NÖHÜ Müh. Bilim. Derg. / NOHU J. Eng. Sci., 2023; 12(4), 1232-1238
Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi
Niğde Ömer Halisdemir University Journal of Engineering Sciences
Araştırma makalesi / Research article
www.dergipark.org.tr/tr/pub/ngumuh / www.dergipark.org.tr/en/pub/ngumuh

Investigation of load-displacement behavior of cement-coated geotextile reinforced sandy soils

Çimento kaplı geotekstil ile güçlendirilmiş kumlu zeminlerin yük deplasman davranışının incelenmesi

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Abstract

In this study, typical California Bearing Ratio (CBR) experiments were conducted to examine the behavior of cement-coated geotextile reinforced soils. For this purpose, firstly geotextile-reinforced then cement-coated geotextile-reinforced tests were carried out for sand soil and base material. The results of the experiments reinforced soils with geotextile were compared with the results obtained from the tests of reinforced soils with cement-coated geotextile. In addition, the test results of the unreinforced soil were compared with the reinforced conditions. The results of the experiments were evaluated in terms of load-displacement behavior and CBR values. In view of this results, base material reinforced with cement-coated geotextile outperformed compared to the unreinforced case; however, geotextile reinforced base material demonstrated worse than the unreinforced case, up to 6 mm displacement. On the other hand, both the geotextile reinforced, and cement-coated geotextile reinforced cases outperformed the unreinforced case on sand soil. In addition, cement-coated geotextile reinforced cases demonstrated better performance compared to the geotextile cases on both sand soil and base material. In terms of CBR values, geotextile and cement-coated geotextile reinforced sand soil indicated improvements of 1.68 and 3.25 times, respectively. While the CBR value of the cement-coated geotextile reinforced base material increased by 59%, it decreased by 4% in the geotextile reinforced case.

Keywords: Geotextile, Cement-coated geotextile, CBR experiment, Load-displacement behavior, CBR value

Özet

Bu çalışmada, çimento kaplı geotekstil ile güçlendirilmiş zeminlerin davranışını incelemek için tipik Kaliforniya Taşıma Oranı (CBR) deneyleri yapılmıştır. Bu amaçla kum zemin ve temel malzemesi için önce geotekstil daha sonra çimento kaplı geotekstil ile güçlendirilmiş deneyler yapılmıştır. Geotekstil ile güçlendirilmiş zeminler ile yapılan deneylerin sonuçları çimento kaplı geotekstil ile güçlendirilmiş zeminlerin deneylerinden elde edilen sonuçlarla karşılaştırılmıştır. Ayrıca güçlendirilmemiş durumdaki zeminin deney sonuçları güçlendirilmenin yapıldığı durumlar ile de kıyaslanmıştır. Deney sonuçları yük-deplasman davranışı ve CBR değerleri açısından değerlendirilmiştir. Bu sonuçlara göre, çimento kaplı geotekstil ile güçlendirilmiş temel malzemesi, güçlendirilmemiş duruma göre daha iyi performans göstermiştir; ancak geotekstil ile güçlendirilmiş temel malzemesi 6 mm yer değiştirmeye kadar güçlendirilmemiş durumdan daha kötü performans göstermiştir. Öte yandan hem geotekstil hem de çimento kaplı geotekstil ile güçlendirilmiş durumlar, kum zeminde donatısız duruma göre daha iyi performans göstermiştir. Ayrıca çimento kaplı geotekstil ile güçlendirilmiş durumlar hem kum zeminde hem de temel malzemesinde geotekstil ile güçlendirilmiş durumlara göre daha iyi performans göstermiştir. CBR değerleri açısından, geotekstil ve çimento kaplı geotekstil ile güçlendirilmiş kum zemin sırasıyla 1,68 ve 3,25 kat iyileşme göstermektedir. Çimento kaplı geotekstil ile güçlendirilmiş temel malzemesinin CBR değeri %59 artarken, geotekstil ile güçlendirilmiş durumda %4 azalmıştır.

Anahtar kelimeler: Geotekstil, Çimento kaplı geotekstil, CBR deneyi, Yük-deplasman davranışı, CBR değeri

1 Introduction

In practice, there may be applications where it is necessary to increase the bearing capacity of the soil. For this purpose, soil can be reinforced with additives [1,2], fibers [3–5], and geosynthetics [6–8]. Geosynthetics are widely used not only to increase bearing capacity, but also in many fields in geotechnical engineering [9–11]. Therefore, geosynthetics are of significant importance for geotechnical engineering.

The highway layer consists of pavement, base, subbase, and subgrade layers. The traffic loads acting on the pavement layer are transmitted to the lower layers under the pavement. Traffic loads cause rutting in the pavement and the soil layers under the pavement. Thus, the deformation of the highways affects comfort considerably. In order to get rid of the effects of this adverse situation, the weak subgrade can be changed, the thickness of the base layer can be increased, or the soil layer can be strengthened. Increasing the layer thickness and replacing the weak soil is not always appropriate and

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Geliş / Recieved: 08.08.2023 Kabul / Accepted: 24.08.2023 Yayımlanma / Published: 15.10.2023
doi: 10.28948/ngmuh.1286185

applicable. For this reason, reinforcement with geosynthetics is widely used in highways [12,13].

California Bearing Ratio (CBR) value of soils is crucial for the design of flexible pavements and highways [14]. CBR parameter provides information about the strength of the subbase and subgrade soil [15]. For instance, the thickness of the subbase or subgrade pavement of airways, railroads, and highways is indirectly estimated using the CBR value [16]. Therefore, determining the CBR value is crucial for geotechnical structures [17,18]. In addition, while it is beneficial to have information about the CBR value, there are many studies in the literature to estimate the CBR value [18–21].

It is essential to determine the CBR value for design procedure of geotechnical structures. Besides, improving the CBR values of soils is even more essential. For this purpose, many studies were carried out by adding Palm tree pruning waste [12], fly ash [22], fibers [23], cement [24], lime [25], rubber waste [26], and geotextile [27] to the soils. Önal et al. [12] have conducted CBR experiments to investigate the impact of palm tree pruning waste and geotextile usage on the load-displacement behavior of the subgrade soil. They located the palm tree pruning waste and geotextile at H/4 and H/8 from the surface of the CBR mold. As a result of the tests, it was observed that palm tree pruning waste reinforced cases outperformed geotextile reinforced cases in terms of CBR value. Bağrıaçık [25] carried out CBR experiments by mixing 3%, 4%, 5%, and 6% lime by volume on soil with a low CBR value. As a result of the experiment, it was understood that reinforcing the soil with lime increased the performance in load-deformation behavior and CBR value. The optimum lime ratio was determined as 5% by volume. Öztürk et al. [28] carried out CBR experiments on sand soil and mine wastes (olivine and serpentine) at 30% and 80% relative density. They stated that sand soil demonstrated better behavior than serpentine and olivine at 30% and 80% relative density. Negi and Singh [27] have carried out CBR experiments to examine the CBR value of geotextile reinforced soils (sandy and clayey soil). They placed non-woven and woven geotextiles in different combinations. They stated that woven geotextile reinforcement outperformed non-woven geotextile reinforcement.

In this study, the load displacement behaviors of the unreinforced, geotextile reinforced, and cement-coated geotextile reinforced cases were investigated via the CBR test on both sand soil and base material. The obtained results were compared in terms of load displacement behavior and CBR values.

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2 Material and methods

2.1 Sand subgrade and base soil

In unpaved roads, the highway base material consists of granular soil with a high CBR value, and the subgrade layer consists of soils with a low CBR value. Therefore, two different soils (i.e., sand soil and base material) were used in the experiments. The properties of sand soil which were determined before [29] and base material are presented in Tables 1 and 2, respectively. According to ASTM D2487 [30], while the sand soil was classified as poorly graded sand (SP), the base material was classified as well-graded gravel (GW). The particle distributions of base material and sand soil were obtained according to ASTM D6913 [31] and are given in Figure 1. Also, in the same figure, the upper and lower limits of base material were given. As the CBR value of the subgrade soil is generally low on unpaved roads, sand soil with a relative density of 70% was used in the experiments. Experiments with the base material were carried out at optimum water content.

Table 1. Properties of the base material

Properties	Value
Los Angeles abrasion (%)	22.80
$MgSO_4$ loss (%)	2.71
Water absorption (%)	0.40
Methylene blue (%)	0.50
Coefficient of curvature, C_c	1.50
Coefficient of uniformity, C_u	18.00
D_{10} (mm)	0.50
D_{30} (mm)	2.60
D_{50} (mm)	6.00
D_{60} (mm)	9.00
w_{opt} (%)	4.94
Maximum dry density (kN/m^3)	2.33

Table 2. Properties of the sand soil [29]

Properties	Value
Specific gravity	2.74
D_{10} (mm)	0.38
D_{30} (mm)	0.50
D_{60} (mm)	0.70
Coefficient of uniformity, C_u	1.84
Coefficient of curvature, C_c	0.94
Minimum dry density (kN/m$_3$)	14.12
Maximum dry density (kN/m$_3$)	16.97
Maximum void ratio, e_{max}	0.79
Minimum void ratio, e_{min}	0.62
Relative density (%)	70

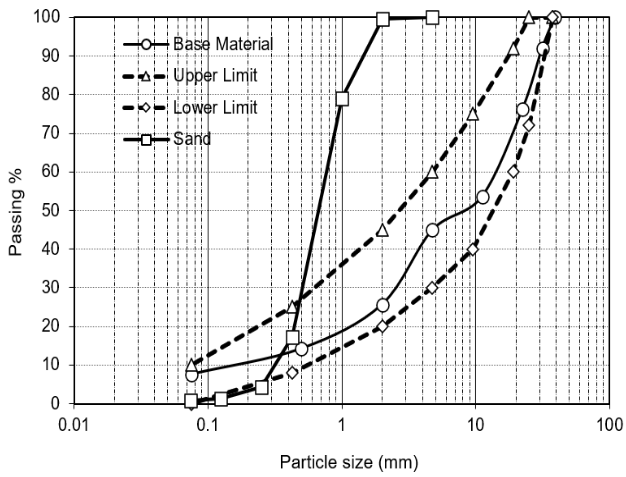

Figure 1. Particle size distribution of sand soil and base material

2.2 Geotextile and cement-coated geotextile

In the study, a geotextile made of polypropylene material with a density of 400 g/m^2 and a thickness of 2.5 mm was used. The properties of the geotextile used in the experiments are presented in Table 3.

Table 3. Properties of geotextile

Properties	Units	Value
Material Composition	-	Polypropylene (PP), white
Material Density	g/m^2	400
Thickness	mm	2.5
Tensile Strength, md/cmd*	kN/m	21 / 23
Elongation at Break	%	50
UV Resistance	%	70
Dynamic Puncture Strength	mm	8
Static Puncture Strength	N	4000
Apparent Opening	mm	0.11
Liquid Permeability	m/s	0.04

* cmd = cross-machine direction, md = machine direction

Cement-coated geotextile was produced by using the same geotextile that was introduced in Table 3. Cement paste was prepared at a water/cement ratio of 0.5 according to TS EN 196-1[32] standard. CEM I 42.5 R Portland cement was used to prepare of cement paste. Cement-coated geotextile is obtained by applying cement paste on both sides of the geotextile. When the process was completed, 0.5 grams of cement paste were applied to each surface of the geotextile per cm^2. The obtained cement-coated geotextile was used in the experiments after being kept in the standard curing pool for 28 days. The thickness of the cemented geotextile was measured in many places of cement-coated geotextile, and the average thickness was determined as 5.5 mm. A photograph of the geotextile and cement-coated geotextile used in the experiments is given in Figure 2.

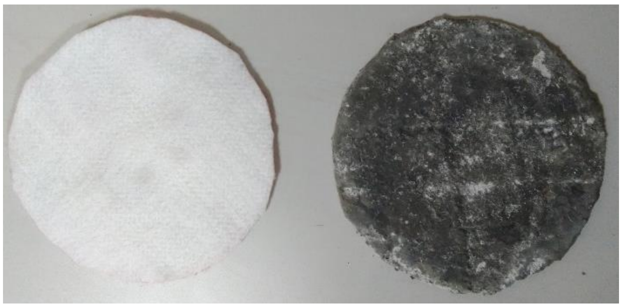

Figure 2. The photograph of geotextile and cement-coated geotextile

2.3 Experimental program

Experiments were performed according to ASTM D4429-09a [33] and ASTM D1883 [34]. In the experiments, force values were obtained in relation to deformations. The program of the experiments carried out within the scope of the study is given in Table 4. Standard CBR mold was used in the experiments. The diameter and height of the standard CBR mold are 152.4 and 116.4 mm, respectively. H refers to the height of the standard CBR mold. The burial depth of the reinforcement elements was chosen as H/8 for sand soil and H/5 for granular soil. The H/8 burial depth of the reinforcement element is compatible with the literature [12]. The reason for choosing H/5 for the granular soil is that the maximum particle size of the granular soil is 19 mm. A schematic sketch of the experiments and a photograph of the experimental setup are presented in Figure 3 and Figure 4, respectively.

Table 4. Program of the experiments

No	Reinforcement Type	Soil Type	Burial Depth (u) (mm)
1	Unreinforced	Sand Soil	-
2	Geotextile reinforced	Sand Soil	H/8
3	Cement-coated geotextile reinforced	Sand Soil	H/8
4	Unreinforced	Base material	-
5	Geotextile reinforced	Base material	H/5
6	Cement-coated geotextile reinforced	Base material	H/5

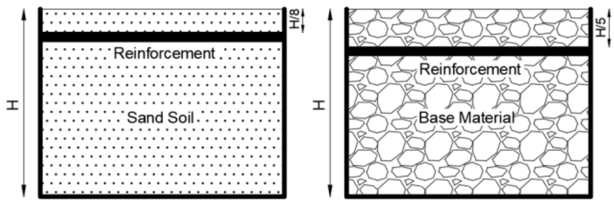

Figure 3. Schematic sketch of the experiments a) sand soil b) base material

Figure 4. Experimental setup

3 Results and discussions

The load displacement curves of the unreinforced, geotextile reinforced, and cement-coated geotextile reinforced on the sand soil are given in Figure 5. In unreinforced and geotextile reinforced cases, the load becomes constant after a certain peak value. However, in the case of reinforced with cement-coated geotextile, it can be understood that the load is constantly increasing, does not reach a certain peak value, and does not remain constant at a certain load value. Figure 5 illustrates that after 3 mm of deformation, both geotextile and cement-coated geotextile reinforced cases demonstrated greater strength than unreinforced cases. Additionally, cement-coated geotextile reinforcement cases performed better than geotextile reinforcement.

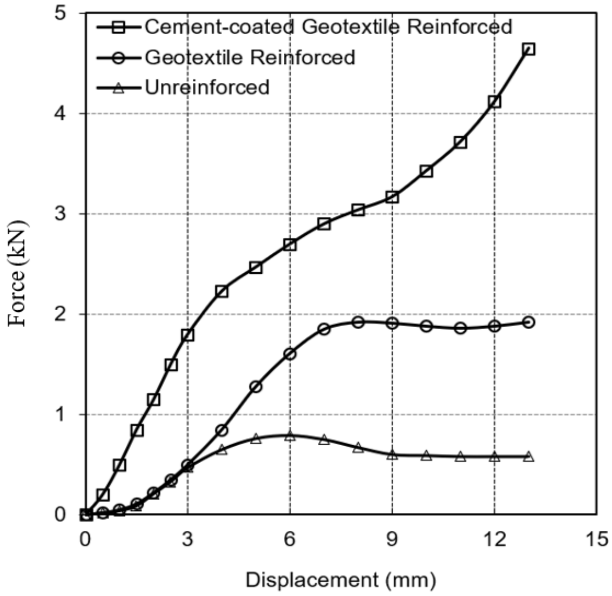

Figure 5. Force-displacement curves for sand soil

The load displacement curves of the unreinforced, geotextile reinforced, and cement-coated geotextile reinforced on the base material are given in Figure 6. In all experiments, the load value increased with increasing deformation. After 2 mm of deformation in all curves, the curves continued with a constant slope. The behavior of the geotextile-reinforced subgrade is worse compared with the unreinforced case while the behavior of the cement-coated geotextile reinforced case is better than the behavior of the unreinforced case.

Photographs of cement-coated geotextiles after the tests on sand soil and base material are shown in Figure 7. After the test on the sand soil, it can be understood from the figure that the center of the cement-coated geotextile is deformed. Nevertheless, it can be observed that the cement-coated geotextile did not occur any damage after the test on the base material.

The improvement factor in the bearing capacity (I_f) proposed by Dash et al. [35] is used to represent performance improvement owing to reinforcement in the bearing capacity. The ratio of the load carried with reinforced case to the load carried by the unreinforced case at the same deformation is known as the bearing capacity improvement factor, and a greater value of I_f indicates a better increase in the bearing capacity. Table 5 demonstrates the improvement factor in the bearing capacity of reinforced cases on the sand soil. The improvement factor in the bearing capacity of the base material is given in Table 6.

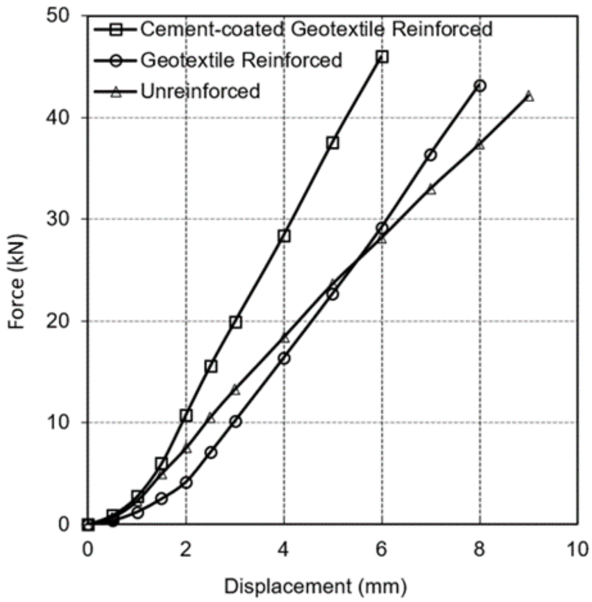

Figure 6. Force-displacement curves for base material

(a) (b)

Figure 7. The photographs of cement-coated geotextiles after the experiments a) sand soil b) base material

CBR values determined according to ASTM D1883 [34] are presented in Table 7. The CBR values for unreinforced, geotextile reinforced, and cement-coated geotextile reinforced sand soil cases were 3.93%, 6.62%, and 12.77%, respectively. CBR values increased in both cases with reinforcement. However, as a result of the experiments on the base material, the CBR value increased in the case of reinforced with cement-coated geotextile while the CBR value decreased in the case of reinforced with geotextile. The CBR values obtained for unreinforced, geotextile reinforced, and cement-coated reinforced cases in the base material were 122.22%, 117.31%, and 194.32%, respectively. The decrease in CBR value in the case of reinforcement with geotextile may be due to the already strength sufficient base material.

Table 5. Improvement factor in the bearing capacity for sand soil

Reinforcement Type	Burial Depth (u)	Improvement factor in the bearing capacity (I_f)										
Geotextile	H/8	1.00	1.22	1.06	1.06	1.31	1.68	2.04	2.47	2.87	3.18	3.21
Cement-coated Geotextile	H/8	10.0	9.44	4.55	3.83	3.43	3.25	3.42	3.87	4.54	5.28	6.41
Deformation (mm)		0.5	1.5	2.5	3	4	5	6	7	9	11	13

Table 6. Improvement factor in the bearing capacity for base material

Reinforcement Type	Burial Depth (u)	Improvement factor in the bearing capacity (I_f)										
Geotextile	H/5	0.56	0.54	0.51	0.56	0.67	0.77	0.83	0.89	0.93	0.96	1.04
Cement-coated Geotextile	H/5	1.30	1.19	1.20	1.43	1.48	1.50	1.52	1.54	1.57	1.59	1.63
Deformation (mm)		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0

Table 7. CBR values of reinforced and unreinforced soils

Reinforcement Type	Soil Type	Burial Depth (u)	CBR Value (%)
Unreinforced	Sand	-	3.93
Geotextile	Sand	H/8	6.62
Cement-coated Geotextile	Sand	H/8	12.77
Unreinforced	Granular	-	122.22
Geotextile	Granular	H/5	117.31
Cement-coated Geotextile	Granular	H/5	194.32

4 Conclusions

This study included conventional California Bearing Ratio (CBR) experiments to examine the behavior of geotextile, and cement-coated geotextile reinforced soils. For this reason, experiments were carried out on sand soil and base material using geotextile and cement-coated geotextile reinforcement. The outcomes of the reinforced tests were compared with those of the unreinforced tests as well as with each other. The load-displacement behavior and CBR values were used to assess the experiment's outcomes. From the results of the experimental study can be deduced from the following conclusions:

- Compared to the unreinforced case, base material reinforced with cement-coated geotextile performed better; nevertheless, geotextile reinforced base material performed worse, up to 6 mm displacement.
- On sand soil, the geotextile and cement-coated geotextile reinforced cases both demonstrated better performance compared to the unreinforced case.
- On both sand soil and base material, cement-coated geotextile reinforced cases outperformed geotextile reinforced cases regarding load-displacement behavior.
- Geotextile and cement-coated geotextile reinforced sand soil cases showed improvements in CBR values of 1.68 and 3.25 times, respectively.
- The CBR value of the geotextile reinforced base material case decreased by 4%, while it increased by 59% for the cement-coated geotextile reinforced base material.

Acknowledgement

This paper was produced from the Ph.D. thesis study of the first author within the Osmaniye Korkut Ata University, Institute of Science and Technology. The authors thank to Geoplas company for the supply of geotextile. This study was partly supported by Osmaniye Korkut Ata University Scientific Research Projects Unit (Project No: OKÜBAP-2022-PT2-041).

Conflict of interest

The authors declare that there is no conflict of interest.

Similarity rate (iThenticate): 16%

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