

Research Article

The Effects of Geocell Height and Lime Stabilization on Unpaved Road Settlements at Different Water Contents

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Received 12 April 2021; Revised 17 June 2021; Accepted 24 August 2021; Published 6 September 2021

Academic Editor: Kumar Anupam

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In this study, lime stabilization and geocell reinforcement methods were investigated for a clayey subgrade of unpaved road at different water contents. This study is especially important in terms of determining the soil improvement method for road construction on wet lands. The effects of the geocell height (50, 100, 150, and 200 mm) and lime content (3, 6, and 12%) on the settlement of the subgrade soil at different water contents (25, 28, 30, 32, and 35%) were analyzed. Accordingly, a large scale plate loading test was designed, and it is utilized to achieve loading-settlement curves. The bearing capacity and modulus of subgrade (k) of soil were determined. It was detected that the geocell height and lime content have different effects at different water contents, and the modulus of subgrade reaction became stable beyond a constant height of the geocell. It was understood that none of these two improvements did not meet the Highways Technical Specifications. It is detected that at least these two improvement techniques are needed to be applied together to meet the specifications for the soil examined in this study.

1. Introduction

Performance and bearing capacity of the road surfacing significantly depend on the specifications of the ground that it subsides. Therefore, foundation floors must safely withstand the stresses caused by traffic loads. Therefore, base soils need to safely withstand the stresses that traffic loads constitute. Generally, soil type, water content, and degree of compaction affect the bearing capacity of the foundation soil. Swelling or blistering of the base soil depends on its moisture content. No superstructure constructed on this type of base soils can withstand against cracking and settlements. Base soils must be able to withstand high level loads without excessive settlements. Base soils that are not suitable for the road superstructure should be improved and stabilized adequately. With the improvement of the base soil, the bearing capacity and surfacing performance increase, while settlements and, thus, the surfacing thickness decrease [1].

With the addition of lime to the soil, the strength and modulus of elasticity of the soil increases. Thus, an increase in the strength of the soil occurs [2]. In general, lime leads to

a decrease in the dry volume weight of the soil, a change in the plastic features, and an improvement in the bearing capacity of the soil. Thanks to the lime stabilization, the difference between the liquid limit and the plastic limit is reduced. This means that the plasticity index decreases [1]. Lime stabilization is commonly used in the fillings done from clayey soils and especially road constructions. Dasha and Hussain [3] determined the optimum lime content as 5% for residual soil-rich samples and 9% for expanding soils. Excessive lime treatments increase the swell potential of soils and decrease the soil strength. Dasha and Hussain [3] stated that this content is 9% for coarse-grained soils and 5% for fine-grained soils. Pancar and Akpınar [1] demonstrated that the settlement of the unpaved road subgrade with 12% lime content was less than the subgrade with 6% lime content, and the settlement of subgrade with 6% lime content was also less than the subgrade with 3% lime content at a high water content by 10% increasing the optimum water content. In their studies, Sivapullaiah et al. [4] investigated the behavior of Terra rossa soil with the addition of 1% lime, 1% cement, and 20% bentonite.

They concluded that the strength of Terra rossa soil increased rapidly within 7 days with the addition of the cement-bentonite mixture; on the other hand, the increase occurred after 7 days with the addition of the bentonite-lime mixture [4].

In their study, Keskin and Kavak [5] reviewed the effects of improvement of a road base clayey soil by lime stabilization. The soil water content was 35%, and this ratio was 12% more than the optimum water content. It was concluded that the CBR values increased up to 8 times in 28 days.

Madhavi Latha and Somwanshi [6] showed that the most advantageous form of the soil reinforcement technique is different forms of geosynthetic reinforcement (i.e., randomly distributed mesh elements, planar layers, and geocell) of the geocell. Tafreshi and Dawson [7] stated that more than 200% increase in the bearing capacity and up to 75% reduction in settlements can be achieved with geocell reinforcement. In addition, it has been determined that geocell reinforcement is more preferred than planar reinforcement [7, 8].

Dash et al. [8] stated that the overall frictional resistance on the geocell walls increases with the increase in the geocell mattress height, and the increase in the geocell height reduces the beneficial effect of the geocell. It has been observed that the overall performance improvement is significant, up to a geocell height of 2.1 times the diameter of the footing. However, only marginal improvement was observed beyond this geocell height. In addition, it was concluded that a seven-fold increase in the bearing capacity of the circular footing is possible by using geocell and geogrid reinforcements together.

Zhou and Wen [9] stated that the settlement can be reduced by 44% by geocell reinforcement. Dash et al. [10] stated that when a planar geogrid is added to the base of the geocell, an increase of 30% more than the increase in the bearing capacity of the foundation obtained using the geocell alone can be achieved.

Zhang et al. [11] determined that the two effects are very important for the increase in the bearing capacity of the foundation soil and stated that these effects are the “vertical stress distribution effect” and the “membrane effect.”

In their study, Dash et al. [10] stated that the bearing strength used in geocell production is not a critical parameter when evaluating geocell performance. Sofiev and Pancar [12] investigated the effect of heterogeneity on parametric instability of axially excited orthotropic conical shells, similar to the vertical stress distribution effect of the geocell, and stated that the area of the main instability regions decreases with increasing L/R_1 (slant length/small mean radii) ratio.

It was indicated that the geocell shape of 1:1.2 (width: height), which was filled with sand, and the geocell shape of 1:0.8, which was filled with sedimentary clay gave the largest ultimate bearing capacity [13]. Engineering properties of the modified soil and ground improving materials and techniques are still being observed [14–20].

Kong et al. [14] modified the soil to produce a restoration material for silty earthen sites. They used lime and starch

ether both separately and together to modify the soil. They found that the shear strength and the compressive ability of the soil have been improved for both single-mixed modification and multiple-mixed modification. They stated that the optimum lime and starch ether contents for single-mixed soil were 9% and 5%, respectively, while these values were 6% and 5%, respectively, for multiple-mixed soil.

Yünkül et al. [16] investigated the uplift behavior of the horizontal square anchor in cohesionless soil reinforced with or without geocell using PLAXIS 3D finite element software and determined the optimum design parameters, including geocell properties, according to the dimensionless breakout factor (F_q). As a result of their study, they found that the optimum values for the geocell width ratio (B_g/B), geocell height ratio (h/B), geocell distance ratio (U/B), and geocell stiffness are 2.5, 0.75, 0, 1000 kN/m, respectively. In addition to these values, they indicated that the geocell pocket size ratio (a/B) significantly affects the uplift capacity of the plate anchor. When a/B is decreased, the uplift capacity of the plate anchor increases.

Tiwari and Satyam [18] investigated the behavior of lime and silica fume treated coir geotextile reinforced expansive soil subgrade. They found that the upward swelling pressure decreased 52.19% in single-layer and 81.89% in double-layer with the lime treated coir geotextile. Jahandari et al. [19] treated clayey soil with lime and geogrid and investigated the mechanical properties of treated soil within 365 days curing period. As a result of their experimental study, they found that geogrids and lime improve the geotechnical properties of clayey soils.

In this study, the effect of lime and geocell reinforcement has been studied under varying moisture contents. The overall goal of this study was to analyze the effects of the geocell height (50, 100, 150, and 200 mm) and lime content (3, 6, and 12%) on the settlement of the clayey pavement subgrade at different water contents (25, 28, 30, 32, 35%). This comparison has not been made before in other studies.

2. Materials and Method

In this article, clayey soils with different water contents (25, 28, 30, 32, and 35%) have been subjected to a number of experiments. The soil is classified according to the AASHTO and the unified soil classification system. Accordingly, sieve analysis, consistency limit, and hydrometer analyzes were performed on the soil, respectively. Proctor tests were carried out on the samples in order to determine the optimum water content and dry unit weight of the clay material. In this study, model plate loading experiments were conducted on the mixtures that were prepared from optimum water content (25%) and high water contents (28, 30, 32, and 35%). In these experiments, soil was reinforced at different heights (50, 100, 150, and 200 mm) of the geocell, and lime was mixed to soil at the rates of 3, 6, and 12%. These treatments were made solely and together at different water contents (25, 28, 30, 32, and 35%). The sieve analysis of the soil used as a subgrade is given in Table 1.

In accordance with ASTM D2487 [21], the soil to be used as the subgrade is specified as Class CH. Clays in the CH

TABLE 1: Sieve analysis.

| Sieve no | Sieve diameter (mm) | Sieve analysis | | |
|----------|---------------------|-------------------------|-------------|--------------------|
| | | Residue of sieving (gr) | Sieved (gr) | Sieved percent (%) |
| 3/8" | 9, 53 | 0 | 420 | 100 |
| 4 | 4, 76 | 42, 7 | 377, 3 | 90 |
| 10 | 2 | 30, 1 | 347, 2 | 83 |
| 40 | 0, 42 | 18, 73 | 328, 47 | 78 |
| 100 | | 15, 4 | 313, 07 | 75 |
| 200 | 0, 074 | 11, 5 | 301, 57 | 72 |
| Pan | | 301, 57 | | |

class have high plasticity. Its liquid limit and plastic limit are found to be 57% and 26%, respectively.

Dry sand was preferred as the infilling material for the geocell (Figure 1). It was used as a base layer for the unreinforced test section. The effective particle size (D_{10}) was 1.2 mm, specific gravity was 2.64, coefficient of uniformity (Cu) was 2.25, and coefficient of curvature (Cc) was 1.05. It is classified as poorly graded sand (SP) according to the unified soil classification system [21]. The void ratio of the sand was 0.42, and the internal friction angle was 37° .

The technical properties of the geocell specified by the manufacturer are given in Table 2. In addition to the features in the table, there are drainage holes with a diameter of 10 mm in the geocell cell walls.

Laboratory scale loading tests were used to investigate the influence of lime stabilization (3 different lime contents were used) and geocell (4 different geocell heights were used) reinforcement on increasing the bearing capacity of clayey soil with 3 different water contents in a steel box.

The inner dimensions of the box are given in Figure 2. As can be seen from this figure, the box is 1.2 m long, 1.2 m wide, and 1.2 m high. Unpaved road test sections were made inside the box.

Dash et al. [8] indicated that, when the pocket diameter/footing width is around 0.8, it gives maximum performance. The pocket diameter was 25 cm, and the diameter of circular footing was 30 cm to get maximum performance in this study. The footing was loaded with a hydraulic actuator.

The acceptable range of settlements was not considered in some studies [8, 10, 22], and bearing capacity was estimated to be unreal. The value of footing settlement equals 12% of footing width (s/B) and is considered an absolute upper limit [7].

In this study, the peak load was selected to simulate a single wheel load of 40 kN (equivalent to an axle load of 80 kN and a tire contact pressure of 550 kPa).

The test box was filled with clayey soil with optimum water content (25%) and high water contents (28, 30, 32, and 35%). The soil was used as a subgrade and placed in 3 layers with 25 cm thickness for each layer. The placed layers were compacted in lifts inside a box using a vibratory plate compactor. After preparing the subgrade, three strain gages were installed on the top of the subgrade. 5 pressure cells were installed on the surface of the subgrade at the center, 15 cm, and 30 cm away from the center of the loading plate, respectively. A linear variable differential transducer (LVDT) was also placed on the footing model to provide the value of footing settlement during the loading (Figure 1).



FIGURE 1: Filling the geocell with sand.

TABLE 2: Technical properties of the geocell.

| Properties | Values |
|-------------------------------|------------|
| Density (gr/cm ³) | 0.94 |
| Welding size (cm) | 40 |
| Cell length (mm) | 300 |
| Cell width (mm) | 250 |
| Thickness (mm) | 2 |
| Cell height (cm) | 5-10-15-20 |

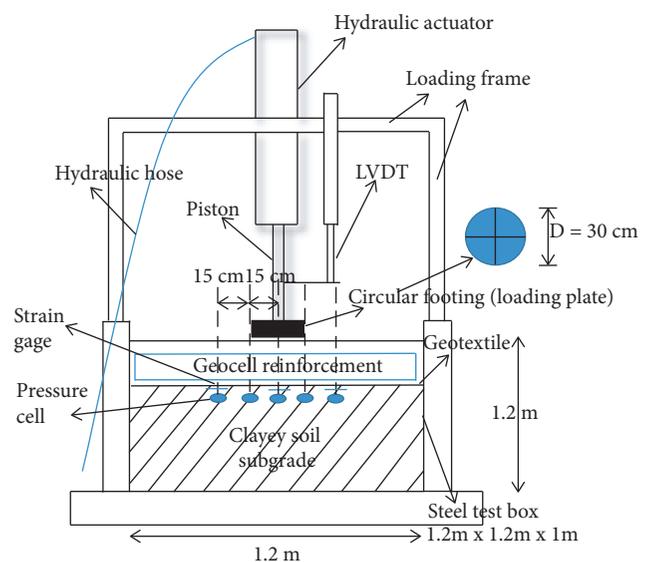


FIGURE 2: Schematic diagram for the set-up of the plate loading test.

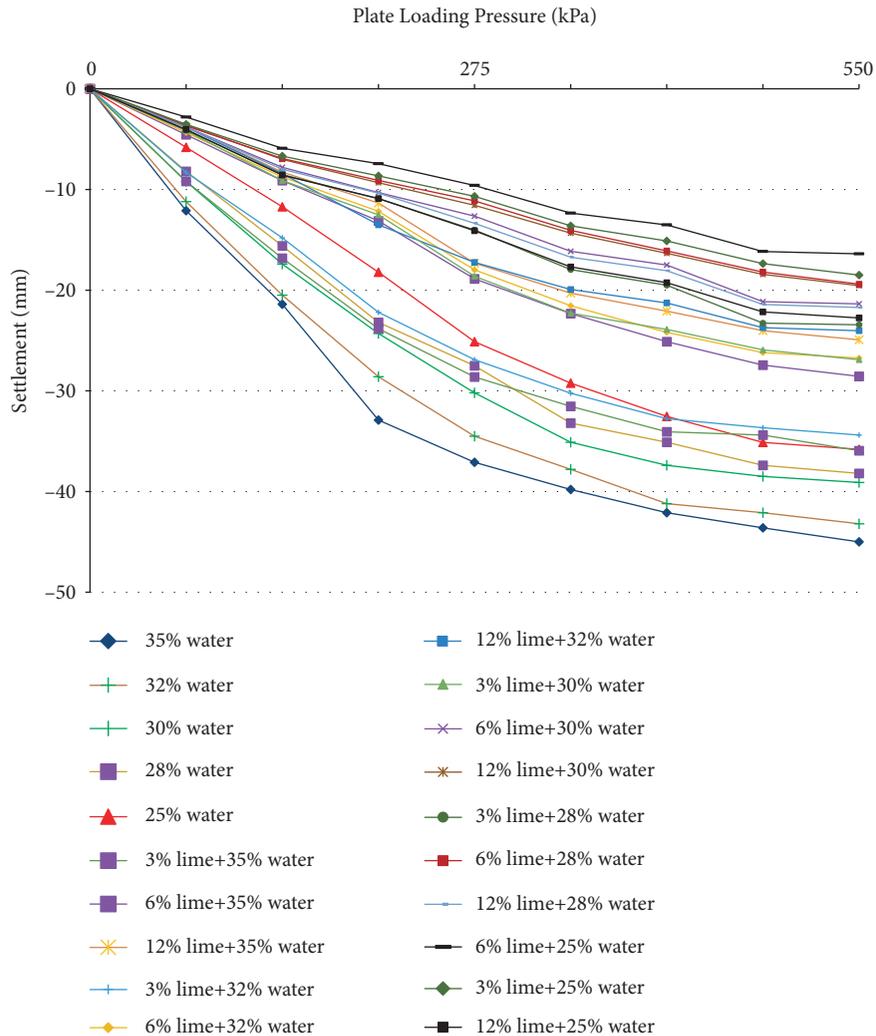


FIGURE 3: Loading-settlement curve for lime stabilizations at different water contents.

After the installation of pressure cells and strain gages, a geocell was placed on top of the subgrade. The top of the geocell mattress was at a depth of 3 cm from the bottom of the footing to get optimum test results as Tafreshi and Dawson [7] indicated in their study.

32 unpaved road test sections were prepared in the test box. Settlements of lime stabilized and geocell (with different heights) reinforced soils with different water contents were examined.

3. Results and Discussion

Comparison between the improvement of the clayey unpaved road subgrade with geocell and lime stabilizations at different water contents was made in the laboratory. The height of the geocell used in this study was 50, 100, 150, and 250 mm. The lime content was 3, 6, and 12%. The water content was 25 (optimum), 28, 30, 32, and 35%.

Effects of lime stabilization at a rate of 3, 6, and 12% at 25, 28, 30, 32, and 35% water contents are shown in Figure 3.

The settlement in soil with 25, 28, 30, and 32% water contents was 0.80, 0.85, 0.87, and 0.96 times the settlement in soil with 35% water content under 550 kPa, respectively.

Lime stabilization at a rate of 12, 12, 12, 6, and 6% was most effective at 35, 32, 30, 28, and 25% water contents, respectively. The settlement in soil with 35% water content was 1.8, 1.6, and 1.3 times the settlement of 12, 6, and 3% lime-stabilized soil at the same water content under 550 kPa, respectively. The settlement in soil with 32% water content was 1.8, 1.6, and 1.3 times the settlement of 12, 6, and 3% lime-stabilized soil at the same water content under 550 kPa, respectively. The settlement in soil with 30% water content was 2, 1.8, and 1.4 times the settlement of 12, 6, and 3% lime-stabilized soil at the same water content under 550 kPa, respectively. The settlement in soil with 28% water content was 1.8, 2, and 1.6 times the settlement of 12, 6, and 3% lime-stabilized soil at the same water content under 550 kPa, respectively. The settlement in soil with 25% water content was 1.6, 2.2, and 2 times the settlement of 12, 6, and 3% lime-stabilized soil at the same water content under 550 kPa, respectively. Adequate quantities of lime must be added into

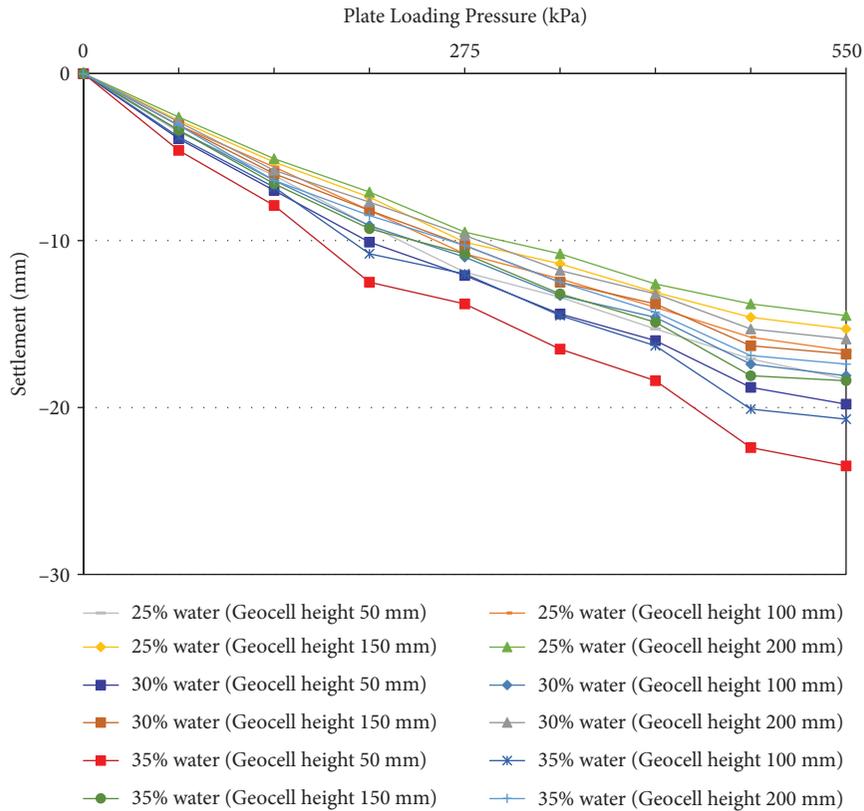


FIGURE 4: Loading-settlement curve for geocell reinforced soil at different water contents.

the soil to get minimum settlements under loading. Although better results were obtained by using 12% lime content for soils at 30, 32, and 35% water contents, it was seen that the lime content must be decreased to 6% for soils with 28 and 25 (optimum)% water contents. Dash and Hussain [3] explained the effect of lime on the liquid and plastic limit of the soil in their study, and they determined that the optimum lime content giving maximum strength was 3% for residual soil. When the lime is added into soil, lime is hydrated. The water content of the soil is important for hydration. Hydrated lime reacts with clay particles. This reaction produces additional drying because it reduces the soil's moisture holding capacity. Determining different optimum lime contents for soils with different water contents in this study is due to these reasons.

Soil settlements under pressure when the soil is reinforced by geocell with 4 different geocell heights at 3 different water contents are shown in Figure 4.

The ratio between the settlement of the soil at 35% water content under 550 kPa and geocell reinforced soil with 200 mm height at the same water content was 2.6. The ratio between the settlement of the soil at 30% water content under 550 kPa and geocell reinforced soil with 200 mm height at the same water content was 2.5. The ratio between the settlement of the soil at 25% water content under 550 kPa and geocell reinforced soil with 200 mm height at the same water content was 2.5.

When the height of the geocell was 50 mm at geocell-reinforced soil at 35% water content, the settlement was 1.1,

1.3, and 1.4 times the settlement when the height of the geocell was 100, 150, and 200 mm under 550 kPa, respectively. When the height of the geocell was 50 mm at geocell-reinforced soil at 30% water content, the settlement was 1.1, 1.2, and 1.3 times the settlement when the height of the geocell was 100, 150, and 200 mm under 550 kPa, respectively. When the height of the geocell was 50 mm at geocell-reinforced soil at 25% water content, the settlement was 1.1, 1.2, and 1.3 times the settlement when the height of the geocell was 100, 150, and 200 mm under 550 kPa, respectively.

The effect of the height of the geocell on settlement of soil was different for soils at different water contents. Soil settlement differences between different heights of geocell at 25, 30, and 35% water contents are shown in Figure 5. In these Figures, cell 200, cell 150, cell 100, and cell 50 means that the geocell height is 200 mm, 150 mm, 100 mm, and 50 mm, respectively.

The modulus of subgrade reaction values (k) for lime-stabilized soil at different water contents was calculated with the help of Figure 3 by determining the inclinations of the loading-settlement curves. " k " values were also calculated for soil reinforced by geocell with different heights at different water contents with the help of Figure 4. These values are listed in Table 3. As it is seen from Table 3, the " k " value (three biggest value) was 27.500, 25.000, and 24.750 kN/m^3 for soil stabilized with 6% lime at 25% water content, 3% lime at 25% water content, and 6% lime at 28% water content, respectively. According to Highways Technical Specifications in Turkey, this value is to be no less than 55.000 kN/m^3 and none of them met this requirement.

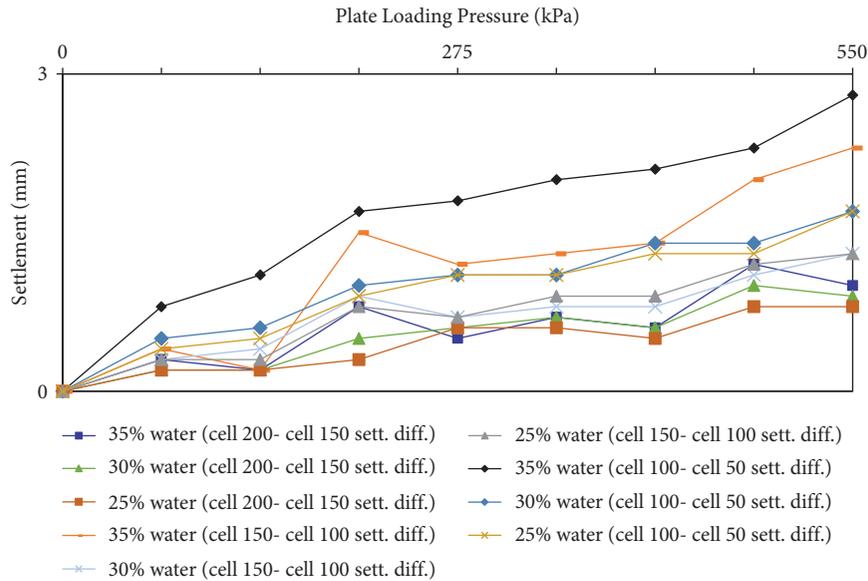


FIGURE 5: Settlement differences between different heights of the geocell at different water contents.

TABLE 3: Modulus of subgrade reactions (k) for lime-stabilized soils and geocell reinforcements.

| States | Modulus of subgrade reaction (k) (kN/m ³) |
|--|---|
| 35% water content | 6.550 |
| 32% water content | 6.880 |
| 30% water content | 8.100 |
| 28% water content | 9.050 |
| 25% water content | 11.460 |
| 3% lime at 35% water | 8.490 |
| 12% lime at 35% water | 15.100 |
| 3% lime at 32% water | 9.170 |
| 6% lime at 32% water | 14.470 |
| 12% lime at 32% water | 14.600 |
| 3% lime at 30% water | 14.030 |
| 6% lime at 30% water | 15.800 |
| 12% lime at 30% water | 24.700 |
| 3% lime at 28% water | 14.750 |
| 6% lime at 28% water | 24.750 |
| 12% lime at 28% water | 15.350 |
| 3% lime at 25% water | 25.000 |
| 6% lime at 25% water | 27.500 |
| 12% lime at 25% water | 15.280 |
| Geocell height 200 mm at 35% water content | 27.500 |
| Geocell height 150 mm at 35% water content | 26.190 |
| Geocell height 100 mm at 35% water content | 22.900 |
| Geocell height 50 mm at 35% water content | 18.300 |
| Geocell height 200 mm at 30% water content | 28.950 |
| Geocell height 150 mm at 30% water content | 27.230 |
| Geocell height 100 mm at 30% water content | 25.000 |
| Geocell height 50 mm at 30% water content | 18.350 |
| Geocell height 200 mm at 25% water content | 29.570 |
| Geocell height 150 mm at 25% water content | 28.650 |
| Geocell height 100 mm at 25% water content | 26.250 |
| Geocell height 50 mm at 25% water content | 18.950 |

Lime stabilization increased the “k” value 2.1, 1.9, 2, 1.8, and 1.4 times the value in soil at 35, 32, 30, 28, and 25% water contents, respectively. As it is seen, these increments decrease while water content decrease. The best lime

content to get the highest “k” value was 6% for soils at 25 and 28% water contents. 12% lime content was the best alternative to get the highest “k” value for soil at 30, 32, and 35% contents.

TABLE 4: Bearing capacities of lime-stabilized soils and geocell reinforcements.

| States | Bearing capacity (kN/m ²) |
|--|--|
| 35% water content | 28 |
| 32% water content | 31 |
| 30% water content | 38 |
| 28% water content | 43 |
| 25% water content | 60 |
| 3% lime at 35% water | 38 |
| 12% lime at 35% water | 86 |
| 3% lime at 32% water | 44 |
| 6% lime at 32% water | 74 |
| 12% lime at 32% water | 75 |
| 3% lime at 30% water | 74 |
| 6% lime at 30% water | 95 |
| 12% lime at 30% water | 110 |
| 3% lime at 28% water | 86 |
| 6% lime at 28% water | 115 |
| 12% lime at 28% water | 95 |
| 3% lime at 25% water | 127 |
| 6% lime at 25% water | 142 |
| 12% lime at 25% water | 86 |
| Geocell height 200 mm at 35% water content | 138 |
| Geocell height 150 mm at 35% water content | 121 |
| Geocell height 100 mm at 35% water content | 93 |
| Geocell height 50 mm at 35% water content | 86 |
| Geocell height 200 mm at 30% water content | 140 |
| Geocell height 150 mm at 30% water content | 135 |
| Geocell height 100 mm at 30% water content | 120 |
| Geocell height 50 mm at 30% water content | 103 |
| Geocell height 200 mm at 25% water content | 148 |
| Geocell height 150 mm at 25% water content | 138 |
| Geocell height 100 mm at 25% water content | 120 |
| Geocell height 50 mm at 25% water content | 112 |

It was determined that the modulus of the subgrade reaction increases when the height of the geocell increased. It was also observed that the modulus of the subgrade reaction increase stopped at 200 mm geocell height at 25, 30, and 35% water contents.

Half of the stress corresponding to 10 mm settlement at the load-deformation curve obtained from the plate loading experiment gives the bearing capacity of the base soil. By starting from this information, half of the stresses corresponding to 10 mm at load-deformation curves were calculated, and bearing capacity values were determined. The bearing capacity values for lime-stabilized soils are given in Table 4.

As it is seen from Table 4, the bearing capacity (three biggest value) was 142, 127, and 115 kN/m² for soil stabilized with 6% lime at 25% water content, 3% lime at 25% water content, and 6% lime at 28% water content, respectively. The bearing capacity was increased maximum 3.1, 2.4, 2.9, 2.7 and 2.4 times by lime treatment at 35, 32, 30, 28, and 25% water contents, respectively. The bearing capacity values for reinforced soils by geocell with different heights at different water contents are also given in Table 4.

When the height of the geocell was 200 mm, the highest bearing capacities were obtained as it was expected. The

effect of height of the geocell on the bearing capacity of soil decreases at all water contents in this study.

The bearing capacity was increased 5, 3.7, and 2.5 times by geocell reinforcement of soil at 35, 30, and 25% water contents, respectively. The bearing capacity ratio between the geocell reinforcement and lime stabilization (maximum bearing capacity by using geocell/maximum bearing capacity by lime stabilization) was 1.60, 1.27, and 1.04 at 35, 30, and 25% water contents, respectively. It was determined that, when the water content decreases, lime stabilization can be used instead of geocell reinforcement.

4. Conclusion

Lime stabilization and geocell reinforcement can be used to improve soil. In this study, lime stabilization and geocell reinforcements were made at different water contents for clayey subgrade of the unpaved road. Different lime contents and geocell heights were investigated for this purpose. Model plate loading experiments were done in the laboratory. Thirty-two different unpaved road test sections were examined. The peak load was selected to simulate a single wheel load of 40 kN (equivalent to an axle load of 80 kN and a tire contact pressure of 550 kPa). The effects of lime content and geocell height were investigated on the bearing capacity and the modulus of subgrade reaction of soil at different water contents. It was examined whether those improvements met the requirement of Highways Technical Specifications or not. These comparisons have not been made before in the literature for thirty-one different states examined in this study.

From the data presented in this study, the following conclusions can be drawn:

- (1) The settlement in lime-stabilized soil was at most between 1.8 and 2.2 times the settlement in unstabilized soil.
- (2) The settlement in geocell reinforced soil was at most between 2.5 and 2.6 times the settlement in unreinforced soil.
- (3) The effect of the height of the geocell on the settlement of soil under pressure decreases when the water content of the soil decreases.
- (4) It was observed that, when the height of the geocell increased, the modulus of the subgrade reaction also increased and became stable beyond 200 mm geocell height at 25, 30, and 35% water contents.
- (5) The bearing capacity was increased maximum 5 times by geocell reinforcement.

It is recommended that at least lime stabilization and geocell reinforcement need to be applied together to meet the Highways Technical Specifications for wetlands.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no competing interests.

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