Dokuz Eylül Üniversitesi Mühendislik Fakültesi Fen ve Mühendislik Dergisi
Dokuz Eylul University Faculty of Engineering Journal of Science and Engineering
Elektronik/Online ISSN: 2547-958X

*RESEARCH ARTICLE / ARAŞTIRMA MAKALESI*

# A Laboratory Examination of CBR Value of Soil Reinforced with Waste Denim

## Atık Kot ile Güçlendirilmiş Zeminin CBR Değerinin Laboratuvarda İncelenmesi

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### Abstract

The utilization of waste materials for the reinforcement of soils should be investigated in order to prevent pollution and encourage sustainable solutions and a circular economy. The aim of this study is to investigate the effect of waste denim on soil reinforcement. For this purpose, California Bearing Ratio (CBR) experiments were performed by adding the waste denim as a whole and in pieces on sand soil. The results of the tests were assessed with regard to CBR values and load-displacement behavior by comparing them with unreinforced test specimens. In terms of load-bearing capacity and CBR value, the reinforcement of the soil with waste denim improved the performance compared to the unreinforced condition. Reinforcement of the soil with waste denim increased the load-bearing capacity by a maximum of 9.8 times and the CBR value by a maximum of 4.2 times. The results are promising about the usability of waste denim for soil reinforcement.

***Keywords:*** *Waste denim, CBR value, Load-displacement behavior, Soil reinforcement*

### Öz

Kirliliği önlemek, sürdürülebilir çözümleri ve döngüsel ekonomiyi teşvik etmek için atık malzemelerin zeminlerin güçlendirilmesinde kullanımı araştırılmalıdır. Bu çalışmanın amacı, atık kotun zemin güçlendirmesi üzerindeki etkisini araştırmaktır. Bu amaçla, atık kot bir bütün olarak ve parçalar halinde kum zemine eklenerek Kaliforniya Taşıma Oranı (CBR) deneyleri gerçekleştirilmiştir. Deney sonuçları CBR değerleri ve yük-deformasyon davranışı açısından güçlendirilmemiş örnekler ile karşılaştırılarak değerlendirilmiştir. Yük taşıma kapasitesi ve CBR değeri açısından, zeminin atık kot ile güçlendirilmesi, güçlendirilmemiş duruma kıyasla performansı artırmıştır. Zeminin atık kot ile güçlendirilmesi, yük taşıma kapasitesini en fazla 9,8 kat, CBR değerini ise en fazla 4,2 kat artırmıştır. Sonuçlar, atık kotun zemin güçlendirmesi için kullanılabilirliği konusunda umut vericidir.

***Anahtar Kelimeler:*** *Atık kot, CBR değeri, Yük deformasyon davranışı, Zemin güçlendirmesi*

## 1. Introduction

With population growth, the volume of traffic on the roads is increasing; therefore, the traffic load on the roads is also increasing. The increase in traffic load leads to deterioration and reduces comfort on the roads. In order to prevent such adverse effects, it is critical to strengthen subgrade soils, which are weak road layers [1]. In order to increase the bearing capacity of soils and improve the performance of roads, researchers have employed many methods such as reinforcing the soil with geosynthetics [2,3], additives [4,5], and waste materials [6–9].

California Bearing Ratio (CBR) value is a parameter that plays a critical role in the design of a road [10]. CBR value is used to estimate the subbase or subgrade thickness of highways, airways, and railroads [11]. Therefore, determining the CBR value and enhancing the CBR value is crucial for geotechnical applications. Many researchers in the literature have conducted studies on determining and increasing the CBR value [1,12–14]. Erginer et al. [14] performed CBR experiments by adding tire waste to the soil in small pieces. Tire waste was added to the soil between 0% and 75%. The experiments were carried out at the optimum water content determined based on the variation of the tire waste ratio. As a result of the experiments, it was stated that up to 25% of tire waste increased the CBR value. 20% of tire waste significantly increased the CBR value compared to other ratios. Öztürk et al. [1] investigated the effect of geotextile and cement coated geotextile on CBR value on subgrade material. Cement-coated geotextile was manufactured by improving the geotextile with cement paste at 0.5 water/cement ratio. The burial depth of the reinforcement element in the subgrade soil was H/8. As a result of the experiments, it was stated that the CBR value of the subgrade soil reinforced with cement-coated geotextile improved by 3.25 times. Geçkil et al. [13] added lime to the soil at ratios ranging from 2.5% to 20% in order to stabilize the clay soil with lime. CBR tests were carried out on the obtained clay-lime mixtures after the 7 and 28-day curing period. As a result of the experiments, the highest increase value was obtained from 5% lime added soil. The CBR value increased by 1.37 and 2.08 times after the 7 and 28-day curing period, respectively. Geçkil et al. [12] investigated the effect of black carbon, a recycling product of waste vehicle tires, on the stabilization of the subgrade soil. They added black carbon ranging from 2.5% to 20% by weight to the soil and left the samples to cure for 1 and 7 days. The highest CBR value was obtained from 10% black carbon added soil. The CBR values of 10% black carbon added soil with 1 and 7 days curing time increased by 1.28 and 1.77 times, respectively, compared to the control sample.

In this research, the usability of waste denim was evaluated as a soil reinforcement element. For this objective, CBR tests were

DOI: https://doi.org/10.21205/deufmd.2025278019

Geliş Tarihi / Received: 06.04.2024
Kabul Tarihi / Accepted: 07.11.2024

performed by placing the waste denim as a whole and in pieces into the sand soil at burial depths of H/4 and H/8. The results were assessed regarding the CBR value and load-displacement behavior.

## 2. Materials and Methods

Poorly graded sand soil classified as SP according to ASTM D2487 [15] was used. The particle size distribution graph of the soil derived in accordance with ASTM D6913 [16] is given in Figure 1 and the soil properties are given in Table 1.

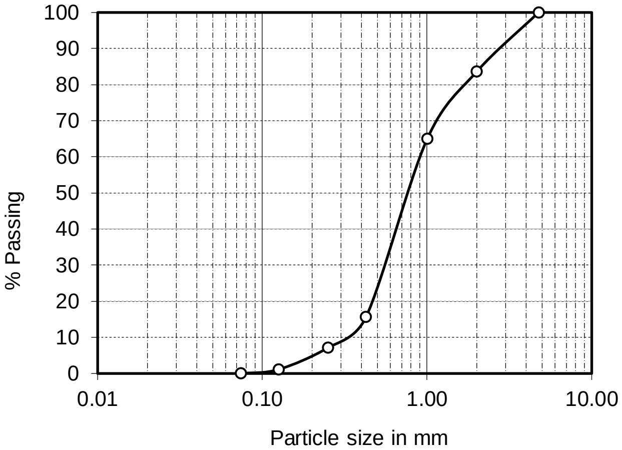
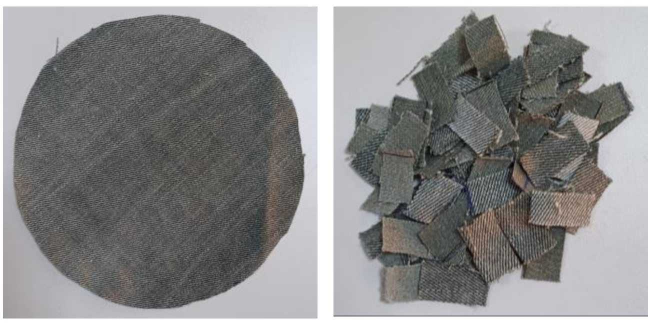



**Figure 1**. Particle sizes distribution curve of the soil.

**Table 1.** Characteristics of the soil.

| Properties | Value |
|---|---|
| Specific gravity | 2.73 |
| $D_{10}$ (mm) | 0.35 |
| $D_{30}$ (mm) | 0.55 |
| $D_{60}$ (mm) | 0.90 |
| Coefficient of uniformity, $C_u$ | 2.57 |
| Coefficient of curvature, $C_r$ | 0.96 |
| Minimum dry density (kN/m$^3$) | 15.15 |
| Maximum dry density (kN/m$^3$) | 17.20 |
| Maximum void ratio, $e_{max}$ | 0.81 |
| Minimum void ratio, $e_{min}$ | 0.59 |
| Relative density (%) | 70 |

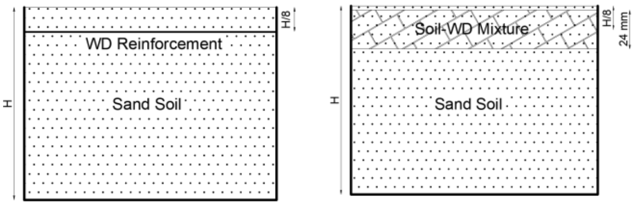
The waste denim parts were gathered from a tailor's shop. The waste denim was cut into a whole piece to fit exactly into the CBR mold and cut into small pieces. The materials obtained from waste denim for soil reinforcement are illustrated in Figure 2. The diameter of the whole piece is 150 mm and the size of the small pieces is 12 x 24 mm. The size of the pieces was chosen in accordance with a study in the literature [17]. The thickness of the waste denim was measured 0.7 mm.



(a) (b)

**Figure 2**. Waste denim utilized for reinforcement: a) whole piece, b) small pieces

The maximum length of the waste denim pieces was 24 mm; therefore, the soil reinforcement was carried out so that the CBR mold was at a height of 24 mm. A schematic illustration of the experiments representing the reinforcements at H/8 height is presented in Figure 3. Soil reinforcement in the standard CBR mold was carried out at heights H/8 and H/4 from the soil surface. The burial depth of the reinforcing element H/8 and H/4 is in accordance with the literature [18]. The specified heights served as a point of reference for the placement of entire waste denim pieces. However, in the case of mixing small denim pieces with soil and reinforcement, these same heights were indicative of the midpoint of the resulting soil-waste denim combination.




(a) (b)

**Figure 3**. Schematic illustration of the test: a) reinforced with whole piece, b) reinforced with small pieces

The soil was reduced by the volume of waste denim from the reinforced section. When the soil was placed in the CBR mold, it was placed and compacted in 3 layers with a relative density of 70%. CBR tests were conducted in conformity with ASTM D1883 [19]. The area of the whole piece of waste denim used for reinforcement is equal to the area of 62 pieces of 12 x 24 mm waste denim; therefore, for comparison purposes, the soil was reinforced by mixing the soil with 62 pieces of waste denim. In addition, the soil was reinforced with 124 pieces of waste denim. While comparing the results, the soil reinforced with whole waste denim pieces was named as WD reinforced, the soil reinforced with 62 waste denim pieces was named as WD Mix1 and the soil reinforced with 124 waste denim pieces was named as WD Mix2.

## 3. Results and Discussion

Load-vertical displacement behavior of reinforced and unreinforced tests at H/8 and H/4 burial depths are illustrated in Figure 4 and Figure 5, respectively. According to Figures 4 and 5, the reinforcement of the soil with waste denim exhibited better behavior compared to the unreinforced condition. In cases where soil reinforcement is implemented, the vertical displacement behavior under load exhibits similarity. Notably, the most favorable performance was observed in soils reinforced with WD Mix2, WD, and WD mix1, respectively. However, for reinforcement at a burial depth of H/4, the WD-reinforced soil demonstrated superior performance after undergoing a vertical displacement of 9 mm.

In soils reinforced with geosynthetics, the mechanism of geosynthetics is provided by lateral confinement, stretched membrane effect and wider-angle load distribution [20,21]. Reinforcement with whole waste denim used in this study is very similar to the case of reinforcing the soil with geotextile. In the case of soil reinforcement with WD, the lateral confinement of the soil and the occurrence of tensile stress in the WD with vertical displacement causes the applied load to distribute over the soil at a wider angle. Consequently, the bearing capacity increased in the case of reinforcement with WD. Similarly, in the case of reinforcement with soil-waste denim mixtures, the load is distributed over the soil.

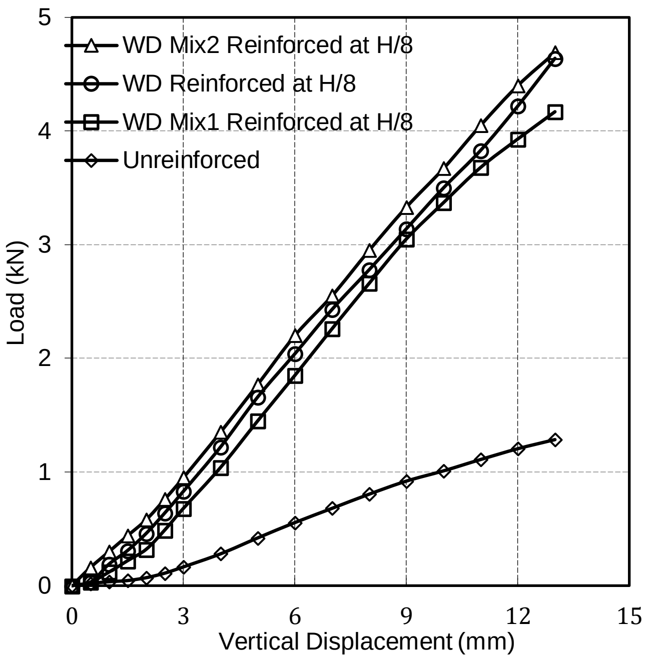



**Figure 4**. Load vs. vertical displacement curves reinforced at H/8 burial depth.

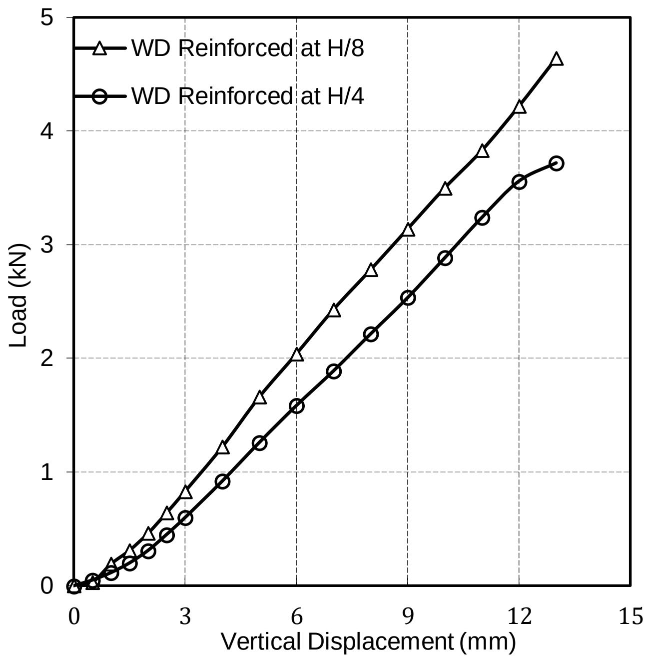



**Figure 6**. Load vs. vertical displacement curves for WD reinforced soils.

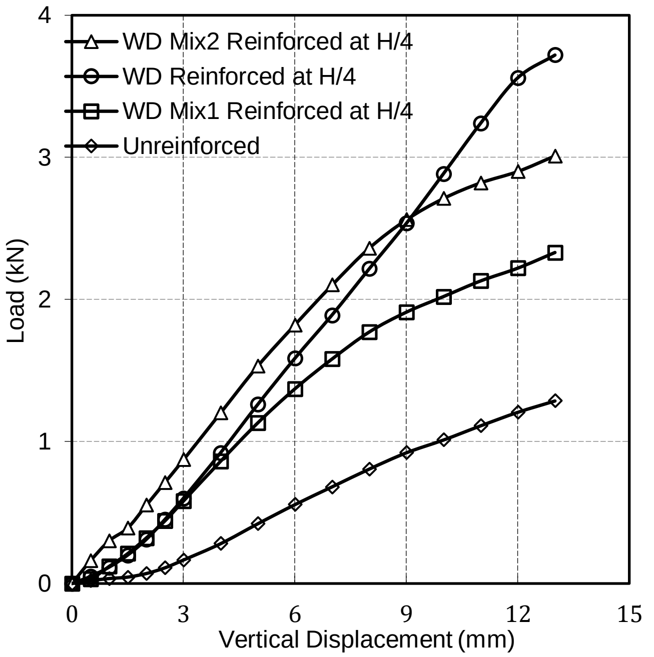



**Figure 5**. Load vs. vertical displacement curves reinforced at H/4 burial depth.

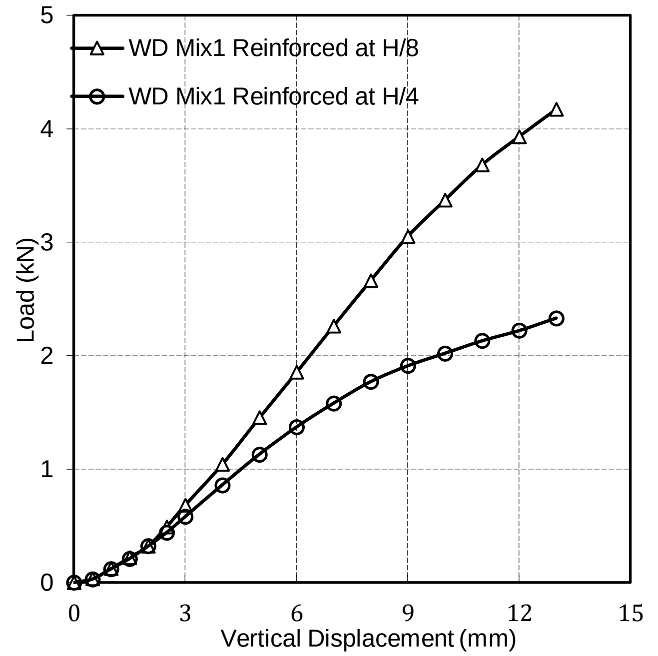



**Figure 7**. Load vs. vertical displacement curves for WD Mix1 reinforced soils.

The curves for the cases where the soil is reinforced with WD, WD Mix1, and WD Mix2 according to the burial depth are presented in Figure 6, 7, and 8, respectively. According to the graphs, reinforcement at H/8 burial depth is more effective in reinforcing the soil compared to reinforcement at H/4 burial depth. It is clearly understood that the reinforcing effect increases as the reinforcement depth decreases from the soil surface.

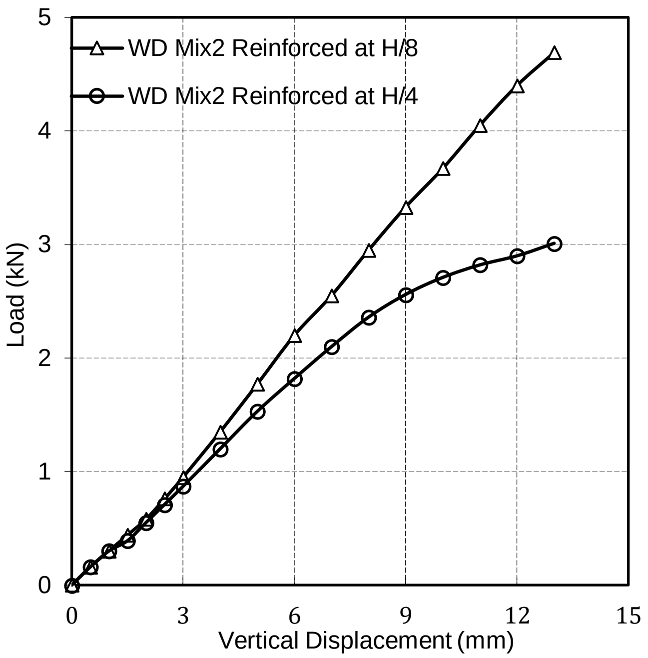



**Figure 8**. Load vs. vertical displacement curves for WD Mix2 reinforced soils.

Dash et al. [22] suggested the calculation of the improvement factor in carrying capacity ($I_f$). The $I_f$ is utilized to indicate an increase in improvement due to strengthening in carrying capacity compared to an unreinforced soil. The $I_f$ value may be expressed as the ratio of the carrying capacity of the reinforced soil to the carrying capacity of the unreinforced soil at the same vertical displacement value; therefore, a large $I_f$ value indicates a large increase in carrying capacity. The $I_f$ values of the experiments for the soils reinforced at H/8 and H/4 burial depths are demonstrated in Figure 9 and Figure 10, respectively.

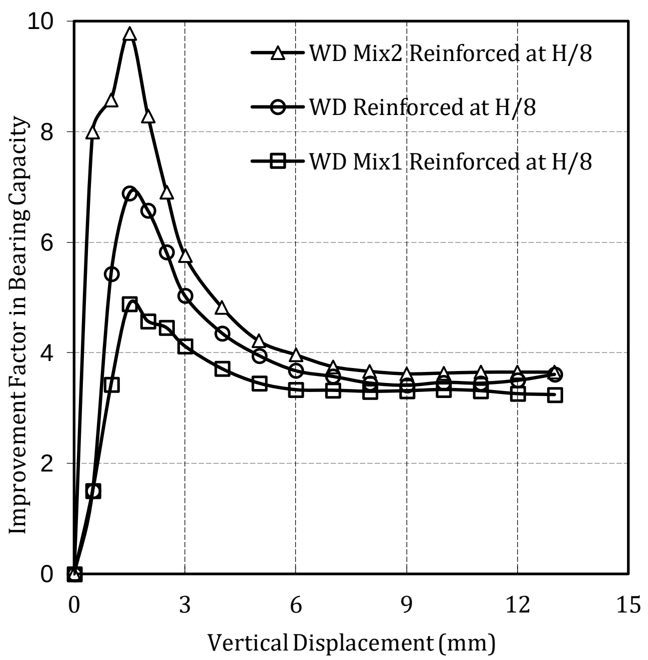



**Figure 9**. Improvement factor in bearing capacity for reinforced soils at burial depth of H/8.

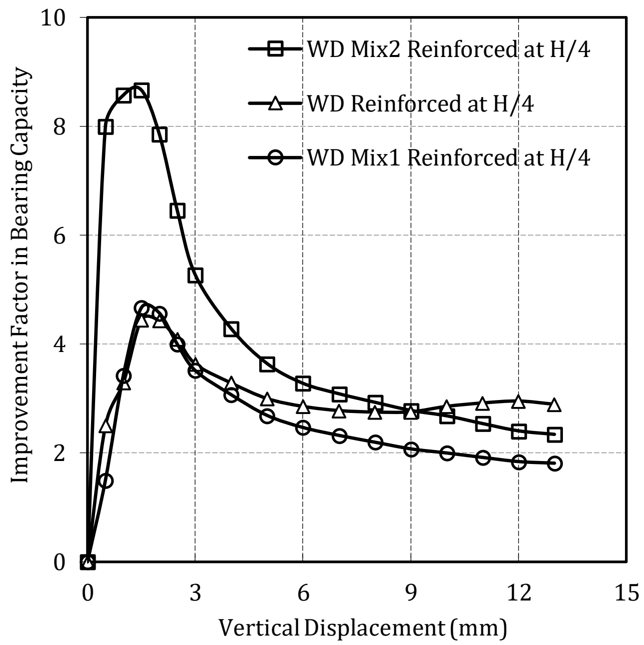



**Figure 10**. Improvement factor in bearing capacity for reinforced soils at burial depth of H/4.

CBR is defined according to ASTM D1883 as the ratio of the load needed to pierce 2.5 and 5.1 mm of the specimen material to the load needed to pierce a standard material consisting of well-graded crushed stone. As a result of the test, the CBR value of the unreinforced soil was calculated as 2.15%. The improvement factor values obtained by the ratio of the CBR values of the reinforced tests to the CBR value of the unreinforced test are illustrated in Figure 11. According to the Figure, reinforcement at H/8 burial depth resulted in higher CBR values compared to H/4 burial depth. WD Mix2, WD, and WD Mix1 at H/8 burial depth reached values of 4.21, 3.95, and 3.45 in terms of improvement factor in CBR value, respectively.

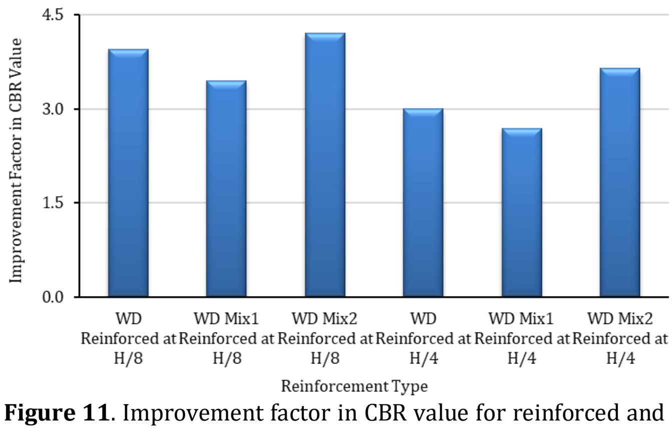



**Figure 11**. Improvement factor in CBR value for reinforced and unreinforced soils.

Due to the impossibility of obtaining sufficiently large whole pieces of waste denim, reinforcing the soil with the whole waste denim is not practical for the field applications. Therefore, it was concluded that it would be more appropriate to reinforce the soil with waste denim pieces. When the soils reinforced with WD Mix2 and WD Mix1 were compared, no enormous improvement in CBR value was noticed despite the use of two times more waste reinforcement elements in the case of reinforcement with WD Mix2. Therefore, in this study, reinforcement with WD Mix1 is recommended as an optimum case compared to the other cases.

## 4. Conclusions

The objective of this research is to investigate the usability of waste denim for soil improvement. For this purpose, standard California Bearing Ratio (CBR) tests were performed on soils reinforced with waste denim. The waste denim was placed in the soil as a whole and in pieces at burial depths of H/8 and H/4 from the soil surface. The test outputs were examined in terms of CBR values and load-displacement behavior. The fallowing conclusions can be derived from the experimental results:

- Reinforcement of the soil with the waste denim at a burial depth of H/8 or H/4 performed better in terms of load bearing capacity compared to the unreinforced case.
- In terms of load-displacement behavior, reinforcement of the soil at H/8 burial depth is superior compared to reinforcement at H/4 burial depth.
- At a burial depth of H/8, adding waste denim pieces to the soil increased the bearing capacity by a maximum of 9.78 times.
- Reinforcing the soil with waste denim pieces resulted in an increase in CBR value up to 4.2 times.

### Ethics committee approval and conflict of interest statement

This article does not require ethics committee approval. This article has no conflicts of interest with any individual or institution.

### Acknowledgment

This research did not receive any specific grant.

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