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Research Article

Hawraa Hadi Elias*, Alaa M. Shaban and Raid R. Almuhanna

Assessing strength properties of stabilized soils using dynamic cone penetrometer test

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Abstract: The subgrade soil layer is the most essential part of the pavement system. Many pavement failures can be associated with subgrade weak strength and stiffness qualities. Therefore, it is necessary to strengthen this layer before building the other pavement layers. One of the essential methods utilized to enhance the engineering characteristics of this layer is soil stabilization. Stabilization methods are many and varied, but chemical and mechanical stabilization are the most common. This research aims to evaluate the strength of stabilized soils by using a dynamic cone penetration (DCP) test. To achieve this aim, subgrade soil was provided from a roadway project in Kerbala city and stabilized with 2.5 and 5% of Portland cement by weight of the dry soil. Then, the cemented subgrade soil was reinforced with 6 and 12 mm of polypropylene discrete fiber. The fiber was added to the soil with the following contents: 0.5, 1, and 2%. The characteristics of stabilized soils were evaluated by determining three parameters: dynamic cone penetration index (DCPI), *in-situ* California bearing ratio (CBR), and bearing capacity obtained from the DCP test. The results showed that when Portland cement was increased from 0 to 2.5% and then to 5% by weight of the dry soil, the DCPI value gradually decreased while increasing both CBR and bearing capacity. However, adding 6 and 12 mm fiber contents (0.5, 1, and 2) to the cement–sand mixture containing 2.5 and 5% cement led to increased DCPI and a gradual decrease in CBR and bearing capacity. Also, the results showed that the DCPI for a 12 mm fiber is lower than that for 6 mm fibers, while the CBR and bearing capacity for a 12 mm fiber are greater than those of 6 mm fibers for all ratios. Accordingly, the results of the DCP tests showed that the most significant support for the soil is obtained when the soil is stabilized using 5% cement with 12 mm of fiber by weight of dry soil.

Keywords: DCPI, CBR, soil stabilization, subgrade strength, polypropylene fiber

*** Corresponding author: Hawraa Hadi Elias**, Department of Civil Engineering, University of Kerbala, Kerbala, Iraq,
e-mail: hawraa.hadi@s.uokerbala.edu.iq
Alaa M. Shaban: Civil Engineering Department, Engineering College, University of Kerbala, Kerbala, Iraq,
e-mail: alaa.shaban@uokerbala.edu.iq
Raid R. Almuhanna: Civil Engineering Department, Engineering College, University of Kerbala, Kerbala, Iraq, e-mail: raidr@uokerbala.edu.iq

1 Background

The durability of roadway substances that support the stress put onto the roadway by traffic significantly impacts the sustainability of flexible roadway structures. Due to the quick increase in traffic, strain appears within the pavement layers and gradually develops, which causes cracking stresses to develop [1]. Every load applied to a roadway structure is transferred to the subgrade, which serves as the basis for the structure. Therefore, the indicator qualities of the subgrade upon which the roadway surface is constructed determine to what extent a layer of pavement can withstand the stress placed on it without failure. Problematic soils are those that, without improvement, cannot be economically and safely used for road building. Therefore, suitable strategies have been suggested to improve the general feature of the strength of the soil, either by replacing it directly or stabilizing it, to ensure that road roadway systems never collapse before the end of their planned lifespan [2,3].

The method of improving soils' mechanical and chemical properties with the goal of achieving a preset, targeted bearing capacity on the soil is known as soil stabilization. Stabilization methods are many and varied, but the most common methods are chemical and mechanical stabilization. Using chemical and mechanical methods to strengthen problematic soil is effective [4,5]. Soil cement stabilization is one of the chemical stabilization techniques most frequently employed to change the characteristics of the soil and enhance its engineering performance. Portland cement serves as a binder and provides the necessary technical qualities for hardening and strengthening. However, using only cement with sandy soil causes the cemented soil to exhibit brittle behavior. This issue can easily be resolved by adding fibers to the cemented soil, which can change the behavior of the cemented soil from brittle to more ductile while also increasing its peak and residual shear strengths. A recent strategy is to use discrete fibers to improve the mechanical properties of soils [6].

The advantages of employing discrete fiber over traditional geosynthetics (strips, geotextile, geogrid, etc.) are as follows: (1) Like when mixing soil with cement, lime, or other additions, the discrete fibers are added and mixed at random with the soil. (2) Potential planes of weakness that could form parallel to the reinforcement's normal orientation can be stopped by randomly distributed fibers. (3) There is no environmental impact from the addition of fiber; it just modifies the physical characteristics of the soil [7].

Polypropylene fibers are among the most widely used and regarded fibers and offer benefits such as being non-corrosive and resistant to alkalis, chemicals, and chlorides, making them an ideal reinforcement fiber for a variety of applications. It is cost-effective because little volume is needed. High tensile strength and high elastic modulus are simply two of the excellent mechanical characteristics of polypropylene fibers. Polypropylene fibers have the disadvantage of a relatively low density, which can cause them to float in some composite matrices. Furthermore, due to their hydrophobic nature, they exhibit low hydrophilic characteristics, which could potentially hinder their ability to bond with certain matrices [8].

According to a study by Benziane et al. [9], when conducting a direct shear test on sandy soil and adding polypropylene fibers with varying content levels of 0, 0.25, 0.5, and 0.75, the results indicated that the shear strength of the reinforced soil increased as the fiber content increased. Furthermore, the maximum amount of cohesion and friction angle also increased with an increase in fiber content. In a study conducted by Qadir et al. [10], sandy soil was subjected to compaction Proctor and unconfined compression strength (UCS) tests with the inclusion of polypropylene fibers at varying concentrations of 0, 0.5, 1, 1.5, and 2. The results indicated that with an increase in fiber content, the maximum dry density (MDD) decreased while the optimum moisture content (OMC) increased. Moreover, the addition of 1% polypropylene fiber resulted in an increase in UCS from 0.25 to 0.418 MPa.

An experimental work examined the effects of adding polypropylene fibers to sand soils [11]. The fiber was added at varying content levels including 0.1, 0.3, 0.6, and 1.0% by the weight of soil mass. Proctor and UCS tests were carried out, and the findings indicated that the addition of 0.6% polypropylene fibers led to a 24% increase in the soil's friction angle (ϕ), a 20% increase in shear strength (τ), and a 182.2% increase in California bearing ratio (CBR). Moreover, even with a small amount of only 0.1% polypropylene fiber, the soil's permeability reduced by 26%. According to a study by Hasrajain [12], a CBR test was conducted on sandy soil with the addition of polypropylene fibers at varying content levels of 0.05, 0.1, 0.15, and 0.2%. The results of the study showed that under unsoaked conditions, the CBR values in reinforced sand increased significantly compared to unreinforced sand. Specifically, the CBR values increased by 60, 73, 100, 106, and 113% with the inclusion of 0.5, 1, 1.5, 2, and 2.5% polypropylene fibers, respectively. Furthermore, under soaked conditions, the CBR values in reinforced sand also showed significant improvement, with improvements of 61.6, 76.9, 96.2, 113.2, and 139% seen with the inclusion of 0.5, 1, 1.5, 2, and 2.5% polypropylene fibers, respectively.

Another study has been conducted to investigate the impact of adding polypropylene fibers to cement–sand mixtures. Sbahieh and Teymur [6] conducted a UCS test on sandy soil by adding Portland cement with contents of 3, 5, and 7%, as well as polypropylene fibers with content levels of 0, 0.1, 0.3, and 0.5%. The study's results showed that the addition of fiber reinforcement to cemented soil increased its unconfined compressive strength and axial strain at failure while altering its brittle behavior by making it more ductile. Consoli et al. [13] conducted a UCS test on sandy soil by adding Portland cement with content levels of 0 and 7%, as well as 0.5% polypropylene fibers. The study's findings showed that the inclusion of polypropylene fibers in reinforced cemented sand can significantly increase its ductility by reducing its brittleness. The fibers provide flexibility to the material, altering its failure mode from brittle to ductile, especially for longer fibers. In addition, the addition of fibers can also decrease the stiffness of the cemented sand.

Hamidi and Hooresfand [14] conducted triaxial tests on sandy soil by adding 3% Portland cement, as well as polypropylene fibers with content levels of 0, 0.5, and 1%. The study showed that the addition of fibers resulted in an increase in both peak and residual shear strength while reducing the soil's initial stiffness and brittleness index. Also, the study showed that the energy absorption capacity of the cemented soil increased by 20–50% with the inclusion of 1% fiber content.

Although many aspects influence the long-term performance of flexible pavements, one primary determining factor is the appropriate assessment of subgrade soil strength [15]. Many soil samples need to be taken from the site and tested in a lab to quantify the soil strength accurately. This procedure is regarded as being exceedingly expensive, arduous, and time-consuming.

Consequently, it is essential to use tests in geotechnical research. Experiments can be used to determine the mechanical characteristics of the subgrade and pavement layers, and some scientists have proposed criteria for doing so. One of these ideas uses a dynamic cone penetration test (DCP) [16,17]. The DCP test determines the strength of compacted or undisturbed materials *in situ*. Dr. D.J. Van Vauren developed the DCP in South Africa in the 1960s to calculate the ability of subgrade substances and layering of pavement to provide on-site stability. Due to its portability, speed, and convenience, the DCP offers a straightforward test method for determining the subgrade strength. DCP excels at providing test results quickly and is lightweight and easy to use [18,19]. The DCP was first manufactured by Scala (1959) in Australia. Since then, it has been applied to the location assessment of pavement layers and subgrades in South Africa, the UK, Australia, New Zealand, and several US states, including California, Florida, Illinois, Minnesota, Kansas, Mississippi, and Texas [20]. Experimental studies have been conducted to establish correlations between DCP measurements and other laboratory tests. The most popular correlation equations are listed in Table 1.

This research aims to investigate the feasibility of using the DCP test to evaluate the strength properties of stabilized soils, which can be helpful in geotechnical engineering and construction applications.

2 Materials and methods

2.1 Subgrade soil sample collection

The sample of soil used in this study was supplied from a roadway project location in Kerbala city (32°41′13″N and 43°53′50″E). Figure 1 shows an aerial photo of a specimen site in Kerbala.

The collected soil was tested in a lab to determine its classification and properties. As shown in Table 2, according to the American Association of State Highway and Transportation Officials and the unified soil classification system, the subgrade was classified as A-3 and the poorly graded sand soil as SP, respectively. Figure 2 depicts the grain size distribution curve. The modified Proctor compaction test was conducted to attain optimum water content and maximum dry unit weight, as shown in Figure 3. The fundamental physical features of the subgrade were then determined using CBR tests that were both soaked and unsoaked.

2.2 Portland cement

This study uses sulfate-resisting Portland cement to stabilize the subgrade soil and enhance its characteristics. Table 3 summarizes this type of Portland cement's fundamental chemicals and physical properties.

2.3 Fiber

Polypropylene discrete fiber (PPF) is one of the most essential synthetic fibers to reinforce soil and improve its engineering properties. In this study, 6 and 12 mm PPFs, as

Table 1: Summary of correlation DCP with laboratory and field tests

Reference	Material	Correlation equation
[21]	Cohesive soil	$\log\ UCS = 3.56 - 0.809 \log DCP$
[22]	Granular and cohesive soil	$\log(CBR) = 2.45 - 1.12 \log(DCPI)$
[23]	Granular and cohesive soil	$\log\ CBR = 2.465 - 1.12 \log(DCPI)$
[24]	Gravel base course	$\log\ CBR_{(lab)} = 2.438 - 1.065 \times \log(DCP)_{field}$
[25]	Various soils	$\log(CBR) = 2.46 - 1.12 \log(DCPI)$
[26]	Granular and cohesive soil	$\log\ CBR = 1.4 - 0.55 \log(DCPI)$
[27]	Natural compacted soil	$E_S = 537.76 \times DCPI^{-0.6645}$
[20]	Sandy soil	$Dr = 189.93/[(DCPI)]^{0.53}$
[20]	Sandy soil	$\phi'(deg) = 52.16/[(DCPI)]^{0.13}$ $\phi'(deg) = 26.31 + 0.21(Dr)$
[20]	Sandy soil	$E_S(MN/m^3) = 898.36/[DCPI]^{0.9}$
[28]	Cohesive soil	$\log\ S_u = 2.95 - 0.67 \log DCP$
[29]	Various soils	$MDD = 21.908DCP - 0.099$ $CBR = 24.903DCP^{-1.331}$ $UCS = 3.1237DCP^{-0.865}$

Note: DCPI denotes dynamic cone penetration index.

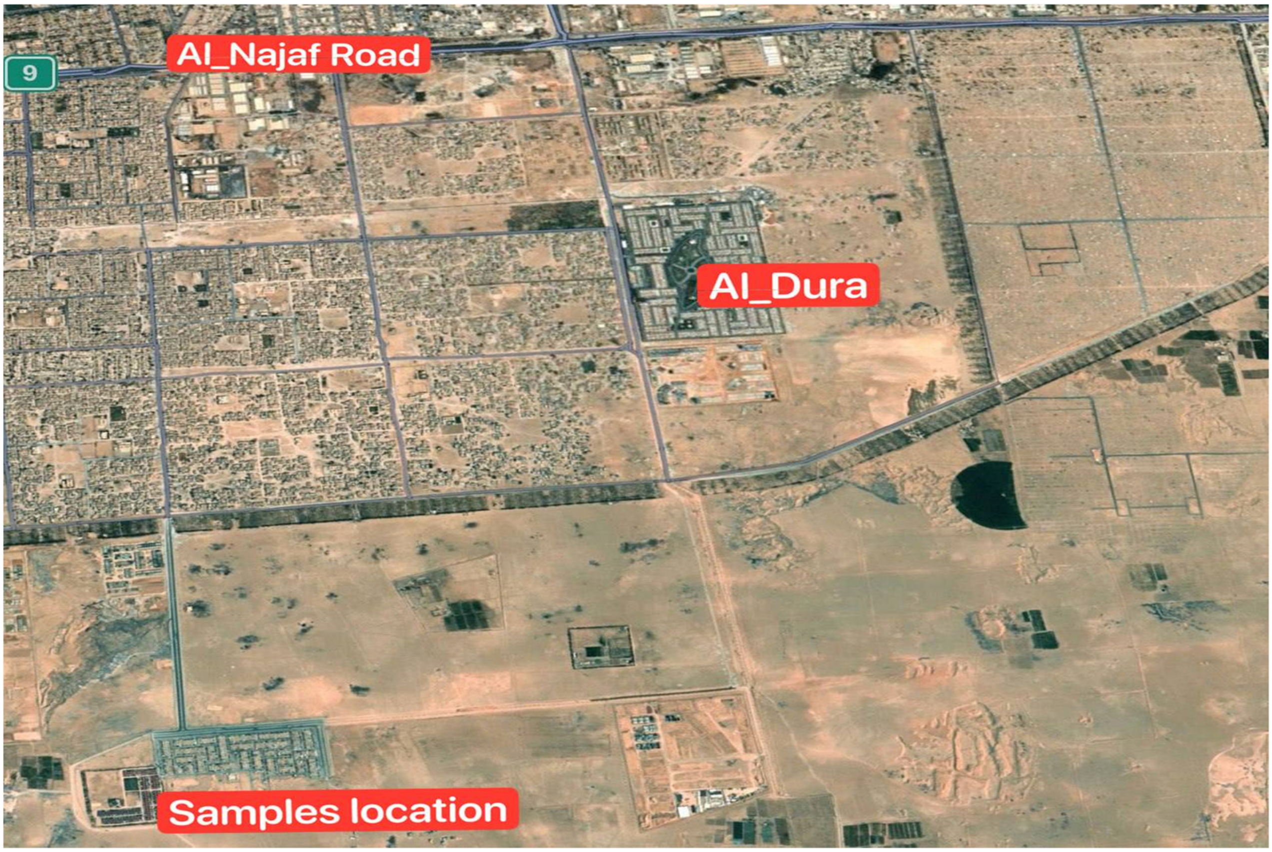

Figure 1: Aerial image of the soil collected from the site.

Table 2: Fundamental physical and chemical features of the subgrade

Property	Results	Source
Classification of soil	A-3	[30]
	SP	[30]
Optimum water content (%)	6.6	[31]
Max. dry unit weight (kN/m^3)	20.59	[31]
Specific gravity (G_s)	2.67	[32]
Curvature coefficient (C_c)	1.52	[30]
Uniformity coefficient (C_u)	3.91	[30]
Gravel fraction (G_f)	2.91%	[30]
Fine content	8.10%	[30]
CBR unsoaked (%)	38	[33]
CBR soaked (%)	29	[33]
SO_3	0.9%	[34]
Gypsum content	1.94%	[34]

shown in Figure 4, were added to the cemented soil mixture as a tensile member to reduce brittleness and cracking and to create a more homogenous and stable variety. The basic properties of PPF used in this research are summarized in Table 4.

2.4 Cement and fiber stabilization procedure

In this study, the stabilization of the sandy soils with Portland cement and PPF is as follows. First, the soil was stabilized with 2.5 and 5% of Portland cement by weight of dry soil, and then every cemented sand mixture was reinforced with 6 and 12 mm discrete fiber with content levels of 0.5, 1, and 2% by weight of the dry soil, as shown in Table 5. The modified Proctor test is utilized to find the OMC for each mixture. An electric mixer was used for mixing. Figure 5 shows the method to prepare the treated soil mixtures. Each sample and the natural subgrade sample were compacted into a large cylindrical steel mold designed and manufactured with dimensions such as diameter = 70 cm and height = 100 cm to simulate *in-situ* subgrade conditions. The thickness of each soil layer is 15 cm, whereas the desired height inside the cylindrical steel mold is 60 cm, as shown in Figure 6.

2.5 DCP test

The DCP test process involves evaluating the rate of penetration of the DCP into compacted materials or undisturbed

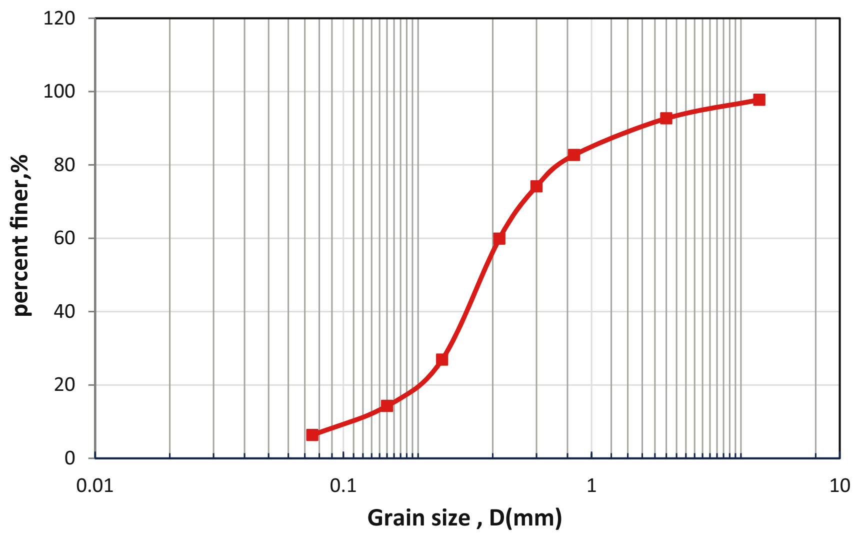

Figure 2: Curve representing the soil's grain size distribution.

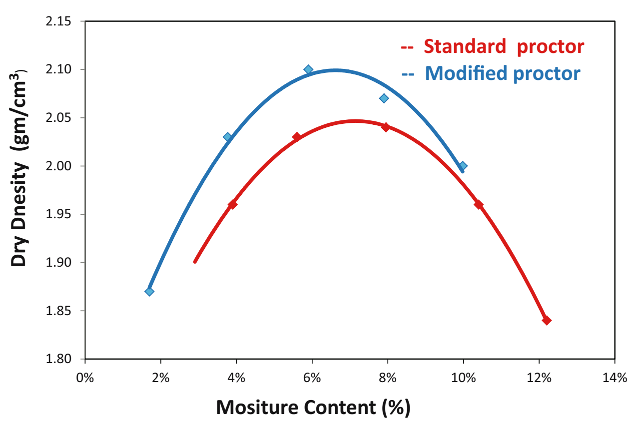

Figure 3: Proctor compaction curve of the soil.

subgrade soil. The DCP device consists of a top drive assembly, a sliding drop hammer, lower drive rods, and a penetration cone. The drop hammer, an incorporated anvil, and a rod with a handle at the top make up the upper drive assembly. It is connected to the lower driving rod's 16 mm diameter by a quick-connect pin connection. The bottom driving rod is threaded with hardened steel multi-use penetration cones. Cones have a maximum diameter of 20 mm, with the taper ending in a point at a 60° angle. Regarding blows per millimeter, penetration resistance is tested using a drop hammer with a free fall of 575 mm. Figure 7 displays a schematic diagram of the DCP device [17].

Three parameters, dynamic cone penetration index (DCPI), *in-situ* CBR, and bearing capacity, were obtained

Table 3: Fundamental chemical and physical features of Portland cement

Property	Unit	Specification	Results	Requirement
Chemical requirement				
Loss on ignition (as LOI)	(%)	IQS 5/2019	3.61	<4.0
Non soluble substances	(%)		0.58	≤1.5
Sulfate Content (as SO_3)	(%)		2.31	≤2.5 if C_3A ≤3.5 ≤2.5 if C_3A ≥3.5
Tricalcium aluminates (C_3A)	(%)		2.68	≤3.5
Magnesium oxide (MgO)	(%)		1.79	≤5.0
Chloride content	(%)		0.04	≤0.1
Physical requirement				
Finesse (blaine)	(m^2/kg)	IQS 5/2019	344	≥300
Initial setting time	(min)		149	≥45
Final setting time	(h)		3:21	≤10
Soundness (expansion)-Le Chatle	(mm)		0.32	≤10
Compressive strength is not less than (MN/m^2)	2 days		24.3	≥20
	28 days		47.5	≥42.5

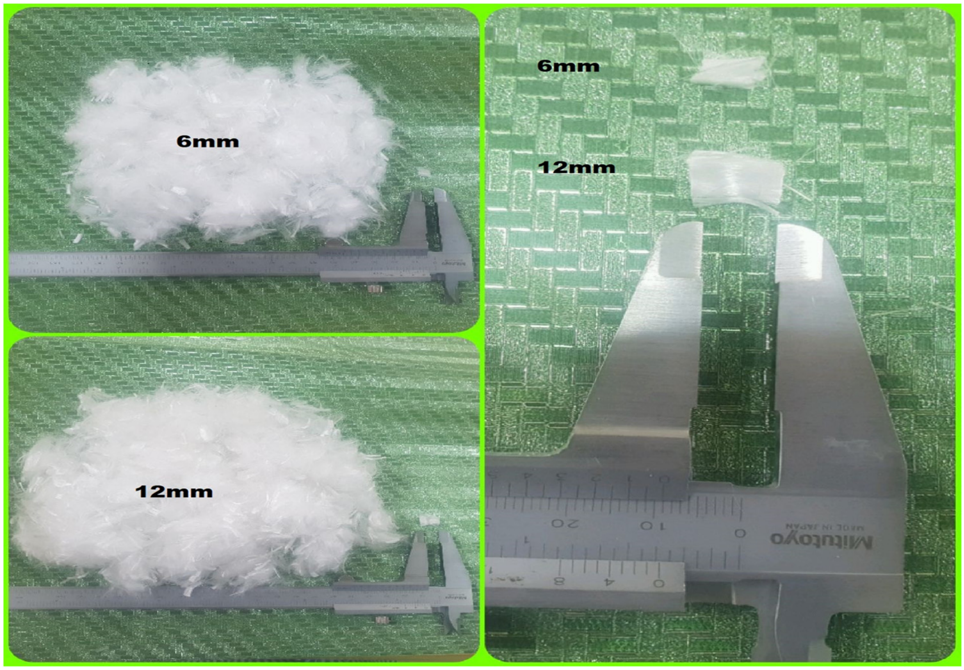

Figure 4: Photos of 6 and 12 mm PPF.

Table 4: Basic properties of 6 and 12 mm PPF

Form	100% Virgin polypropylene fiber
Specific gravity	0.91 g/cm^3
Diameter	0.02–0.052 mm
Alkali content	Nil
Sulfate content	Nil
Chloride content	Nil
Elasticity modulus	3,500–4,800 MPa
Tensile strength	350 N/mm^2
Melting point	160–170°C
Ignition point	590°C
Cement compatibility	Excellent

from DCP test data. The DCP penetration distance per drop is the DCPI. The CBR has been determined according to the equation which the US Army Corps of Engineers recommended and used.

$$\text{CBR}(\%) = \frac{292}{(\text{DCPI})^{1.12}} \quad (1)$$

where DCPI denotes dynamic cone penetration index (mm/blow).

Over time, a number of relationships for different types of soils' bearing strength metrics have been found.

Table 5: Summary of soil mix proportions

Soil mixture	Cement (%)	Fiber (%)
Natural soil (NS)	0	0
SS-2.5% C	2.5	—
SS-2.5% C + 0.5% 6F	2.5	0.5
SS-2.5% C + 1% 6F	2.5	1
SS-2.5% C + 2% 6F	2.5	2
SS-2.5% C + 0.5% 12F	2.5	0.5
SS-2.5% C + 1% 12F	2.5	1
SS-2.5% C + 2% 12F	2.5	2
SS-5% C	5	—
SS-5% C + 0.5% 6F	5	0.5
SS-5% C + 1% 6F	5	1
SS-5% C + 2% 6F	5	2
SS-5% C + 0.5% 12F	5	0.5
SS-5% C + 1% 12F	5	1
SS-5% C + 2% 12F	5	2

SS is defined as stabilized sand soil. C is defined as Portland cement. F is defined as polypropylene fiber.

According to the correlations were used to solve the following equation to determine bearing capacity:

$$q = (3.794 \times \text{CBR}^{0.664})144, \quad (2)$$

where q denotes the bearing capacity (kPa) and CBR denotes the California bearing ratio (%).

Figure 5: Method to prepare a soil sample.

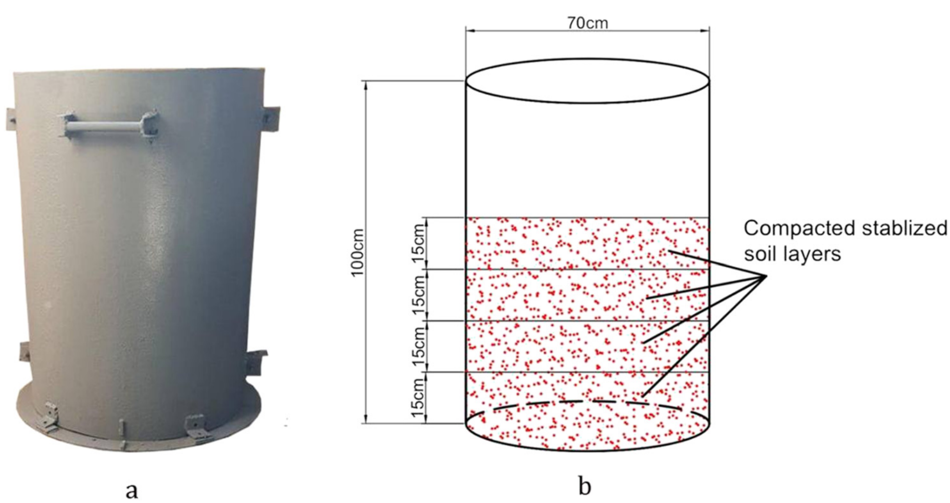

Figure 6: (a) Cylindrical mold. (b) A sketch of the cylindrical mold showing the thickness of the compacted layers.

2.6 Sand replacement method (SRM) test

Based on ASTM D1556, the SRM, as shown in Figure 8 is a test technique used to figure out soil's field density and moisture content (MC). This approach can be used with soils that include no appreciable amounts of rock or coarse substances larger than 1.5 inches (38 mm). This approach is also suitable for organic, saturated, or highly plastic soils.

3 Results and discussion

3.1 Density and MC of stabilized soils

Sand replacement tests were performed as shown in Figure 8 to calculate the natural and stabilized subgrade soils' MC and dry density (DD). The findings of these tests are

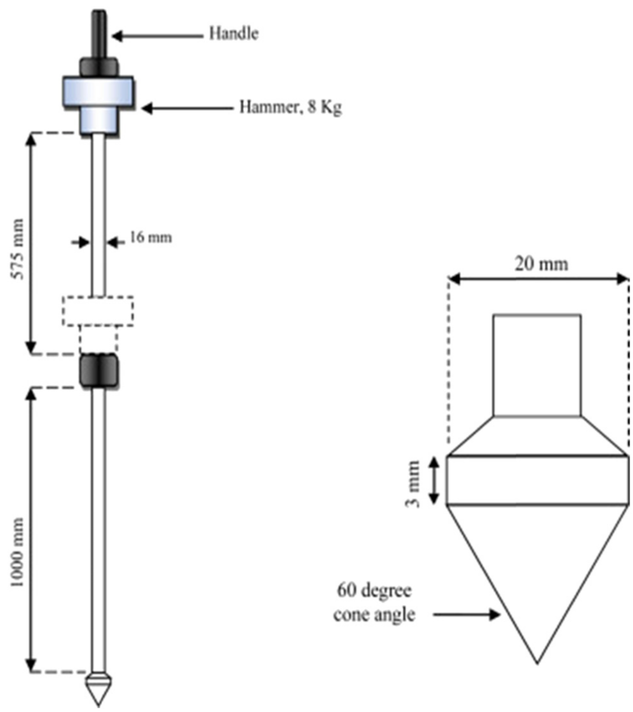

Figure 7: DCP [17].

summarized in Table 6. The MDD value for the natural subgrade soil increased from 2.01 to 2.07 and 2.13 g/cm^3 with the addition of 2.5 and 5% of Portland by weight of dry soil, respectively. The results showed that the MDD of the cemented sand mixture increased with the addition of Portland cement at both ratios. This is consistent with the results of Choobbasti et al. [35], who discovered that Portland cement undergoes the chemical process of hydration when combined with soil and water, creating calcium silicate hydrate (C–S–H) gel. This gel forms a strong link

Table 6: MDD and water content values of natural and stabilized subgrade

Cement content (%)	Fiber length (mm)	Fiber content (%)	Water content (%)	MDD (g/cm^3)
0	—	0	6.23	2.01
2.5	—	0	4.75	2.07
2.5	6	0.5	5.72	2.03
2.5	6	1	6.08	2.01
2.5	6	2	6.56	1.85
2.5	12	0.5	5.62	2.05
2.5	12	1	5.99	2.03
2.5	12	2	6.47	1.90
5	—	0	4.31	2.13
5	6	0.5	5.27	2.08
5	6	1	5.85	2.04
5	6	2	6.35	1.97
5	12	0.5	4.94	2.11
5	12	1	5.45	2.07
5	12	2	6.22	2.01

Figure 8: Sand replacement test.

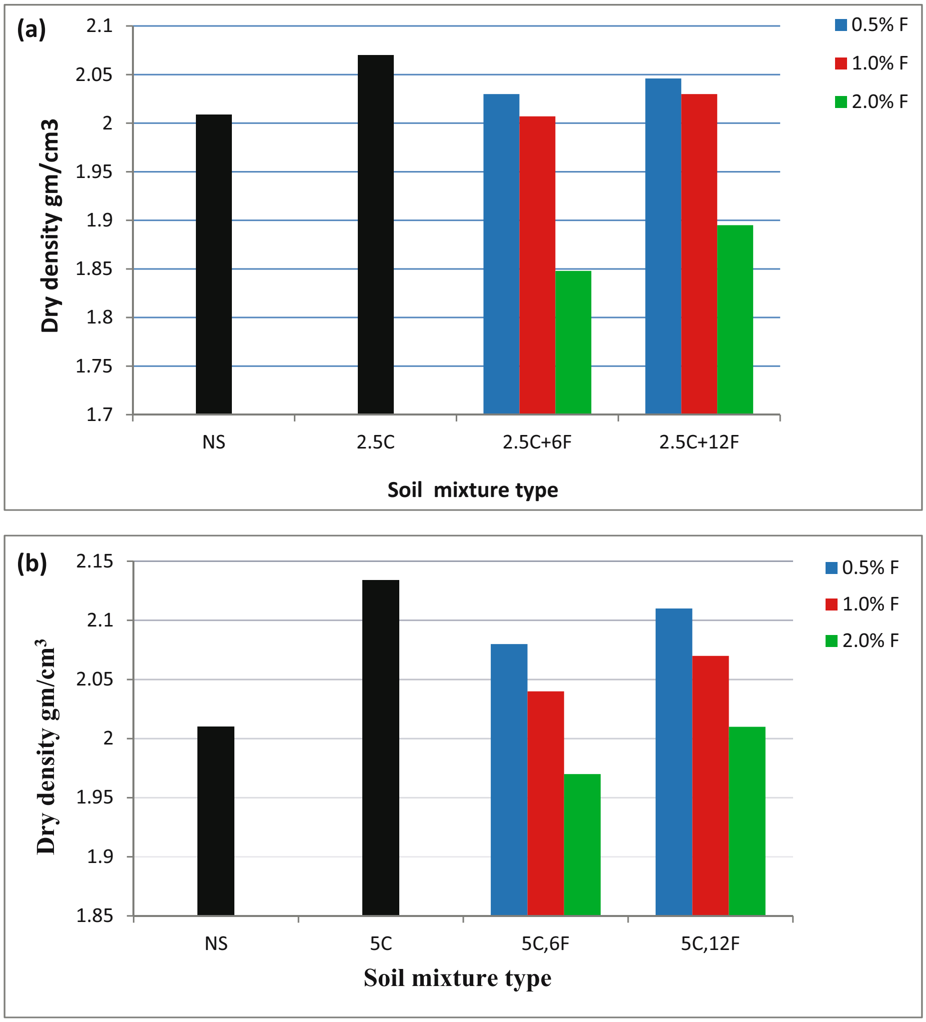

Figure 9: (a) MDD variations caused by adding 2.5% cement and different percentages of discrete fiber. (b) MDD variations caused by adding 5% cement and different percentages of discrete fiber.

between the soil and cement by filling in the pore spaces and creating solid and stable particles, leading to an increase in the strength and stiffness of the cemented sand mixture.

The MDD decreased gradually from 2.07 to 2.03, 2.01, and 1.85 g/cm^3 and from 2.13 to 2.08, 2.04, and 1.97 g/cm^3 after adding 6 mm PPFs with content levels of 0.5, 1, and 2% by weight of the dry soil to the cemented sand mixture at all ratios. Also, it decreased gradually from 2.07 to 2.05, 2.03, and 1.9 g/cm^3 and from 2.13 to 2.11, 2.07, and 2.01 g/cm^3 when adding 12 mm PPFs with content levels of 0.5, 1, and 2% by weight of the dry soil to the cemented sand mixture at all ratios. This reduction might be attributed to the reason that polypropylene fiber has an overall unit weight less than the unit weight of the soil. When natural sandy soil was stabilized with 2.5 and 5% of Portland cement by weight of dry soil, the OMC declined continuously from 6.23 to 4.75 and 4.31%. The findings show that as cement content rose, the OMC decreased. This could be because the cement particles combine with the soil's water to generate solid blocks that bind the soil granules together. As a result, the soil becomes denser and the number of empty areas decreases, and thus the MC that the soil needs to reach the maximum density decreases.

The OMC of the cemented sand mixture with 2.5% Portland cement increased gradually when reinforcing the mixture by adding 6 mm PPF with content levels of 0.5, 1, and 2% by weight of dry soil, and it reached 5.72, 6.08, and 6.56%, respectively, and it reached 5.62, 5.99, and 6.47% when reinforcing cemented sandy soil with 2.5% of cement by adding 12 mm PPF with content levels of 0.5, 1, and 2% by weight of dry soil, respectively. In addition, the OMC reached 5.27, 5.85, and 6.35% for the cemented sand mixture with 5% Portland cement when reinforcing the mixture by adding 6 mm PPF with content levels of 0.5, 1, and 2% by weight of dry soil, and it reached 4.94, 5.45, and 6.22% for the cemented sand mixtures with the same percentage of cement by adding 12 mm discrete fiber with content levels of 0.5, 1, and 2%, respectively.

The findings indicated that the optimum water content of the mixture increases gradually with the increase in PPF content at all ratios. In addition, the results showed that the 12 mm of PPF has a higher density and lower water content than the 6 mm PPF. Figure 9(a) and (b) displays the MDD for the cemented sand mixture using 2.5 and 5% Portland cement with/without 6 and 12 mm of PPF with content levels of 0, 0.5, 1, and 2% by weight of dry soil, respectively.

3.2 DCP tests results

The findings of the DCP test are explained in Table 7. The DCP test results indicated that the DCPI value for NS was 9 mm/blow. After adding Portland cement at a rate of 2.5% by the weight of dry soil, the DCPI value decreased to 2.36 mm/blow. The findings showed that Portland cement addition decreases DCPI compared to the NS results. It may be that when Portland cement is added to the soil, it reacts with the water present in the soil and forms a cementitious material. This material fills the voids in the soil and binds the particles together, strengthening the soil. As a result, the DCPI decreases indicating that the soil has become

Table 7: Summary of DCP test results

Cement content (%)	Fiber length (mm)	Fiber content (%)	DCPI (mm/blow)	CBR (%)	Bearing capacity (kPa)
0	—	0	9	25.16	222
2.5	—	0	2.36	119	620
2.5	6	0.5	2.6	107	578
2.5	6	1	3.6	74	456
2.5	6	2	5.3	48	342
2.5	12	0.5	2.5	113	598
2.5	12	1	3.2	87	502
2.5	12	2	4.5	55	375
5	—	0	1.77	187	825
5	6	0.5	1.96	154	692
5	6	1	2.5	114	603
5	6	2	3.1	93	523
5	12	0.5	1.93	167	766
5	12	1	2.3	121	628
5	12	2	2.70	101	557

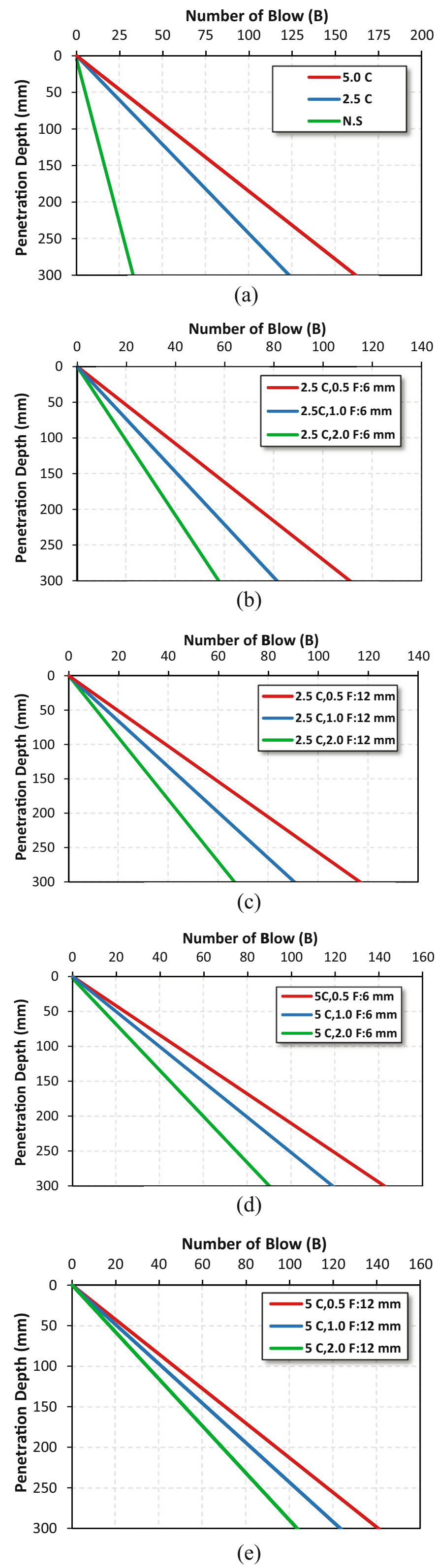

Figure 10: Number of blows values variations with depth. (a) NS, SS-2.5&5C, (b) SS-2.5C:6F, (c) SS-2.5C:12F, (d) SS-5C:6F, and (e) SS-5C:12.

stronger. For soil stabilized using 5% Portland cement content, the value of DCPI is 1.77 mm/blow. The findings indicated that the increase in cement content from 2.5 to 5% led to a decrease in DCPI. It is probably because the density of the mixture increased after the amount of cement was increased. Figure 10(a) displays the continuous blows for the DCP test with depth for NS and cemented sand with 2.5 and 5% Portland cement.

The values of DCPI were 2.6, 3.6, and 5.3 mm/blow for subgrade stabilized using 2.5% Portland cement content and 6 mm PPF with content levels of 0.5, 1, and 2%, respectively. Similarly, the study also investigated the effect of using 12 mm PPFs with content levels of 0.5, 1, and 2% in combination with 2.5% Portland cement for soil stabilization, where the findings of DCPI were 2.5, 3.2, and 4.5 mm/blow, respectively. The findings indicated that the values of

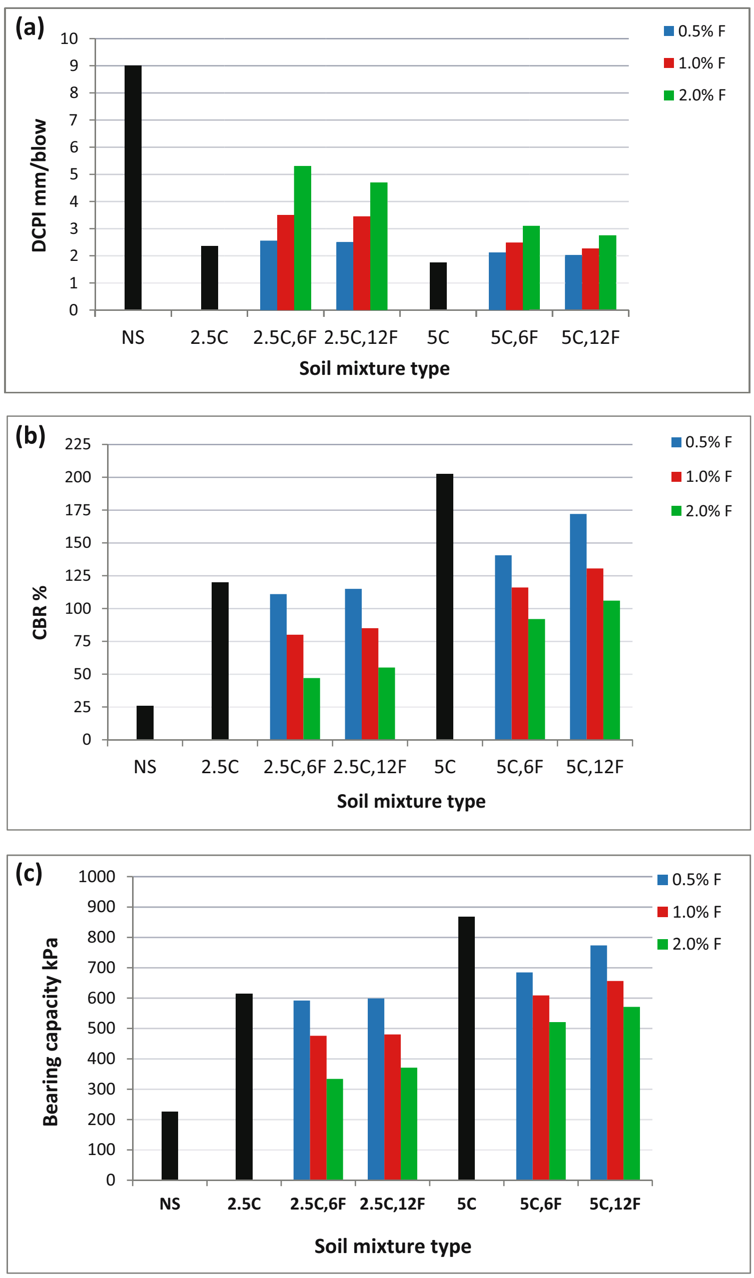

Figure 11: (a) DCPI value variations caused by adding different percentages of cement and discrete fiber. (b) CBR value variations caused by adding different percentages of cement and discrete fiber. (c) Bearing capacity value variations caused by adding different percentages of cement and discrete fiber.

DCPI increased gradually after reinforcing the cemented sand with polypropylene fiber.

After stabilizing the soil using 5% Portland cement and reinforced with 6 mm PPF with content levels of 0.5, 1, and 2%, the DCPI values were 1.96, 2.5, and 3.1 mm/blow, respectively. Finally, for soil stabilized using 5% Portland cement and reinforced with 12 mm PPF with content levels of 0.5, 1, and 2%, the DCPI values were 1.93, 2.3, and 2.7 mm/blow, respectively. Figure 10(b)–(e) displays the continuous blows for the DCP test with depth for different percentages of cement and discrete fiber.

In addition, two parameters were calculated from DCPI: CBR *in situ* and bearing capacity. For NS, the results showed that the CBR value was 25.16%, while the bearing capacity was 226 kPa. After stabilizing soils using 2.5% Portland cement by the weight of dry soil, the results showed that the CBR value increased from 25.16 to 119%, while the bearing capacity increased from 222 to 620 kPa. For soil stabilized using 5% Portland cement content, the CBR value was 187%, while the bearing capacity value was 825 kPa. The findings indicated that the increase in cement content from 2.5 to 5% led to increased CBR and bearing capacity. The findings showed that Portland cement addition enhances the soil's CBR and bearing capacity. These improvements can be attributed to the formation of cementitious compounds that bind the soil particles together, resulting in a stronger and more stable soil matrix.

For subgrade stabilized using 2.5% Portland cement content and a 6 mm PPF with content levels of 0.5, 1, and 2%, the CBR values were 107, 74, and 48%, while the bearing capacity values were 578, 456, and 342 kPa, respectively. For soil stabilized using 2.5% Portland cement content and 12 mm PPF with content levels of 0.5, 1, and 2%, the CBR values were 113, 87, and 55%, while the bearing capacity values were 598, 502, and 375 kPa, respectively. The findings indicated that the values of CBR and bearing capacity decreased gradually after reinforcing the cemented sand with PPF.

In addition, after reinforced soil using 5% Portland cement with 6 mm PPF with content levels of 0.5, 1, and 2%, the CBR values were 154, 114, and 93%, while the bearing capacity values were 692, 603, and 523 kPa, respectively. Finally, for soil stabilized using 5% Portland cement with 12 mm PPF with content levels of 0.5, 1, and 2%, the CBR values were 167, 121, and 101%. In contrast, the bearing capacity values were 766, 628, and 557 kPa, respectively.

It is clear from this that adding PPF to the cemented sand mixture with content levels of 0.5 to 1% and then 2% caused an increase in DCPI and a decrease in CBR and bearing capacity. This may be due to the incomplete bonding of the cement particles with the soil grains due to the irregular distribution of the fibers into the cemented sand mixture. In addition, the results demonstrated that the 12 mm PPF could significantly improve soil qualities compared to the 6 mm PPF. It might be due to the fact that the longer fibers appear to provide the soil with more support than the shorter, discrete fibers. This is because longer fibers can interlock more tightly and stretch greater distances into the cemented sand mixture, resulting in good load distribution. Figure 11(a)–(c) explains the changes in DCPI, CBR, and bearing capacity by adding cement and fiber.

4 Conclusions

The following conclusions were drawn from testing done on cemented sand mixtures with/without discrete fiber for various parameters:

1) The DCPI value of the natural subgrade soil tends to decrease with the addition of 2.5% Portland cement by weight of the dry ground, and the value continues to decline with increasing cement content until it reaches the minimum value when stabilized soil using 5% of Portland cement by weight of the dry ground.
2) Adding PPF to the cemented sand mixture gradually leads to an increase in the DCPI value. For sand stabilized using 2.5 and 5.0% Portland cement by weight of dry soil, when 6 and 12 mm PPF content increases from 0.5 to 1 and 2%, the DCPI value increases gradually until it reaches the maximum value at the discrete fiber content of 2%.
3) CBR increases when natural subgrade soil is stabilized using 2.5% Portland cement by dry soil weight, and when cement content is increased from 2.5 to 5%, the CBR value is approximately increased by 60%.
4) The addition of PPF to the cemented sand mixture causes a gradual decrease in CBR and bearing capacity values. For sand stabilized using 2.5 and 5.0% Portland cement by weight of dry soil, when 6 and 12 mm PPF content increases from 0.5 to 1 and 2%, the CBR and bearing capacity values decrease gradually until they reach a minimum value at fiber content 2%.
5) Adding 2.5% of Portland cement by the weight of dry soil to the natural subgrade causes an increase in bearing capacity. When increasing cement content from 2.5 to 5%, the bearing capacity rises approximately 35%.
6) The DCPI value for a 12 mm fiber is lower than that for 6 mm fibers. At the same time, CBR and bearing capacity for a 12 mm fiber is greater than those for 6 mm fibers for all rates. Therefore, discrete fibers with a length of

12 mm tend to give the soil more support than 6 mm discrete fibers.

7) The DCP test is a valuable method for assessing the strength properties of stabilized soils.

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