, stiffen, drain, barrier, and protect roadways (Zornberg, 2017). They listed the predominant geosynthetic products used in roadway systems, comprising geotextiles (woven and nonwoven), geogrids (biaxial and multiaxial), geocells, geonets (or geocomposite drainage products), and geomembranes. Geotextiles are commonly used to reinforce poor soil quality. The strength of the geotextile and its interaction with soil particles are the main factors that improve soil characteristics (Kordani *et al.*, 2017). Over the years, the use of geotextiles in geotechnical engineering has been adapted for various applications owing to their remarkable outcomes.

The California bearing ratio (CBR) is a penetration test used to assess the mechanical strength of natural soils, subgrades, and foundations under new carriageways. Subgrade soil supports pavement and is the foundation for carrying loads (Ogundare *et al.*, 2018). Thus, various associations worldwide establish standard CBR values to ensure the strength adequacy of subgrades to support the imposed traffic load. However, not all soil types exhibit improved strength characteristics (Guyer, 2011). Subgrade stabilization is important when the soil available in a given locale is too weak to support traffic loads. Consequently, the use of geosynthetics has proven effective in improving soil quality (Negi & Singh, 2020). Several studies have examined the application of geotextiles for pavements, which have elucidated the use of nonwoven geotextiles in improving the CBR characteristics of clayey soils (Minh *et al.*, 2019; Kordani *et al.*, 2017; Khan *et al.*, 2016). They had similar outcomes from laboratory tests on unreinforced and reinforced soil specimens, in which the CBR values for the non-woven geotextile showed a significant increase compared with those for clayey soil. Moreover, non-woven geotextiles significantly reduce the swelling percentage of expansive soil (Minh *et al.*, 2019).

Clay soil is common in many parts of the world, and its various types exhibit varying mineral and geotechnical properties. This type of soil is prone to volume changes depending on moisture levels. The volume change, either swelling or shrinking, causes failure of the overlay pavements. Clay soil is weak and cannot carry the applied loads (Al-Gharbawi *et al.*, 2018; Jena *et al.*, 2025). This soil typically has a low CBR, indicating it is unsuitable for subgrade use and stabilization. The method of soil reinforcement using geotextiles enhances soil stiffness and load-bearing capacity by leveraging the interdependence between soil and geotextile characteristics. The load exerted on the pavement is transferred to the underlying subgrade. Consequently, if the subsoil beneath the road pavement is deficient, the thickness of the pavement must be augmented. This contributes to higher development costs and more likely failures in the near future. However, the application of geotextiles tends to reduce road pavement construction costs by stabilizing on-site soil, as stated in the literature. However, this was not included in the scope of this study.

The Alae-Kisolon Road in Sayre, along Mangima, Bukidnon Province, is above Adtuyon clay. Concrete pavement stretches from K1449 + 870 to K1452 + 370, approximately 2.5 kilometers, and has experienced failures earlier than expected. The Department of Public Works and Highways rehabilitated and reconstructed the damaged pavement, including drainage on the national road, four times from 2007 to 2016. The occurrence of these failures causes inconvenience not only to motorists and residents but also to the government because of the costly and intermittent repairs. Thus, an attempt was made to evaluate the performance of the Adtuyon clay subgrade soil reinforced with geotextiles to fully understand the behavior of the geosynthetic system when applied to the pavement structure. Specific objectives include, first, determination of grain size distribution, Atterberg limits, compaction, and CBR values of the Adtuyon clay. Second, the optimum moisture content, dry density, and CBR values of the reinforced samples were evaluated. Third, the load-settlement relations of the unreinforced and reinforced soil samples, as well as the resilient modulus, were determined. Meanwhile, equipment calibration during the tests is one of the study's constraints.

## 2. Methodology

The study comprised the following stages: the site for soil sampling was selected (1), preliminary soil samples were collected and tested to determine the highest plasticity index, degree of expansion, and CBR (2), the final testing included the laboratory tests, namely, sieve analysis, Atterberg limits and compaction test on the Adtuyon clay soil sample (3). This was followed by the CBR test for the samples in the soaked condition. The number of samples and tests conducted is listed in Table 1.

Table 1. Testing program matrix

| No. of Samples | Code | Tests Conducted |
|---|---|---|
| Unreinforced sample | US1 | Sieve Analysis<br>Atterberg Limit<br>Modified Proctor<br>California Bearing Ratio |
| Reinforced samples with geotextile placed at: | | |
| 1/4 height of the mold | S1 | Modified Proctor<br>California Bearing Ratio |
| 1/2 height of the mold | S2 | |
| 3/4 height of the mold | S3 | |

### *2.1 Selection of Site for Soil Sampling*

Preliminary Atterberg limits data were obtained from the Department of Public Works and Highways, Region 10, located in Cagayan de Oro City. The agency conducted several Atterberg limit tests on the entire road section. The findings revealed that the highest plasticity index value for the soil sample was at the 1452+000 station. Based on the DPWH's repair records, the road section bounded by stations K1451+855 to K1452+725 was upgraded from asphalt to concrete pavement in 2007. However, after 8 years, it was included in the concrete reconstruction in 2015 with a limit of K1449+870 to K1452+370. Moreover, the road section between stations K1449+770 and K1450+576 was asphalt overlayed in 2011. However, in 2015, it was replaced by a concrete reconstruction program.

Hence, given the history of road repairs, the road section bounded by K1449 + 870 to K1452 + 370 was selected for sampling. For the preliminary sampling, the road section was equally divided into five parts and was appropriately marked with stationary signage.

### *2.2 Collection of Adtuyon Clay Sample*

A soil sample was obtained from five selected stations for the Atterberg limit test. The samples were extracted from a depth of 1.2 m, as illustrated in Figure

1, following the removal of the topsoil. The samples were preserved in plastic cellophane and placed within a clean bag to maintain moisture. The soil samples were sent to the laboratory of Megatesting Center Inc. to identify the most expansive soil, in accordance with the standards set by the American Society for Testing and Materials (ASTM). The soil samples were stored in the laboratory for no more than 15 days before testing to prevent substantial alterations in their strength characteristics.

Figure 1. Measuring the depth of the excavation

## 2.3 *Laboratory Testing*

### 2.3.1 Sieve Analysis

ASTM D422-02: Test method for particle-size analysis of soils was the basis for the sieve analysis test. Sieve analysis was used to determine the grain sizes of the soil samples. Weighing the retained soil yielded the mass of soil retained on each sieve. The equivalent percentage passing through each sieve was calculated using Equation 1.

$$\%\,Passing\ per\ seive = \frac{Total\ Mass - Accumulated\ Mass}{Total\ Mass} \qquad (1)$$

### 2.3.2 Compaction Test on Reinforced Soil

Locally available non-woven polypropylene geotextile, specifically non-woven needle-punched type Polyfelt TS50, was used in this study to reinforce the soil samples. It is a continuous filament, needle-punched nonwoven with a tensile strength of 15 kN/m and a puncture strength of 2350N. The soil samples were reinforced with three varying placement heights. The locations of the geotextiles in the mold are shown in Figure 2. These placement heights were anchored in the reviewed related studies (Negi & Singh, 2020; Khan *et al.*, 2016; Bhole *et al.*, 2015). The samples were subsequently subjected to compaction testing in line with ASTM D1557-12: Standard test methods for laboratory compaction characteristics of soil utilizing a modified effort. Five experiments were conducted to gather data on the weight and moisture content of the compacted soil for each reinforced soil specimen. The dry density and moisture content measurements were thereafter plotted in conjunction with one another.

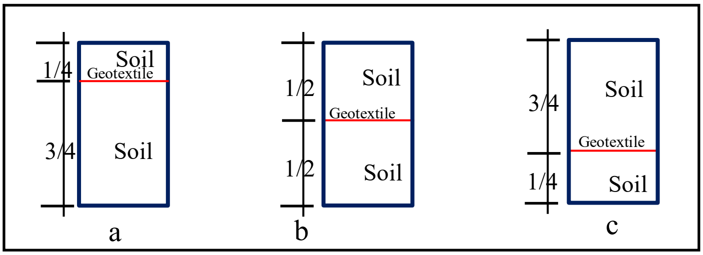

Figure 2. Varying reinforcement placement height where (a) S1, (b) S2, and (c) S3

### 2.3.3 California Bearing Ratio Test of Reinforced Soil

The soil samples were prepared in accordance with ASTM D1883-21, as shown in Figure 3. The moisture content obtained from the compaction test was used to determine the maximum dry density of the soil samples. After compaction, the samples were loaded with a surcharge of 10 lbs and soaked in a water tank for four days. Subsequent to soaking, the soil samples were drained of water and penetrated with a conventional circular piston at a rate of 1.25 mm/min. A graph depicting the relationship between penetration (mm) and penetration load (kN) was constructed, and the CBR under saturated conditions was calculated.

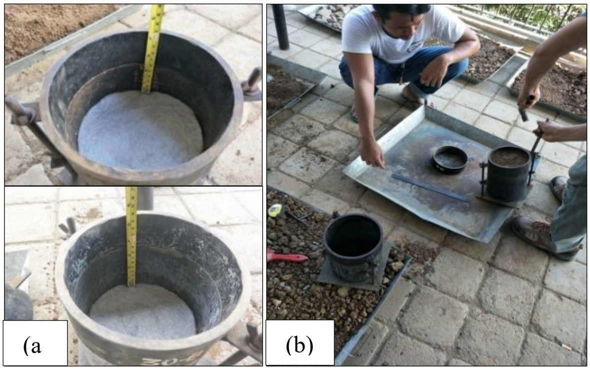

Figure 3. CBR Test for reinforced soil: Measuring placement height (a); and Compaction of soil (b)

### 2.3.4 Plate Load Test

The plate load test conducted was similar to the processes used by Bhole *et al.* (2015) and Kiptoo *et al.* (2016), using only the test pit. A test pit was excavated for sample preparation, measuring 1 m × 2 m × 0.4 m. Next, it was filled with Adtuyon clay soil acquired from Mangima, Bukidnon. The test pit was divided into two chambers, one for the control and the other for the reinforced samples, as shown in Figure 4. The first layer had a height of 0.10 m, and the second or final layer was at 0.30 m. For the reinforced sample, a geotextile was placed after the first layer. The height for reinforcement placement was determined by the results of the CBR test. Following compaction, a field density test utilizing the Sand Cone Method was conducted to verify that the soil samples achieved their designated maximum dry density (MDD). Photographs taken during the sample preparation prior to the plate load test are presented in Figure 5.

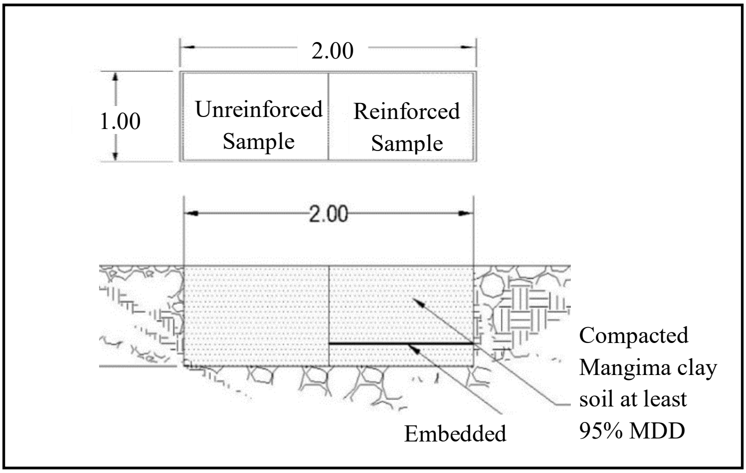

Figure 4. Plate load test set-up test for the samples

After the preparation for the test was completed, the Plate Load Apparatuses were set up. A steel plate with a diameter of 450 mm was initially positioned over the unreinforced sample, with three dial gauges and a hydraulic jack mounted above it. Once the apparatuses were established, a dead load consisting of an excavator was positioned directly above the hydraulic jack. The examination was performed in compliance with the stipulations of ASTM D1196/D1196M-21. Then, the loading started; the first load was 5 kN, then it was increased to 15 kN, 30 kN, 40 kN, and finally 50 kN, one after another. The readings on the dial gauges were recorded over time, starting with the first load and continuing through each subsequent load until the last load. Photographs taken during the plate-load test are shown in Figure 6.

Excavation of test pit

Compaction of first layer

Compaction of second layer

Laying of geotextile

Laying of Adtuyon clay

Field density test

Figure 5. Sample preparation before the plate load test

Setting up of plates and gauges

Preparation for loading

Setting up of dead load

Reading of dial gauges

Figure 6. Plate load testing of samples

### *2.4 Prediction of Resilient Modulus (Mr)*

After obtaining the soaked CBR values of the soil samples from the CBR test conducted during the final testing, the Resilient Moduli of the soil samples were determined using the predictive model suggested by the AASHTO Design Guide for fine-grained soils, as shown in Equation 2.

$$M_r = 1{,}500(CBR) \qquad (2)$$

where *CBR* = California Bearing Ratio value obtained from the laboratory testing.

## 3. Results and Discussion

### *3.1 Grain Size Analysis*

Table 2 lists the percentages of soil particles from the sieve analysis. The soil samples consisted of 0% gravel, 60% sand, and 40% clay. They were predominantly composed of soil particles 0.075-2mm in diameter. The uniformity coefficient and coefficient of gradation were 40.83 and 0.169, respectively. Moreover, based on the particle-size distribution curve shown in Figure 7, the soil was classified as gap-graded, with some mid-range particles missing.

Table 2. Soil sample parameters

| Description | Values |
|---|---|
| Gravel (%) | 0.0 |
| Sand (%) | 60.0 |
| Clay (%) | 40.0 |
| Uniformity Coefficient (Cu) | 40.8 |
| Coefficient of Gradation (Cc) | 0.2 |

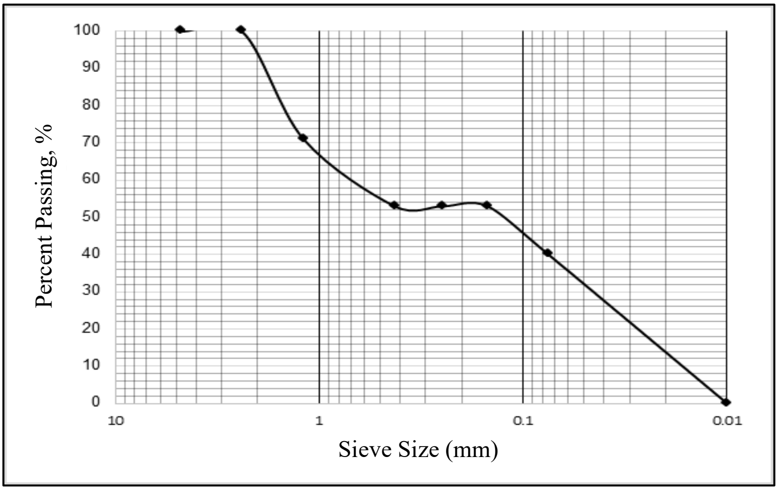

Figure 7. Particle size distribution curve

### 3.2 Soil Classification

The soil sample had a liquid limit of 57% and a plastic limit of 33%. According to the American Association of State Highway and Transportation Officials (AASHTO), the grain-size analysis and Atterberg limits tests categorized the soil as A-7-5, with a group index of 5. According to the Unified Soil Classification System (USCS), it was categorized as SC, consisting of clay and sand as shown in Table 3.

Table 3. Classification of the soil sample

| Soil Classification Standard | Soil Classification |
|---|---|
| AASHTO | A-7-5 (5) |
| USCS | SC-clayey sands, sand-clay mixture |

### *3.3 Compaction Results for the Unreinforced and Reinforced Samples*

The modified proctor compaction test method was used to determine the MDD and Optimum Moisture Content (OMC) for each mixture. The compaction curves of the unreinforced and reinforced soil samples are shown in Figure 8. As observed, the curve for soil reinforced at 3/4 showed peak dry density with respect to moisture content. In contrast, the unreinforced soil exhibited the lowest curve.

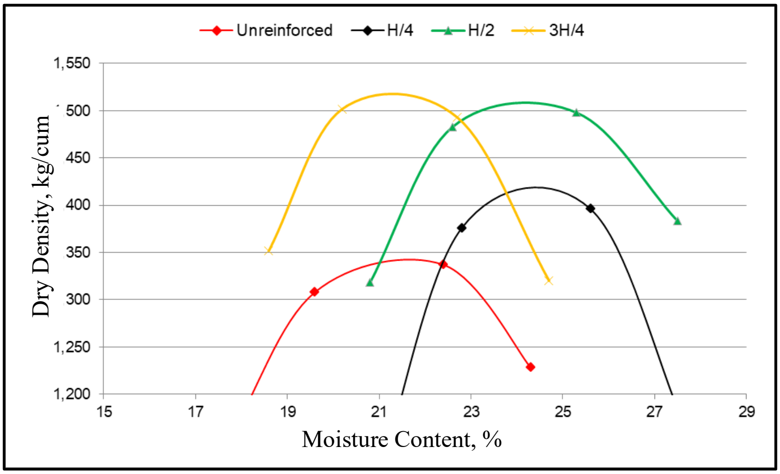

Figure 8. Dry density-moisture content curves of the soil samples

The MDD and OMC values of the unreinforced and reinforced soil samples are presented in Table 4. The MDD of the unreinforced sample was 1,354 kg/m$^3$ only. Subsequently, it increased to 1,438 kg/m$^3$ when the reinforcement was placed 1/4 of the way from the top. It further increased to 1,519 kg/m$^3$ for 1/2 placement of the geotextile, and the highest MDD of 1,530 kg/m3 was obtained at placement height 3/4. Therefore, it could be deduced that the maximum dry density increased when the soil was reinforced with geotextiles. The increase in MDD as the geotextile reinforcement was placed deeper aligns with findings from the study by Basha *et al.* (2022), which demonstrated that geotextile reinforcement with deeper placement improved compaction efficiency by enhancing particle interlock.

Optimum moisture content denotes the moisture level at which optimum dry density is achieved. As shown in Table 3, the inclusion of geotextile reinforcement increased the optimum moisture content from 21.2% for the unreinforced sample to 24.3% for the 1/4-reinforced sample. Subsequently, the values decreased to 24.1% for the 1/2-reinforced sample and 21.5% for the 3/4-reinforced sample. The optimum moisture content increased when the soil was reinforced with 1/4 of the geotextiles. However, the OMC values began to decrease when the reinforcement was placed deeper.

Moreover, it was observed that although the inclusion of geotextile generally increased the MDD, the OMC initially increased at shallow reinforcement (1/4 placement) and then decreased as the reinforcement depth increased. Including geotextile would decrease the voids within the soil particles that moisture must fill to obtain MDD. Thus, the OMC decreased.

Table 4. MDD values of the soil samples

| Soil Code | Maximum Dry Density (kg/cum) | Optimum Moisture Content |
|---|---|---|
| US1 | 1,354 | 21.2% |
| S1 | 1,438 | 24.3% |
| S2 | 1,519 | 24.1% |
| S3 | 1,530 | 21.5% |

### *3.4 California Bearing Ratio Results*

The saturated CBR values for both unreinforced and reinforced soil samples are presented in Table 5. The findings indicated that the unreinforced sample exhibited a CBR value of 2.8, while the 3/4 reinforced sample demonstrated the highest CBR value of 4.8 implying 61.2% increase in value. The trends in the CBR values of the samples are shown in Figure 9. Moreover, it could be observed that the CBR values of the reinforced sample increased as the position of the geotextile was placed at 1/4, 1/2, and 3/4 from the top of the sample soil. It could be inferred that the application of the geotextile in the reinforced sample increases the CBR value of the soil.

The subgrade can be classified based on CBR (Jenkins, 2006), as shown in Table 6. The results revealed that the unreinforced sample was classified as

SG4, which indicated that the sample was a poor material and required treatment, while all the reinforced samples were classified as SG3, which designated the samples as a fair quality subgrade.

Table 5. Soaked CBR values of the soil samples

| Soil Code | CBR value |
|---|---|
| US1 | 2.8 |
| S1 | 3.9 |
| S2 | 4.6 |
| S3 | 4.8 |

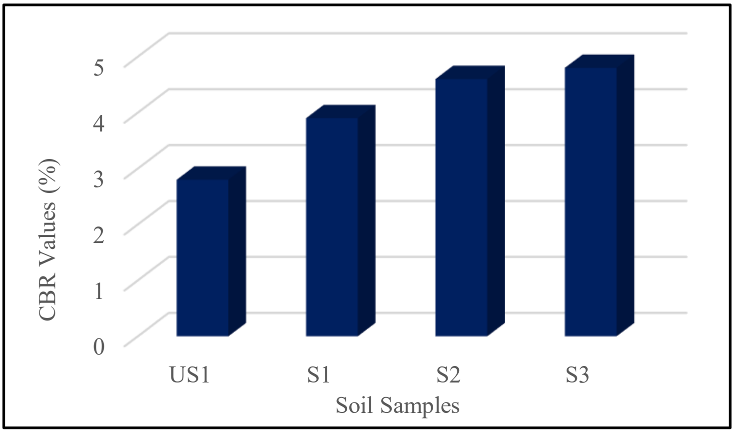

Figure 9. Trend of the CBR values with varying reinforcement height

Table 6. Subgrade classification for structural design

| Class | Subgrade CBR (%) | Comment |
|---|---|---|
| SG1 | > 15 | Good quality material, just rip and re-compact |
| SG2 | 7 to 15 | Moderate quality, needs 150mm of CBR > 15 above |
| SG3 | 3 to 7 | Fair quality, needs 150mm of CBR > 15 + 150mm of CBR > 7 above |
| SG4 | < 3 | Poor material, special treatment |

### 3.5 Plate Load Test Results

The unreinforced and reinforced soils with a 3H/4 placement height of the geotextile were subjected to a plate load test. The settlement values of the unreinforced and reinforced soils are displayed in Table 7. Both soil samples were subjected to the same set of loadings. For the unreinforced, the settlement for the highest load applied of 50 KN was 7.04 mm, while the reinforced sample obtained a settlement for that same load of 4.27 mm.

Table 7. Settlement values

| Load (kN) | Pressure (kPa) | Settlement (mm) | Settlement (mm) |
|---|---|---|---|
| | | Unreinforced | Reinforced |
| 5 | 32.0 | 0.81 | 0.00 |
| 15 | 95.0 | 1.65 | 0.35 |
| 30 | 189.0 | 3.23 | 2.33 |
| 40 | 252.0 | 5.09 | 4.27 |
| 50 | 315.0 | 7.04 | 5.84 |

The load-settlement graphs of the unreinforced and reinforced samples are shown in Figures 10-11, respectively. As the amount of applied pressure increased ten (10) times (from 32 kPa to 315 kPa), the settlement also surged more than eight (8) times (from 0.81 mm to 7.04 mm). The same observation was noted in the load-settlement graph of the reinforced soil. However, as the 32 kPa pressure was applied in this setup, no settlement was recorded. The values for settlement or lack thereof were noted as the pressure was increased. Through these observations, one could deduce that as the pressure applied in the unreinforced and reinforced soil increased, the settlement values also increased.

Figure 12 shows the load-settlement graph of the unreinforced and 3/4 reinforced samples. Under the same load, the settlement values of unreinforced sample were visibly higher than those of the reinforced samples. Considering the load application, 50 kN was applied as the highest load to the reinforced soil, resulting in a 17% reduction in settlement compared to the unreinforced soil. The application of geotextile showed settlement reduction in the soil.

### *3.6 Resilient Modulus Result*

Table 8 shows the predicted values of the soil samples' resilient modulus. The resilient modulus of the unreinforced samples increased from 4,200 psi to 5,850 psi upon inclusion of geotextile placed 1/4 height from the top of the mold. It continued to increase to 6,900 psi and 7,200 psi for placement heights 1/2 and 3/4, respectively.

The usage of Mr could address inferences on the pavement design for the amount of traffic life passing through and its requisite thickness. A high resilient modulus discloses the great amount of traffic the pavement can carry and presupposes the decrease in the pavement's required thickness. Moreover, Mr not only influences the design of flexible pavements but could also have repercussions resulting in the pavement's failure. Two major causes of pavement failures are attributed to tensile strain that develops at the bottom of the surface layer and the stress or strain applied to the subgrade. These parameters have direct relationships with the resilient modulus of the subgrade. As the resilient modulus of the subgrade increases, both the flexible pavement strain and the subgrade stress ratio decrease, indicating an increase in the pavement life. Hence, this study inferred that soil reinforced at 3/4 would result in reduced pavement thickness and most likely contribute to an increased pavement lifespan compared to the unreinforced soil.

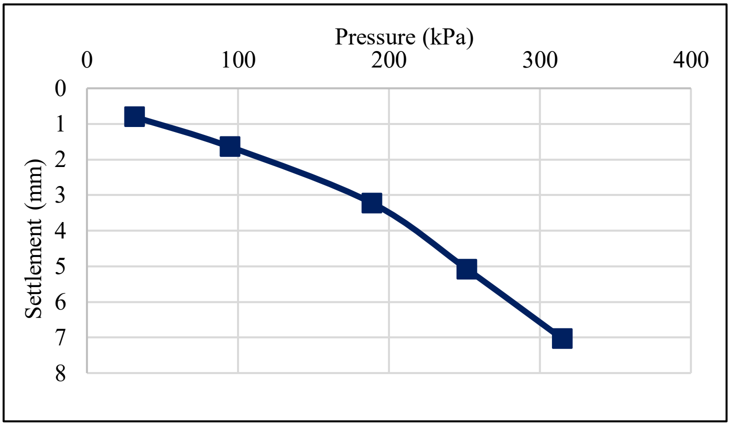

Figure 10. Load-settlement curve of the unreinforced sample

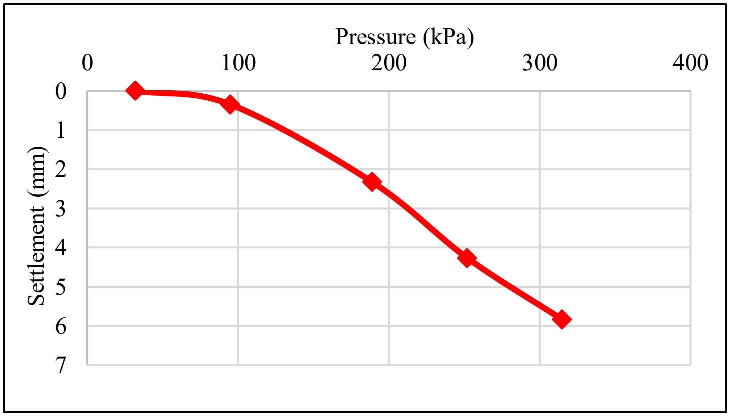

Figure 11. Load-settlement curve of the reinforced sample

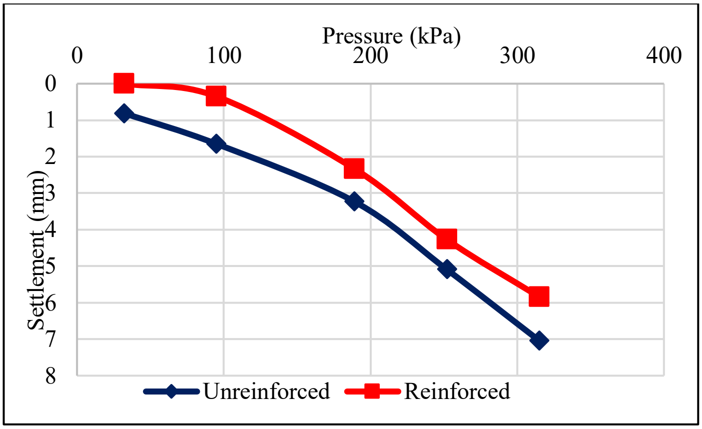

Figure 12. Load-settlement curve of the unreinforced and reinforced soil sample

Table 8. Resilient modulus of soil samples

| Sample Code | Soaked CBR | Predicted Resilient Modulus (psi) |
|---|---|---|
| US1 | 2.8 | 4,200 |
| S1 | 3.9 | 5,850 |
| S2 | 4.6 | 6,900 |
| S3 | 4.8 | 7,200 |

## 4. Conclusion and Recommendation

The results showed significant effects on the CBR, load-settlement behavior, and resilient modulus of the Adtuyon subgrade soil reinforced with geotextile. Thus, the Adtuyon subgrade soil along Alae-Kisolon Sayre Highway is classified as A-7-5 type of soil and has a group index of five which indicates a poor subgrade material. The incorporation of geotextile reinforcement in the Adtuyon subgrade soil enhances its maximum dry density, whereas the optimum moisture content diminishes as the placement height approaches the base. An increase of 61.2% in the CBR value and a 17% reduction in settlement at a 50 kN applied load were also observed, implying greater resistance to penetration. Lastly, it increases its predicted Mr value, indicating improved pavement design and lifespan.

Through the findings and conclusions of the study, the researcher recommends that geotextiles should be used as reinforcement for Adtuyon subgrade soil along Mangima, Bukidnon, to improve its engineering properties, specifically its CBR value and load-settlement characteristics. Also, the determination of the bearing capacity ratio from the settlement values of the unreinforced and reinforced subgrade soil is important to fully evaluate the performance in bearing capacity improvement of the geotextile-reinforced pavement structure.

## 5. Acknowledgement

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