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PAVEMENT SUBGRADE STABILIZATION WITH LIME AND CELLULAR CONFINEMENT SYSTEM

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Abstract. In this study effectiveness of lime stabilization and geocell reinforcement techniques of roads was investigated for low bearing capacity subgrades. For this purpose, a large-scale plate load test was designed and used. Clayey soil with high moisture content was reinforced with different percentages of hydrated lime (5%, 10%, 15% dry weight of the soil). The deflection and stress results indicated that lime stabilization or geocell reinforcement alone did not significantly increase subgrade reaction coefficient and bearing capacity values. Promising results were obtained on stabilization of weak subgrade when both techniques were used together. It was determined that cellular reinforcement increased the reaction modulus coefficient value and bearing capacity of the subgrade soil by more than 15% compared to the lime stabilization.

Keywords: bearing capacity, geocell reinforcement, high water content, lime stabilization, pavement, subgrade.

Introduction

Lime stabilization has gained more acceptance compared to any other techniques applied to pavement layers especially on weak subgrade soils to increase the bearing capacity. Lime added to the soil allows for an increase in deformation resistance of the soil by increasing shear strength and resilient module of the soil.

Kavak (1996) reviewed unconfined compression resistances of pure bentonite and kaolin clays by stabilizing them with lime. As a result of their experiments, unconfined compression resistance of the clay showed 6 times increase in 1 month. They stated that resistance increases had continued in the long-term. Figure 1a shows the results of unconfined compression strength of cured samples of various time intervals by mixing lime to kaolin clay. Figure 1b shows unconfined compression strengths of bentonite clay cured with lime.

Sivapullaiah, Kantha, and Kirian (2003) reviewed the behavior of Terra Rosa soil by adding 20% bentonite, 1% cement and 1% lime. The samples prepared for various additive rates were subjected to consolidation and unconfined compression experiments after 0, 7 and 28 days of cure. They concluded that cement-bentonite mixture increased the shear strength fast within 7 days, while bentonite-lime mixture increased the resistance after 7 days.

In their studies, Kavak, Güngör, Avşar, Atbaş, and Akyarlı (2008) reviewed the behaviour of lime stabilization on Ankara-Bala- Kulu highway that was 14 meters wide. The pavement subgrade layer was stabilized with 1%, 2%, 3%, 4% and 5% lime in two layers. The lime amount was determined as 5% of dry soil weight. It was observed that while dry CBR values of the material to which 5% lime was mixed at the end of 56 days increased 8 times, up to 34 times increases occurred on its wet CBR values compare to the natural material (Figure 2). Plate loading experiments showed that the largest deformation decreased from 22.18 mm to 3.58 mm (Figure 3). When coefficient values of reaction modulus were reviewed, lime-stabilized base layer had 6 times higher K value compared to the state without lime.

Yıldırım, Alataş, and Dağdelen (2009) conducted experiments on soil-asphalt mixtures. Their experiment on unconfined compression tests showed that largest unconfined compression resistance was obtained at 3% asphalt content. CBR values given by that study were two times higher than natural soil when mixed with asphalt that resulted in 5.2% cost saving in pavement layer design thickness.

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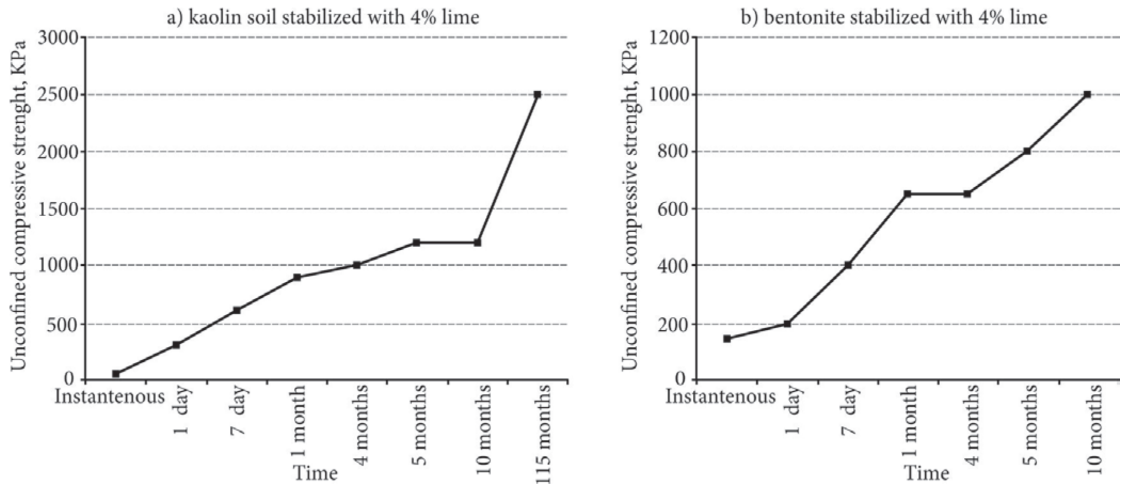

Figure 1. Unconfined compression value change of clayey soils with lime

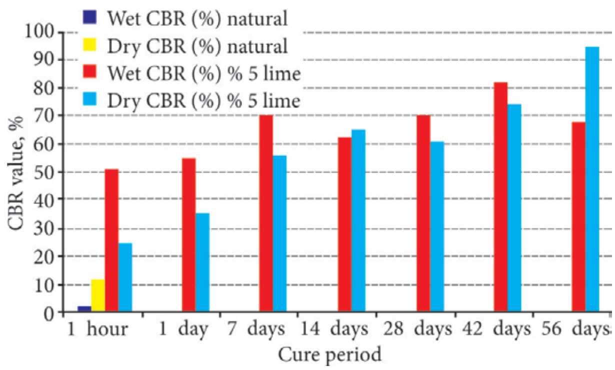

Figure 2. CBR experiment (Kavak et al., 2008)

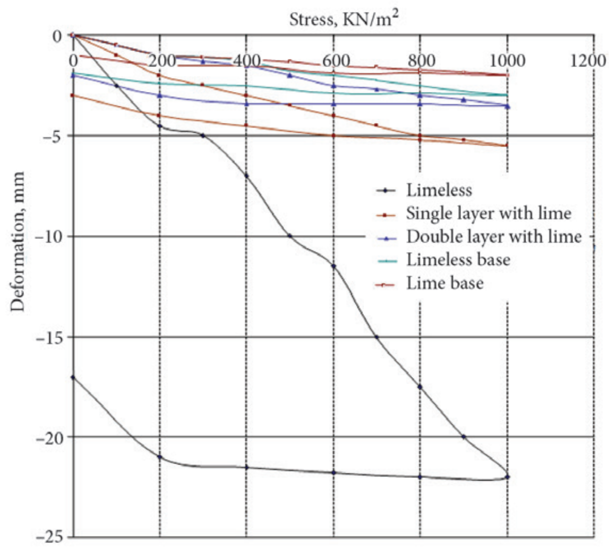

Figure 3. Graphical display of the plate loading experiments (Kavak et al., 2008)

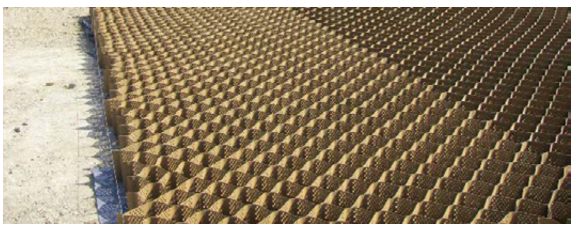

Figure 4. Application of cellular confinement system in the field (Ankara, Turkey)

As seen in Figure 4, cellular confinement system, filled with soil on the field, is a network having cells connected with nodes in the shape of a honeycomb made from polymer material. The cells take the vertical loading stresses at the vertical cell walls and soil resistance of the adjacent cells.

Moghaddas Tafreshi and Dawson (2010) using their laboratory model test reviewed comparison of bearing capacity of a strip base (plate) done on sand reinforced with geocell and strip base done on sand reinforced with a planar type geotextile. It was determined that geocell reinforcement significantly increases load-bearing capacity of the sand layer and decreases the settlements. It was concluded that an increase more than 200% of bearing capacity and a decrease up to 75% at the settlements may be achieved with geocell reinforcement.

Dash, Sireesh, and Sitharam (2003) reviewed the effect of geocell reinforcement placed in the granulated filling laid on soft clay with a small-scale model test in the laboratory. It was observed that an increase was achieved by geocell reinforcement on the bearing capacity and a significant decrease occurred at the surface swelling of the base. It was determined that an additional geogrid layer placed at the base of geocell would provide much more increased load-bearing capacity of the base. It was also concluded that seven times increase in bearing capacity may be achieved when geocell and geogrid reinforcement is used together.

Sireesh, Sitharam, and ve Dash (2009) reviewed the potential of sand reinforced with geocell on porous clay base by utilizing laboratory scale model test. Their study revealed the fact that 3–4 times improvement might be achieved on the performance with geogrid and geocell reinforcement in the granulated filling layer to be placed in the porous soft base. The study also resulted in a load-bearing capacity increasing up to approximately 40 times compared to porous soft clay layer.

Zhang, Zhao, Shi, and ve Zhao (2010) developed a simple performance model of geocells laid over soft base layer. The model and calculation procedures used in the study were proved with a laboratory experiment by taking both distribution effect of geocell reinforcement on vertical stress. It was detected that geocell reinforcement placed in the crushed stone significantly increased bearing capacity of the soft base.

Latha and Somwanshi (2009) conducted model loading tests on geosynthetic reinforced sand. They reviewed performances of geocell and randomly distributed net meshed geogrid. The study suggested that bearing capacity was significantly affected by reinforcement type. It was concluded that geocell gave the highest bearing capacity potential among the reinforcement types.

In the study done by Dash, Krishnaswamy, and Rajagopal (2001a), the results of a strip plate supported by sand reinforced with a geocell were reviewed for laboratory model bearing test. The effect of various parameters such as the pattern of geocell formation, cell size, height and width of geocell, thickness of the material laid on the geocell, the resistance of geogrid used at the manufacture of geocell and relative density of the sand were reviewed at the test program. As a result of the study, it was observed that settlement behavior of strip plate placed on the sand reinforced with geocell was a linear event at a settlement up to 50% of approximate loading plate. Furthermore, the bearing capacity increased 8 times compared to the reinforced state. The study concluded the fact that the bearing strength used at the production of geocell is not an important parameter for assessing the performance of geocell but routing strips of geogrid and space size have an important effect on the load-bearing capacity of the base reinforced with geocell.

Zhou and Wen (2008) studied the development of bearing capacity of soft soil reinforced with the geosynthetic material. They stated that there was an important decrease of the soil settlement under the geocell laid over sand layer. The study showed that vertical deformation and surface stresses decreased 44% due to geosynthetic reinforcement (especially for geocell reinforced soil).

Zhang, Zhao, Zou, and ve Zhao (2009) reviewed a deformation controlled differential equity for geocell reinforcement under the vertical loads by taking internal surface resistance effect into consideration. Besides that, they reviewed appropriate power series, semi-analytic solutions and internal effects of geocell reinforcement for displacements. Also, the effect factors such as length and flexibility rigidity of the geocell reinforcement, internal surface resistance on stress-deformation characteristics and base reaction coefficient were discussed. At the end of the study, it was recommended to take internal surface resistance effect of geocell reinforcement on deformation into consideration in the engineering design.

Dash, Rajagopal, and Krishnaswamy (2001b) reviewed laboratory model test results on the strip plate. They concluded that a geogrid layer placed under the geocell generated much more increase in stability against rotation.

The use of geocells in pavement varies from one country to another due to varying on-site construction methods, calculations, and materials used in geocells. Vaitkus, Šiukščius, and Ramūnas (2014) studied the relationship between regulations in Lithuania and other European countries. Calculation methods and regulations for controlling characteristics were introduced for the first time in Lithuanian. More research is needed to verify the calculations regulations often directly transferred from the standards to some developed countries.

Biabani, Ngo, and Indraratna (2016) studied the pullout strength of rail subballast reinforced with geocells. Mobilised tensile strength and passive strength of a subballast-geocell assembly under a vertical pressure ranging from 1 kPa to 45 kPa were measured. The laboratory large-scale pullout test results showed that the geocell reinforcement provides a significant passive resistance. The opening area and lateral pressure over the geocell strip were found to be important factors. Three-dimensional finite element simulation results showed that the tensile strength in the geocell will increase as the geocell stiffness increases.

Suku, Prabhu, Ramesh, and Babu (2016) studied the permanent deformation performance of geocell-reinforced base layer subjected to different repeated loading. The results showed that geocell decreases the vertical deformation of the unbound aggregate and reduces required thickness of the aggregate layer of unpaved roads.

Yang et al. (2012), utilized an accelerated pavement test on four unpaved road sections including geocell reinforcement of sand bases. Tensile and compressive stresses were measured beneath and outside the wheel path, respectively. Accelerated pavement test results showed that the geocell had a significant effect in reducing the rutting deformation of unpaved roads.

1. Research methodology

1.1. Method

In this paper, experimental studies were conducted on clay soil obtained from Trabzon Province in Turkey. Sieve analysis, consistency limit experiments and hydrometer analyses were applied on the soil material classified according to *ASTM D3282-09*. Modified proctor experiments were also conducted to determine optimum water content and dry unit weight of the clay material.

In this experimental study, plate loading tests were carried out on mixtures containing high clay and water content (20% more moisture than optimum water content). Reaction modulus coefficient of clay soil, geocell reinforcement, lime (5%, 10%, 15%) stabilization was compared to determine the effectiveness of these materials in pavement subgrades.

1.2. Materials

Lime $Ca(OH)_2$ (calcium hydroxide) used in this study was "Barkisan" branded lime that was sold in the market in 25 kg packages and produced by TS 4022. The chemical analysis of lime is given in Table 1.

1.2.1. Cellular confinement system (Geocell)

Texture (weave) type geocell manufactured from dense polyethylene (0.95 gr/cm^3) was used in the plate loading experiment. Single cell diameter and height of the geocell was 25 cm and 20 cm, respectively. Cells with 260 cm^2 cross-sectional area were combined together to obtain a uniform geocell weld. It is worth mentioning that there were 10 mm diameter drainage holes in the geocell walls. For dry sand, having 2 mm maximum grain diameters, the uniform curvature coefficient (C_u), specific gravity, and voids rate were obtained as 3.06, 1.05, 2.63, and 0.40, respectively. Direct shear test results of sand resulted in an internal friction angle of 30°.

Table 1. Chemical analysis of lime, %

Chemical analysis	%
$Ca(OH)_2$	80–86
Active CaO	60.6–65.15
Total CaO + MgO	85–95
MgO	1–3
Density, gr/lt	375–500

Table 2. Liquid limit and plastic limit experiments for natural soil and clay state

	Atterberg limits		
	Liquid limit	Plastic limit	Plasticity index
Natural	58	25	33
2.5% lime	54	30	24
5% lime	53	33	20
7.5% lime	52	33	19
10% lime	52	38	14
12.5% lime	51	40	11
15% lime	51	42	9

1.2.2. Soil classification

With the aim of classifying the material, Atterberg limits are given in Table 2. At the end of the classification the soil was determined as A-7 group clay soil according to *ASTM D3282-09*. Gradation curve of the three clay soils after wet sieve analysis showed practically identical gradation (curves overlaps). Dry sieving was unable to produce an acceptable degree of separation between the individual fractions. While test sieving on dry materials is recommended whenever possible, usually reproducible results are hard to obtain.

1.3. Testing procedure

Plate loading experiment was applied for stabilized soil containing lime at various rates and geocells. The plate loading experiment tool was 1 m^3 cubic box as seen in Figure 5a with the aim of assessing the stress distribution and reaction coefficient values. The vertical load was applied with a hydraulic piston connected to a steel plate.

The sand was poured into the geocell loose until 5 cm thick layer was achieved on top of the geocell structure. The 5 cm sand layer was measured as 3 cm thick after compaction. The load was applied on top of the sand by the plate attached to the piston. The compaction process was carried out until the pressure gauge showed 40 kN/m^2 value.

a) model plate loading experiment device

b) placement of pressure and strain gauges, soil with high water content (45%) prepared outside the test box

Figure 5. The plate loading experiment tool

Field measurements showed that a typical 20.000 tons roller compactor has the capacity to apply 40 kN/m^2 drum static linear load over subbase layer. Similarly, in this study, the piston load was applied over the sand layer and once the 40 kN/m^2 stress was read by the data logger the compaction procedure was completed. In reality, this is also the case where the sand or gravel is dropped loose over the geocell and later compacted by the roller compactor. One disadvantage of this procedure was that it was almost impossible to measure the compaction uniformity of the geocell layer considering each cell. One way of getting good compaction on each cell is manual tamping which is not common in field application.

The clay soil with 45% water content prepared in the laboratory outside the experiment box was placed in the test box in 60 cm thick layers after compaction. Consolidation degree is a very important parameter when assessing the compression of clay. However, clay soil with high water content (45%) was incompressible by nature. Once the pressure was applied on the natural high water content clay, the liquid clay leaked around and upwards the plate. Since mixing the sample with lime produced a quite stiff mixture, the very little movement was measured by the vertical displacement transducers (LVDT). The mixed samples were cured for 12 hours before testing which is the case on the field. When clays are present, the chemical reaction of limes with clays causes further drying. It would be possible to measure consolidation degree in case that the tests were performed immediately after mixing. In general, the upper pavement layers are constructed at least a few days later and the structure is open to traffic much later. During this time the lime mixed layer becomes even much stiffer.

Inside part of the test, the box was covered with the geomembrane to prevent friction between the fill material and test box surface. One 20 cm diameter gauge and two 5 cm diameter pressure gauges were used to measure the vertical stresses at the upper level and beneath the geocell (Zhang et al., 2009). Two strain gauges were used to measure the strain changes in the sub-base material. Stress and strain gauges are shown in Figure 5b.

Stress results from the lower gauges (5 cm diameter) were used in the further analysis in Chapter 3. In this study, the piston load was applied over the sand layer and once the 40 kN/m^2 stress was read by 20 cm diameter gauge located 5 cm beneath the load plate the compaction procedure was completed.

The geocell was filled with dry sand and then compressed (Figure 6). The surface of the geocell layer was covered with 3 cm thick sand layer. Nonwoven geotextile was placed over the soil material to separate the cellular confinement system. The soil with 45% high water content was stabilized with 5%, 10% and 15% lime

The plate loading experiments were done for natural soil (with 45% water content), natural soil + geocell, natural soil + lime at the rates of 5%, 10%, 15%, natural soil + 5% lime + geocell and natural soil + 10% lime + geocell. For all states, 30 cm diameter steel loading plate was placed on top of the compacted material that was placed in the test box. The loading continued until the vertical load reached to a single-axle load (single-axle load = 10 tons, wheel load = 5 tons).

2. Results and discussion

2.1. Load-deformation

Effects of lime stabilization and geocell reinforcement on clay soil with high water content were separately reviewed. The comparison of load-deformation relations of natural state, lime at the rates of 5%, 10%, 15%, geocell, geocell + 5% lime and geocell + 15% lime are given at Figure 7. When the results from Figure 7 are reviewed; while the largest deformation in the natural state of 10 kg/cm^2 stress was 61.32 mm, this deformation was decreased to 53.80 mm, 39.21 mm and 28.92 mm when 5 %, 10% and 15% lime was added, respectively. In case the base soil was reinforced with geocell, it was decreased to maximum 61.32 mm from 26.2 mm (in natural state), to 19.13 in 5% lime + geocell and 16.105 mm in geocell + 10% lime. Decrease of 10%, 35%, 40% in vertical deformation were observed with 5%, 10%, 15% lime stabilization, respectively.

Figure 6. Confinement cells placed on the base soil were filled with sand

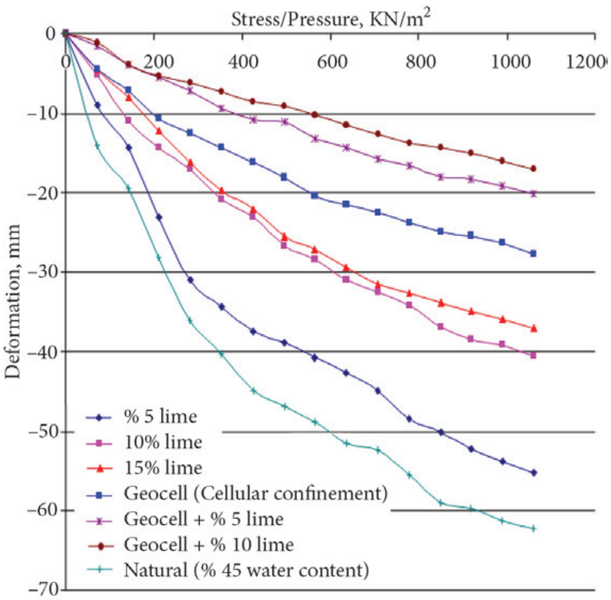

Figure 7. Load-deformation curve

As seen, the amount of decrease at the deformation is little when lime is added to the soil after 10% lime rate. This is because of the decrease of CBR bearing capacity due to the increased amount of filler material. Better success, 55% and 75% decrease in deformation were achieved with geocell and geocell + 10% lime, respectively.

2.2. Vertical stress

The vertical stresses on unreinforced and geocell-reinforced base stabilized with lime at various percent are shown in Tables 3–4. The pressure gauges' readings, on either side of the piston, showed zero stress values at 40 cm distances. In case a comparison among lime stabilization and geocell reinforcement based on vertical stresses is made, the results have indicated that the vertical stresses on the base reinforced with geocell were only 10% less than the base stabilized with 15% lime. It has been seen that geocell reinforcement is more effective compared to lime stabilization in decreasing the vertical stresses due to the fact that the geocell material prevents the lateral movements of the fill material constrained inside due to its geometric structure. The vertical stresses at the bottom of the geocell were lowered by expanding the load to a wide area in the geocell structure. As a reaction, lateral stresses were also generated in congruent cells, which increased the shear strength of the confined soil. This creates a rigid mattress distributing the imposed pressure over a larger area thanks to the ability of geocells spreading imposed loads over a larger area.

The decrease of vertical stresses under the geocell shows similarity with the study done by Dash, Krishnaswamy and Rajagopal (2001a). In their study, they concluded that vertical stresses of the soil reinforced with geocell were decreased to the rates up to 50%.

2.3. Reaction modulus coefficient

As a result of plate loading experiments, along with the coefficient values calculated with the help of load-deformation curves, the reaction modulus coefficient values were also obtained in case of using lime at various rates and geocell. These findings are represented in Figure 8. The review of reaction modulus coefficient values revealed that 2 times, 4 times and 5.5 times increases occurred in the state with 5%, 10%, 15% lime, respectively, compared to the state without lime. The reaction modulus coefficient value increased 6.5 times in the state of reinforcement with geocell compared to the unreinforced state. Furthermore, the 1.5-time

Table 3. Vertical stresses on unreinforced and geocell reinforced base

Distance from the load, cm	Vertical stress, kN/m^2			
	Unreinforced	Soil+geocell	5% lime+geocell	10% lime+geocell
0	280	155	150	140
20 (right)	52	49	48	40
40 (right)	0	0	0	0
–20 (left)	52	49	49	41
–40 (left)	0	0	0	0

Table 4. Base soil stabilized with lime

Distance from the load, cm	Vertical stress, kN/m^2		
	5% lime	10% lime	15% lime
0	265	220	170
20 (right)	135	49	47
40 (right)	0	0	0
–20 (left)	134	48	46
–40 (left)	0	0	0

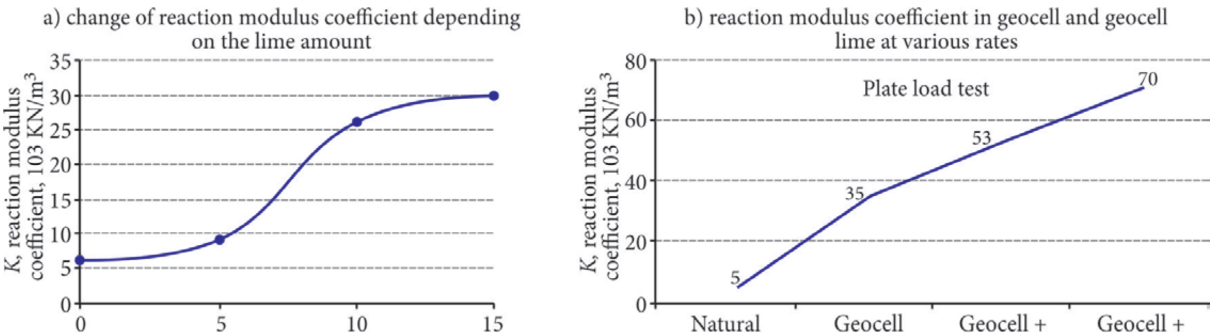

Figure 8. Reaction modulus coefficient values in case of using lime at various rates and geocell

increase is the obtained result compared to the 10% lime stabilized state. In the case of 10% lime-stabilized geocell state reinforced base soil, the reaction modulus coefficient value increases about 14 and 2.5 times compared to the natural state and the base soil stabilized with 15% lime, respectively.

The reaction modulus coefficient value continuously increases up to 10% lime rate in case a soil with high water content is stabilized with the lime. After 10% lime rate, however, the increase rate becomes lower. According to *Turkish highways technical specification,* Ulaştırma (2013), the pavement base soil reaction modulus coefficient (*K*) shall be higher than 5.5 kg/cm^2. Pursuant to this standard, these values were hardly reached. But for when the clay base of high water content is stabilized with 10% lime and then reinforced with the cellular load-bearing system, the *K* value of 6.5 kg/cm^2 was reached satisfying highway need.

Conclusions and recommendations

In this paper, the effects of stabilization of paved road base soil having high water content and clay with lime or reinforcement of cellular system and together the use of these two different improvement methods were reviewed. The following conclusions are made through the findings of the experiments conducted.

1. As a result of the plate loading experiments, it was observed that lime stabilization and cellular confinement system increase the reaction modulus. On the other hand, a decrease in the vertical stress and vertical deformation was obtained compared to the natural state (with a high water content of 45%).
2. It was determined that cellular reinforcement increased the value of reaction modulus coefficient for the base soil more than 15% compared to the lime stabilization and decreased the settlements along with vertical stresses by 13%.
3. Finally, it was concluded from this experimental study that sole lime stabilization or improvement with cellular bearing systems more or less fulfil the required reaction modulus coefficient values recommended by the state engineers for A-7 group clay paved base soils with high water content. As the solution to this problem, though, it is recommended that stabilization of these types of soils need to be implemented through the successive lime stabilization and cellular confinement systems.

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