Performance of Subbase Layer with Geogrid Reinforcement and Zeolite-Waterglass Stabilization

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Abstract

Some laterite soil is an inferior material for engineering applications such as road and highway pavement, dam construction and filling material. Laterite soil stabilization is required to increase its strength for field application purposes. The potential use of zeolite and waterglass as stabilizing agents is their pozzolanic properties. This study aims to analyze the strength and bearing capacity of laterite soil stabilized by waterglass-activated zeolite and reinforced with geogrid. The soil sample was prepared with a zeolite percentage of 4, 8, 12, 16 and 20%, and waterglass as much as 2, 4 and 6% with curing times of 0, 7, 14 and 28 days. Furthermore, the physical model test was carried out in the container with the optimum composition obtained from the compressive strength (UCS) and California bearing test (CBR) test. The stabilized subbase layer with geogrid reinforcement was placed on a subgrade layer with a substandard CBR value. The results showed that the compressive strength (UCS) of stabilized soil with a curing time of 7 days was found significantly increased. The CBR value also increased with the content of additive and curing time compared to the untreated soil. The physical model test results showed that the performance of stabilized laterite soil with additives and reinforced by geogrid (ZW-geogrid) as a subbase layer provides more optimal performance in carrying the load compared to the sand-gravel mixtures material.

Keywords: Laterite Soil; UCS; CBR; Zeolite; Waterglass; Geogrid.

1. Introduction

Laterite soils are collected from various weathered rocks under strong oxidizing states and are rich in iron oxides. Laterite soils are found in humid climates and form in tropical and subtropical areas. Climate (temperature, precipitation, and capillary rise), topography (drainage), vegetation, host rock (iron-rich rock), and time are the main factors in the formation of laterite. Laterite soil is a natural material that is inexpensive and widely available as a construction material. For engineering application purposes, the performance of laterite soil may range from good to poor. However, the use of laterite soil without stabilization often causes problems with bearing capacity, especially when applied to road construction. The problems often encountered in laterite soils include sensitivity, degree of swelling-shrinkage potential, and a decrease in strength during and after construction. The solution can be achieved by adding additives to the laterite soil. Therefore, some previous studies reported that the treatment of reclaimed asphalt pavement (RAP) with coal fly ash using lateritic soil as the base material. The results showed that the CBR value of stabilized lateritic soils increased by up to 6% [1]. Some laboratory test results also showed that lateritic soil stabilization significantly increased the CBR and Resilient Modulus (Mr) of the soil mixtures [2-4].

Recent research has shown that the use of fiber in cement-stabilized soil increases its compressive strength significantly [5-7]. The soil ductility significantly increased with no effect on the compressive strength with the addition of fiber to the cement-stabilized soil mixture [8]. The presence of fibers in stabilized soil with cement can reduce the occurrence of cracks during compressive strength testing [9]. However, the use of cement has a negative impact on the environment because of the release of CO_2 in its manufacture. Therefore, several researchers have developed environmentally friendly materials in an effort to reduce the use of cement as a stabilizing agent. Utilization of bacteria (i.e., Bacillus subtilis) as a lateritic soil stabilization agent showed a significant increase in compressive strength and CBR values. The bacteria can also improve the strength and CBR value of coal contaminated soil for ex-coal mining waste [10, 11]. Moreover, in recent decades, alkaline zeolite materials have been widely used as soil stabilization additives. Zeolite is a pozzolanic material and can be found in large volumes in nature, so that it is economically advantageous compared to cement and lime [12].

Several researchers have also developed reinforcement technology for the road pavement layer using geogrid to increase the tensile strength of the pavement layer. Geogrid will provide resistance to tensile stresses that occur in the pavement layer when receiving vehicle load. This mechanism will reduce the flexure of the pavement [13]. Geogrid reinforcement installed on the road pavement layer also provides resistance to shear forces. The vertical pressure of the vehicle wheel load will cause deflection and, subsequently, the geogrids will be pulled to the pavement layer. The geogrid tensile stress will provide resistance to the vehicle load. The installation of a single layer geogrid increases the bearing capacity of the subbase layer. However, the deeper the geogrid location is from the surface, the more it will cause a decrease in the bearing capacity [14]. A study of 80 plate load tests using a 350×350 mm square plate was conducted to observe the effect of geogrid position, width, number, and tensile strength on the load-deformation response. A similar study was also conducted to observe the tensile strength of geogrid on dense and loose layers [15, 16].

In this study, the addition of an additive (zeolite and waterglass) as a stabilization material for laterite soil and reinforced with geogrid was investigated on a laboratory scale. Several mix design tests were carried out to obtain the optimum composition of the laterite soil mixture with mineral additives and subjected to various curing times. The optimum mixture compositions are combined with a single (1 layer) and a double (2 layer) geogrid to form a composite layer (ZW-geogrid). The ZW-geogrid layer as a subbase layer is then tested by physical models on the laboratory scale. As a control, a test of the subbase layer consisting of the sand-gravel mixture was conducted as a comparison to the reinforced subbase layer.

2. Materials and Methods

2.1. Materials

The laterite soil was collected from the Sangkaropi borrow pit in Toraja, South Sulawesi Province, Indonesia. The laterite soil sample was filtered through an opening of 0.425 mm sieve according to ASTM [17]. The natural water content of laterite soil is 32% and is classified as a high plasticity silt (MH). Zeolite is used as a stabilization agent with waterglass (sodium silicate) as an activator. Zeolites are formed as crystalline alumina-silicates consisting of a three-dimensional framework of SiO_4 and AlO_4 linked by oxygen bonds. This natural zeolite was crushed and screened with an aperture of 0.075 mm. Furthermore, the geogrid used in this test has a hole size of 40×40 mm with a thickness of 1 mm and is made of polypropylene material. The tensile strength of geogrid ranges from 15 to 40 kN/m with a strain of 2–5%.

2.2. Methods

The basic characteristics and mechanical characteristics of laterite soil such as soil density, compressive strength (UCS) and CBR were determined with the reference to the ASTM standard [18-20]. The composition of zeolite used is 4, 8, 12, 16 and 20% while waterglass has a composition of 2, 4 and 6% respectively. The additive mixture composition based on the dry weight of the soil sample to be mixed. The curing time of specimens was set to 0, 7, 14 and 28 days. Prior to the test, all specimens were prepared under conditions of maximum dry density (MDD) with optimum moisture content (OMC). The CBR test was carried out in unsoaked conditions with the assumption of study area where the ground water level was deep enough and the intensity of rainfall was quite low.

The design and composition of the mixture were carried out by initially conducting a compaction test to determine the maximum density and optimum moisture content. Furthermore, the additives (zeolite) and activator (waterglass) were mixed with laterite soil. The mix of laterite soil with stabilizing material was then cured for 0, 7, 14 and 28 days. Compressive strength and CBR tests were carried out for each sample based on its curing period. The value of the optimum mixture composition (soil-ZW mixture) is determined based on the value that meets the design criteria of the road foundation. Furthermore, physical model testing is carried out on three conditions of the road subbase layer. The first model testing was carried out with a subbase layer of a mixture of sand and gravel. The second model was tested with a layer of soil-ZW reinforced with one layer of geogrid (ZW-geogrid). The ZW-geogrid with two layers of geogrid reinforcement was prepared for the third model test. The experimental program in this study is shown in Figure 1.

Physical model testing of the composite subbase layer was carried out in a container with a height of 1.1m, width of 0.9m and length of 1.5m. The size of the container is determined based on the dimensions of the load plate dimension and its zone of influence. The composition of the layer in the container consisted of 2 layers, including alluvial clay as a subgrade with a thickness of 50cm and a subbase composite layer (ZW-geogrid) with a thickness of 15cm which is placed above the subgrade layer. The thickness of the ZW-geogrid layer both single and double geogrid are lower than the standard thickness of the conventional subbase layer in order to observed the effect of the subbase layer thickness. The composition of zeolite and waterglass is determined based on the optimum value obtained from UCS and CBR test results.
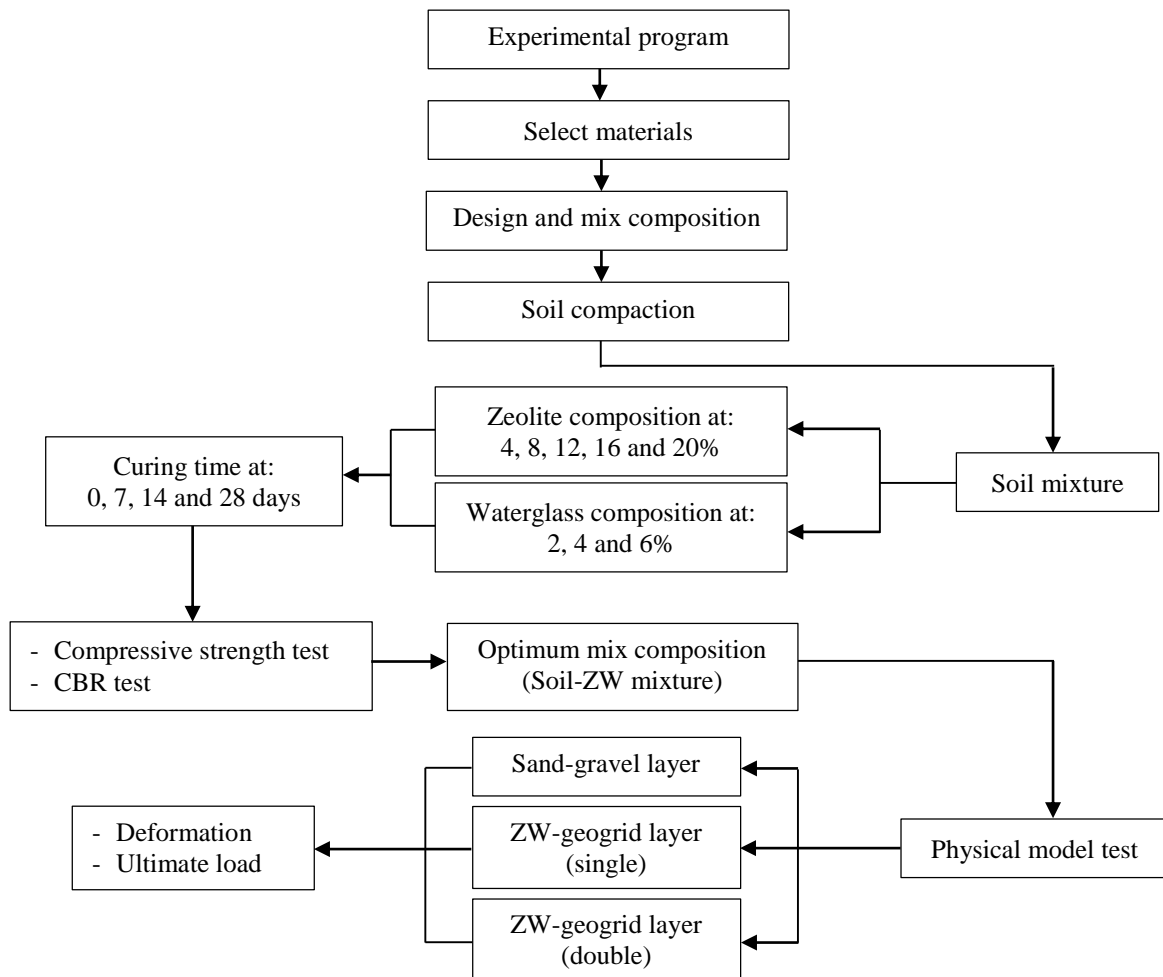
Figure 1. Experimental program

The subgrade layer was prepared with a CBR value of 3.5% to simulate the condition of substandard CBR value (below 6%) which is often found in soft soil. Furthermore, the loading is given by using a plate load test apparatus (30cm in diameter and 2.5cm in thickness) and is loaded until the subbase layer collapses with accordance to ASTM [21]. The previous study reported that the loading stage was terminated when the total settlement was sufficiently large (generally greater than 20mm) [14]. The schematic diagram of the physical model test in the laboratory is shown in Figure 2. Figure 2-a shows the test sequence with a subbase material consisting of a sand-gravel mixture. The second test uses a layer of ZW-geogrid material (1 layer), as shown in Figure 2-b. In the physical model test, the magnitude of the vertical deformation and the ultimate load were measured continuously.
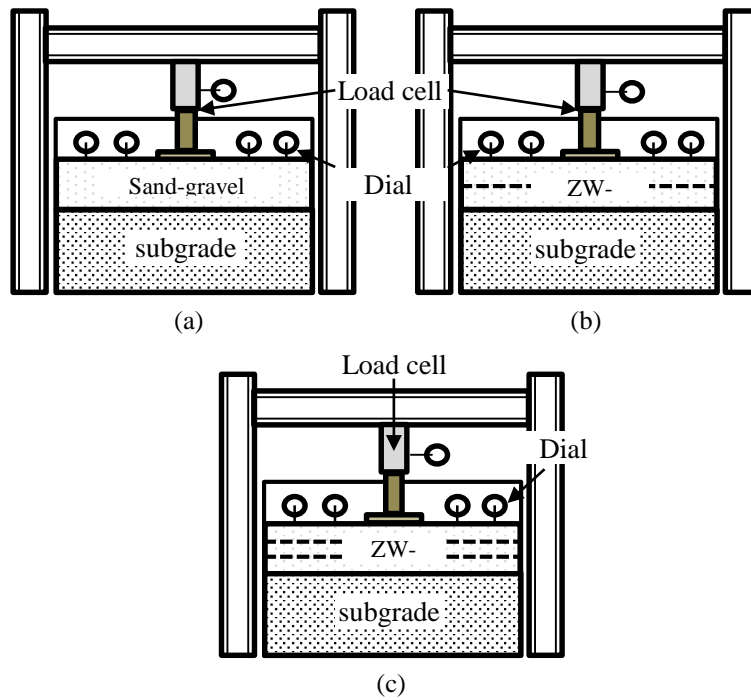
Figure 2. Schematic diagram of experimental setup: (a) Sand-gravel mixture

3. Results and Discussion

3.1. Characteristics of Laterite Soil and Additive Materials

The physical and mechanical characteristics of materials used in this study are presented in Table 1. The laterite soil was classified as silt with high plasticity (MH) with an organic content of 1%. The lateritic soil used in this study has a high level of weathering in alkaline to ultramafic rocks with relatively high dominance of iron metal. This is confirmed by the results of the x-ray diffraction test (XRD) where the FeO content is 59.9%, Al2O3 is 17.7%, SiO2 is 19.2% and remaining compounds are 3.2%. Moreover, the zeolite mineral is dominated by SiO2 of 64.5% and Al2O3 of 17.8%. Zeolite which is a natural pozzolanic material has a compound composition similar to clay minerals but differs in its crystalline structure. Meanwhile, the waterglass as an activator is a waterglass which commercially available.

Table 1. Laterite soil characteristics

Designation	Value	Unit
A. Physical Properties		
Specific Gravity	2,68	
Natural Water Content	32	%
Soil Classification		
a. USCS	MH	
b. AASHTO	A-5	
Attenberg Limit		
a. Liquid limit (LL)	59	%
b. Plastic Limit (PL)	49	%
c. Plasticity Index	10	%
B. Mechanical Properties		
Standard Proctor Test		
a. Optimum Moisture Content (OMC)	25	%
b. Maximum Dry Density (MDD)	14,8	kN/m^3
Unconfined Compression Test (UCT)		
Compressive Strength	97,1	kN/m^3
California Bearing Ratio (CBR)		
Unsoaked	19,0	%

The physical and mechanical properties of laterite soils are highly dependent on the mineralogical composition and grain size distribution of the soil particles. Granulometry vary from fine to coarse depending on the origin and the formation process which will affect the mechanical characteristics such as plasticity and strength. One of the advantages of lateritic soil is the small amount of expandability with an increasing of water compared to other expansive soul types and also depend on its clay mineral [22].

3.2. Compressive Strength of Laterite Soil Stabilized with Zeolite and Waterglass

Variations of the UCS value of laterite soil stabilized with zeolite and waterglass with curing times of 0, 7, 14 and 28 days are shown in Figure 3. The UCS value is expressed as a normalized compressive strength which is the compressive strength ratio between stabilized soil (UCSs) and untreated soil (UCSu). In general, there is an increase in the UCS value for the stabilized laterite soil. The increase in UCS values was found from $300 - 2500$ kN/m^2 (3 to 25 times of magnitude) compared to the original soil (97.1 kN/m^2). The highest increase in the UCS value was observed at 20% of zeolite content with 6% of waterglass. Similar behaviour of UCS was found for other zeolite-waterglass compositions. The mineral content in zeolite and waterglass plays an important role in increasing the strength of stabilized soil [12].
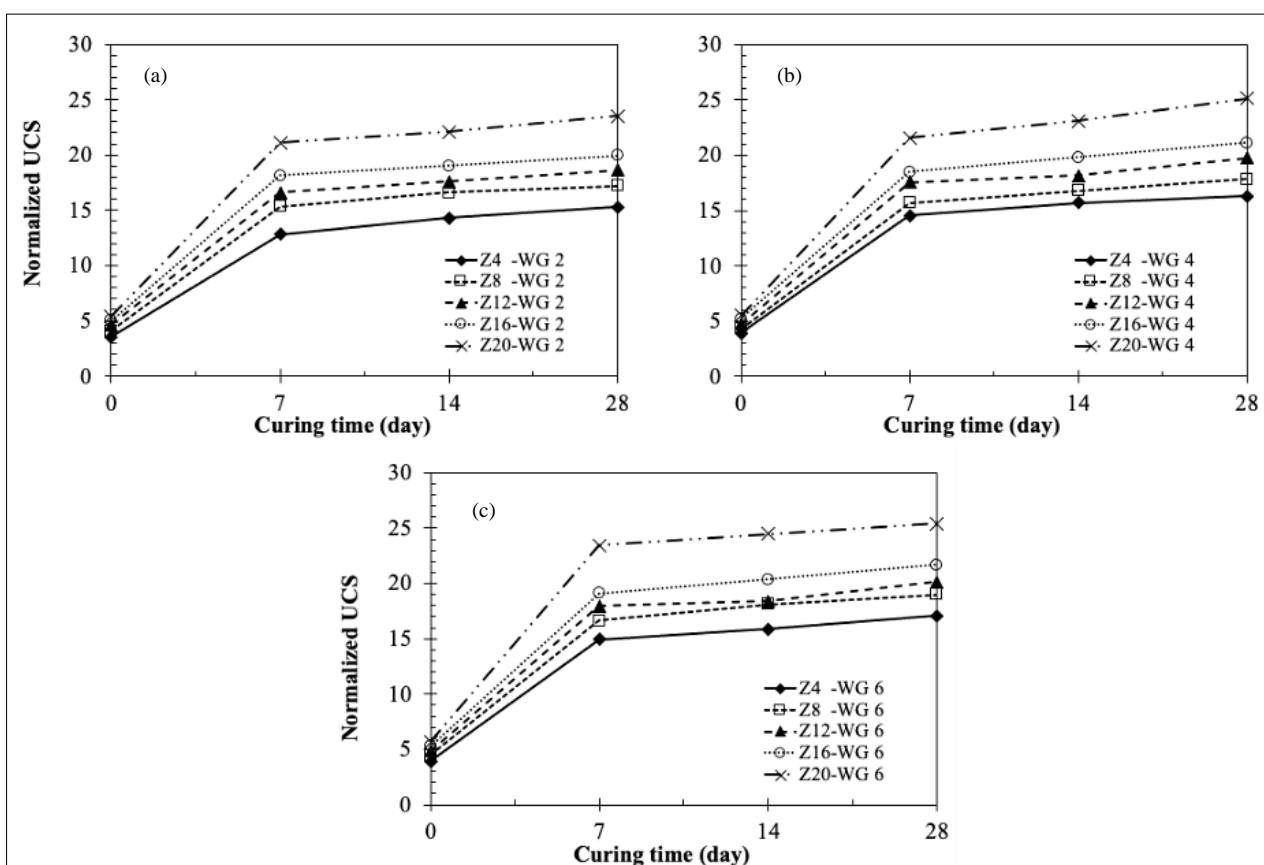

Figure 3. Normalized UCS versus curing time with various waterglass content: (a) 2% (b) 4% and (c) 6%

In general, the increase in the UCS value of the stabilized laterite soil depends on the amount of additive mineral composition added to the laterite soil. However, increasing the zeolite and waterglass content above 20% and 6% respectively is no longer efficient from an economical point of view. Some researchers reported that the 30% of zeolite content as an additive material was the optimum content of mixing. Mixing zeolite exceeding 30% will result in a decrease in its UCS value and is no longer effective [23-25].

Moreover, the UCS value also increased significantly with increasing the curing time. The UCS value changes with variation of waterglass content (2, 4 and 6%) as shown in Figure 4. All the specimens were tested with a curing time of 0, 7, 14 and 28 days. The general trend is the same as the previous test that there is an increase in the UCS value with the addition of water glass content into the laterite soil-zeolite mixed. A significant improvement of UCS value at the curing time of 7 days was observed. Increasing the curing time beyond 7 days, there is no significant change of the UCS value was observed.
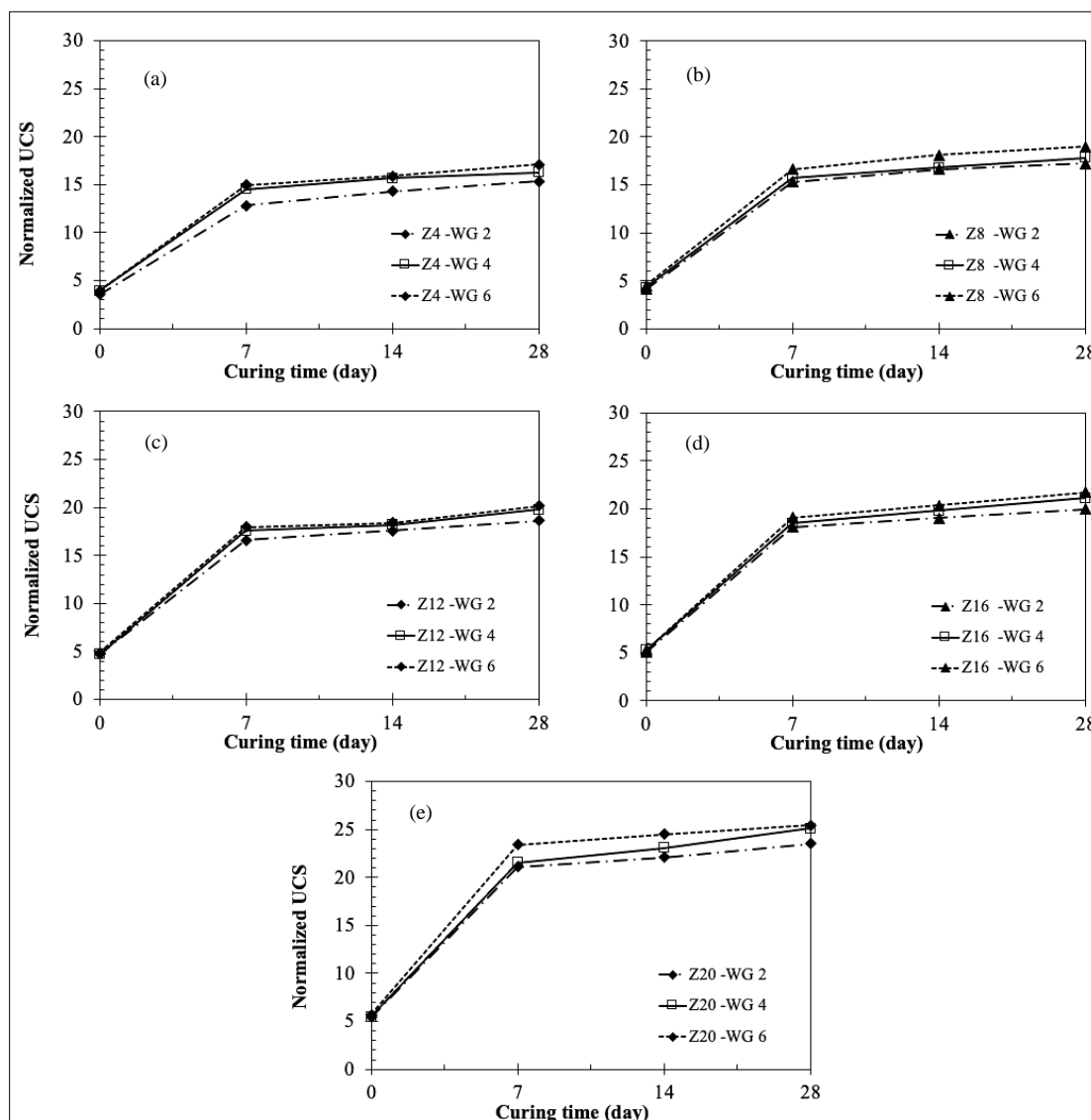
Figure 4. Normalized UCS versus curing time with various zeolite content: (a) 4% (b) 8% (c) 12% (d) 16% and (e) 20%

The addition of a waterglass activator has an effect in increasing the UCS value of the stabilized soil. The higher UCS value of laterite soil stabilized with zeolite and waterglass activator was mainly due to the presence of pozzolanic reaction. The occurrence of reactions between minerals causes a strong bond between soil particles [26]. The high content of silica (SiO_2) and alumina (Al_2O_3) in zeolite affects the cementation reaction with lateritic soil minerals [7, 9]. The cementation reaction is caused by lateritic soil particles which have a high surface charged and can attract positively charge ions (cations). The addition of zeolite into the soil-water system triggers a pozzolanic reaction between H2O, silica and alumina and subsequently produces and cementation products. The cation exchange reaction is rapid and results in improvements in strength, plasticity and stiffness. Cation exchange and flocculation-agglomeration reactions occur during the mixing process [23]. Zeolite particles are microporous and crystalline solids that mixed into laterite soils will result in an increase in soil strength and a decrease in porosity as a result of alkaline-aggregate reaction [27]. Moreover, the effect of curing time also plays an important role in the pozzolanic reaction process which results in an increased compressive strength value.

3.3. California Bearing Ratio of Stabilized Laterite Soil

The CBR values of laterite soil stabilized with zeolite and waterglass activator are shown in Figure 5. In general, it can be observed that the CBR values increased with an increase in the composition of zeolite and waterglass. Similar to the previous section, the CBR value is presented as a normalized CBR which is the CBR ratio between stabilized soil (CBR_s) and untreated soil (CBR_u). The curing time also increases the CBR value of the stabilized laterite soil. For 28 days curing time, the highest increase in CBR value was found for zeolite content of 20% and waterglass of 6% with an increased ratio of 3.6 times of magnitude compared to untreated soil. Every composition of stabilization agent subjected to the laterite soil meet the requirement of the Indonesian National Standard [28]. The standard requires that the minimum CBR value for the subbase is 20%.
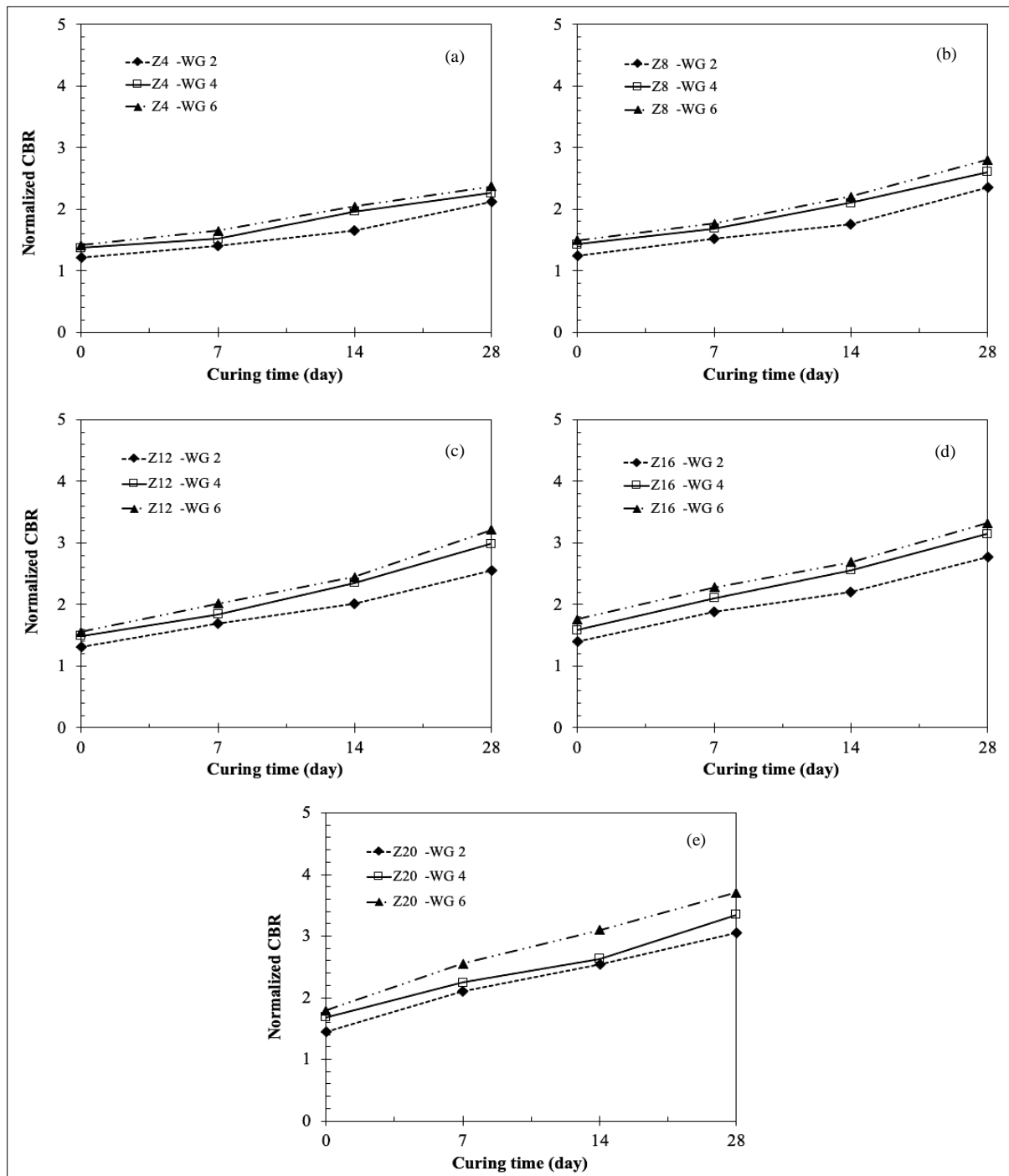
Figure 5. Normalized CBR versus curing time with various zeolite content: (a) 4% (b) 8% (c) 12% (d) 16% and (e) 20%

The additional curing time causes the CBR value of the stabilized soil to experience a significant increase. However, the most significant improvement was found at 28 days curing time which is similar to the UCS test. Increasing the curing time above 28 days is no longer effective because the minimum standard of CBR value for the subbase has been fulfilled. Improvement of CBR value mainly due to the pozzolan reaction of zeolite and waterglass with laterite soil. Agglomeration of soil causes an increase in the value of compressive strength and its bearing capacity. The improvement of bearing capacity is a result of the increase in stiffness of stabilized soil due to the effects of the cementation process [12]. These results are in good agreement with several previous studies [29, 30].

3.4. Laboratory Physical Model Test

The physical model test in laboratory scale is divided into three test models. Initially, the subbase layer consist of sand-gravel mixed material was tested and used as a control for treated subbase layer. The CBR value of this sand-gravel layer was set at 20% following the Indonesian standard for subbase pavement [28]. The composition of the mixture of zeolite and waterglass (ZW) used in plate load test was set to 4% and 2% respectively. This ZW mixture had a CBR

value 26% which meets the existing standard for subbase CBR value. The composition was determined based on the previous CBR test results with a curing time of 7 days. The curing time was determined based on the compressive strength and CBR results where the curing time more than 7 days did not show a significant increase in soil strength and the bearing capacity had been fulfilled (CBR>20%).

The vertical deformation reading dials (dials 2-5) is mounted along the side of the load plate while dial 1 is placed on the load plate. The test results in the form of the relationship between load and vertical deformation on several dials installed are presented in Figure 6. The sand-gravel mixed layer shows a significant vertical deformation until the maximum load achieved (collapse at the load of 10 kN) as shown in Figure 6-a. However, the small amount of deformation was observed at dial 2-5 (outer side of the loading plate). As the distance from the loading plate increase, effect on the vertical deformation decreases. This is due to the relatively small of horizontal distribution of stresses. The laterite soil stabilized with zeolite-waterglass and reinforced with geogrid (ZW-geogrid) are then subjected to the same plate load test method. The observed deformation pattern for the subbase material consisted of ZW-geogrid with a single layer of geogrid is shown in Figure 6-b. The geogrid layer was placed in the middle of the ZW-geogrid layer (7.5cm from the surface). A small amount of deformation was observed at the dial closest to the plate (dial 2) with a load greater than 20 kN. Similar behavior is also found in the ZW-geogrid with a double geogrid layer. However, for dial 2 the amount of deformation is slightly higher compared to the single geogrid layer as shown in Figure 6-c. This behavior indicates that there is lateral displacement near the surface of the ZW-geogrid layer. The geogrid placed at the depth of 5cm and 10cm provides a large enough shear resistance resulting in lateral displacement of the soil near the surface.
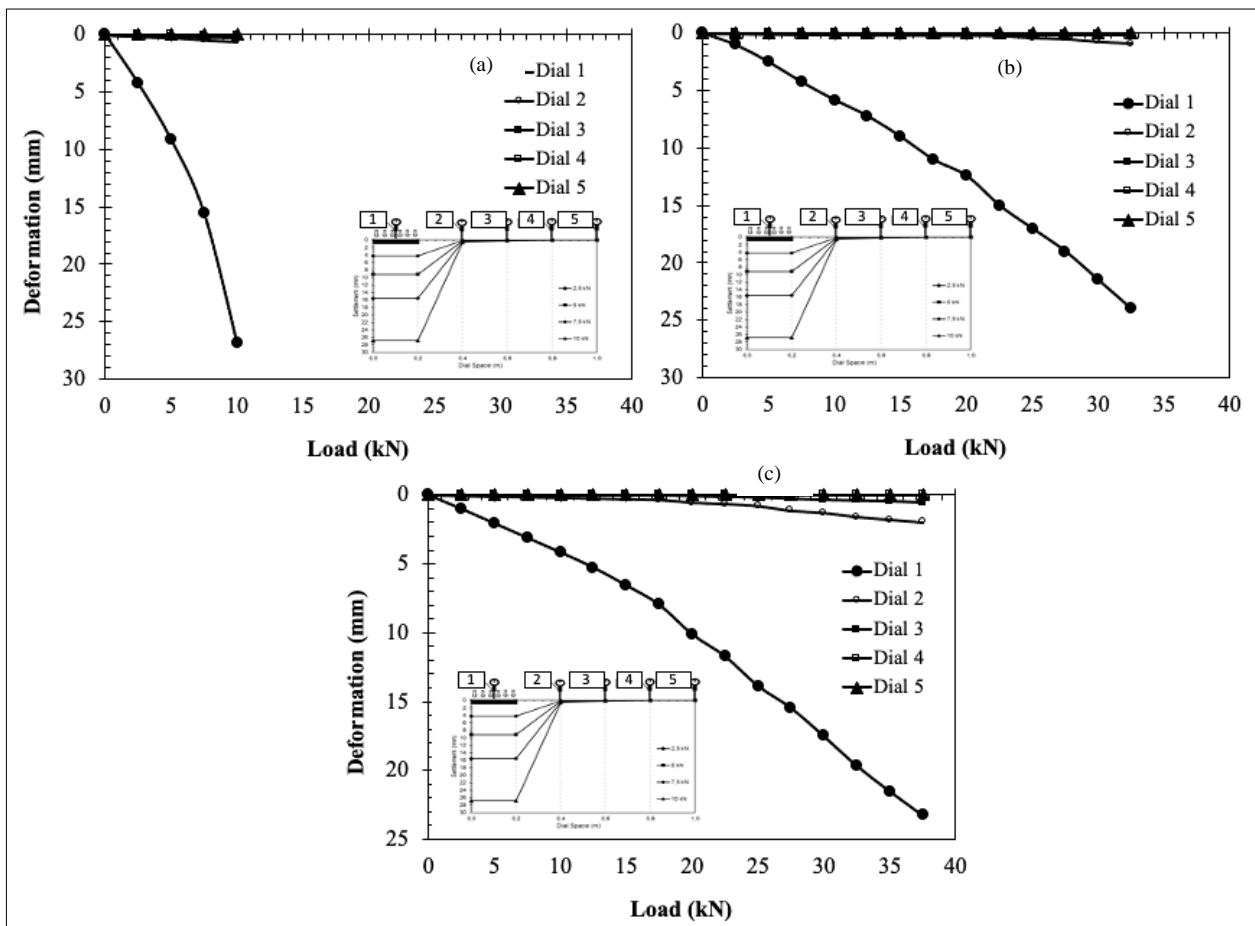

Figure 6. Load-deformation response of various subbase material (a) sand-gravel (b) single geogrid (c) double geogrid

The squeezing mechanism causes the soil between the slab and the geogrid to be laterally deformed. The cause of this phenomenon is due to the rigidity and natural hardness of the geogrid. The presence of shear resistance on the geogrid surface can reduce the potential for vertical deformation under the load plate in the ZW-geogrid layer [31, 32]. Figure 7 shows the relationship between load and vertical deformation for sand-gravel mixture and ZW-geogrid layer both single and double geogrid. It can be seen that the ZW-geogrid layer is able to carry a larger load at the same deformation value. The ZW-geogrid layer not only increase the bearing capacity and the stiffness of the subbase layer which can be seen in the slope of the load-deformation curve, but also changes the load-deformation relationship from ductile to brittle behavior [14].
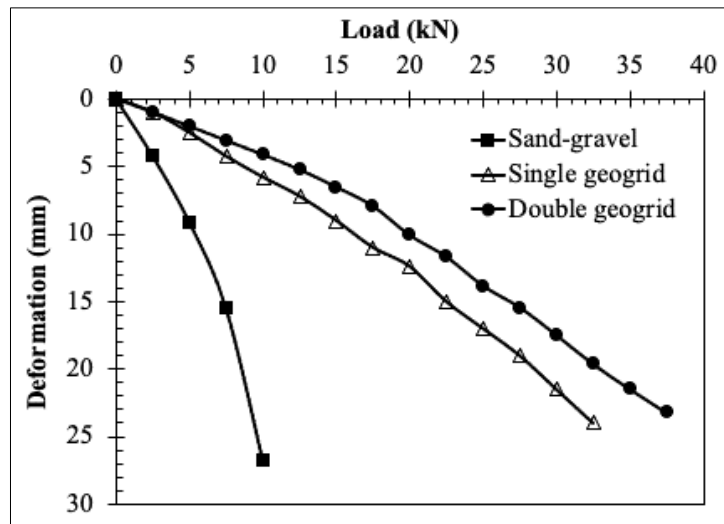
Figure 7. Combination of load-deformation response with various subbase

Based on the results of plate load test, it can be determined the magnitude of the ultimate load of the subbase layer as shown in the Figure 8. The upper tangent line is a straight line which is assumed to be a line under elastic conditions. The lower tangent is obtained by plotting a straight line at a higher load which is assumed to be plastic condition. The ultimate load value is determined from the intersection of two tangent lines. From the results of this test, the ultimate load for sand-gravel mixture layer is 6.8 kN and for ZW-geogrid layer for both single and double geogrid was found 18.5 kN and 20.6 kN respectively.
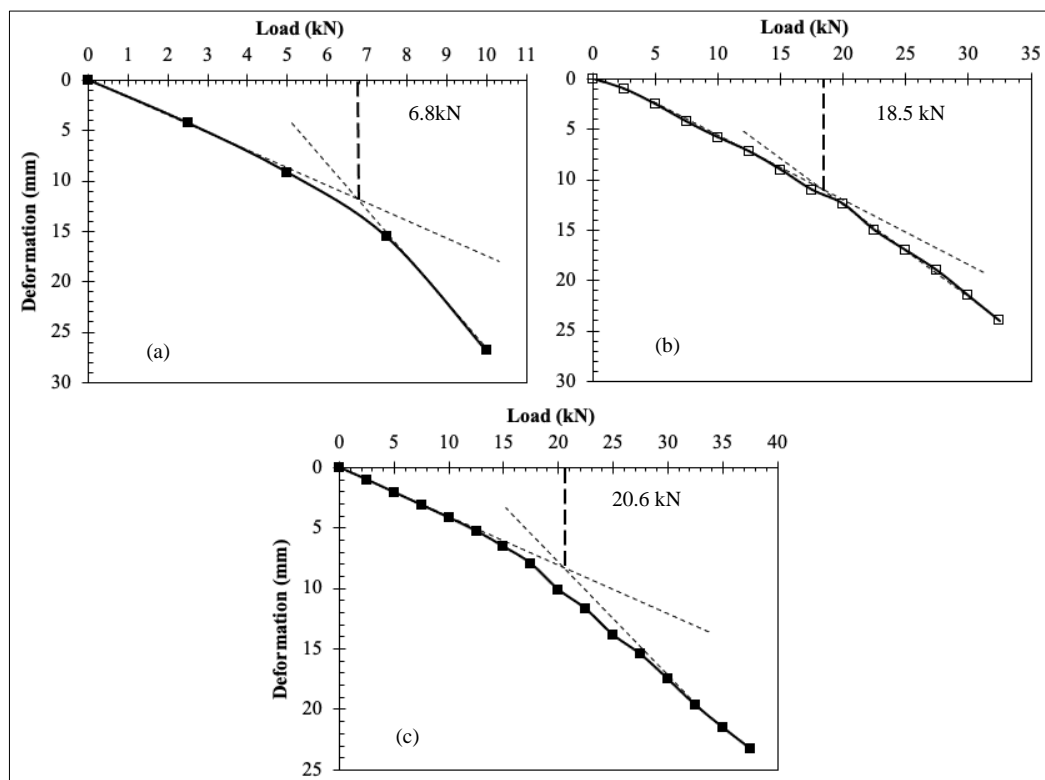

Figure 8. Ultimate load obtained from plate load test (a) sand-gravel mixture (b) ZW-geogrid single layer (c) ZW-geogrid double layer

In the ZW-geogrid layer, the plastic deformation is higher than the elastic deformation under the load plate. The ultimate bearing capacity is determined based on the ratio of the ultimate load to the area of the plate. The improvement magnitude of the ZW-geogrid composite can be expressed in terms of the ratio of bearing capacity of ZW-geogrid to the sand-gravel mixture. In this study, the improvement ratio of ZW-geogrid layer bearing capacity was found to be three times of magnitude compared to the sand-gravel mixture layer. This significant increase in bearing capacity shows that the presence of the ZW-geogrid composite layer provides an increase in the performance of the subbase layer.

In addition, the soil strength increases simultaneously, even at large deformations. The horizontal stress increases under the plate during loading, which means the confinement stress increases. The combination of increased stress at large deformation and confining stress results in a stronger and stiffer layer. The vertical stress transferred to the geogrid layer causes a stress reduction. The geogrid, which acts as a thin slab, redistributes stress over a larger area. As a result, the load-deformation response increased, with less vertical deformation observed. The vertical deformation rate decreases with the presence of a geogrid layer in the stabilized laterite soil. These results are in good agreement with the previous research. The stresses under the plate load are restrained by the presence of confinement tensions which prevent lateral displacement. The increase in shear stress of the composite material causes the coating to behave like a rigid mattress [33-35]. The confinement effect allows the reinforced soil layer to behave like a mat layer, spreading the load over a wider area with higher flexural stiffness and modulus of elasticity. Improvement of these parameters results in a reduction in the load distribution on the foundation layer [36, 37]. Geogrid will provide resistance to tensile stresses that occur in the pavement layer when receiving vehicle load. This mechanism will reduce the flexure of the pavement.

4. Conclusion

The addition of zeolite and waterglass additives to the laterite soil increases the UCS value in line with the increase in curing time. Curing time also plays an important role in the pozzolanic reaction process, which increases the compressive strength of the stabilized soil. The CBR value was increased by increasing the zeolite, waterglass content and curing time. This increase in bearing capacity is a result of the increased strength and stiffness of the stabilized soil due to the effect of the alkali-aggregate reaction. This significant increase in bearing capacity shows that the ZW-geogrid composite layer provides opportunities for this material to be utilized in field application.

The plate load test results showed that the combination of increased stress at large deformation and confining stress results in a stronger and stiffer material. The stresses under the plate load are restrained by the presence of confinement tensions which prevent lateral displacement. Moreover, the vertical deformation rate decreases with a geogrid layer in the stabilized laterite soil. The increase in shear stress of the composite material causes the coating to behave like a rigid mattress. Stabilized soil combined with a geogrid layer can reduce deformation at the subbase surface. Geogrid will provide resistance to tensile stresses that occur in the pavement layer when receiving vehicle load. This mechanism will reduce the flexure of the pavement. Consequently, the service time of the road increases with the same traffic loading. Although the results of this study provide considerable opportunities for the use of multiple layers of geogrid composite reinforcement to overcome localized soft pavement foundation conditions, an economic assessment of layered geogrid reinforcement on a commercial scale needs to be carried out to apply the findings to the large scale project.

5. Declarations

5.1. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.4. Conflicts of Interest

The author declares no conflict of interest.

6. References

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