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Mechanical Properties of Black-Cotton Soil Stabilized with Recycled Concrete Dust

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Abstract:

Black-cotton soils (BCS) impose significant challenges in geotechnical and pavement engineering due to their tendency to undergo large volumetric changes, leading to structural failures of subgrade layer. Stabilization is essential to improve their mechanical properties of these soils, but traditional stabilizers such as cement and lime contribute to higher carbon emissions. Hence, this study aimed for the use of recycled concrete dust (RCD), a waste by-product of concrete demolition, as a sustainable alternative for soil stabilization. The primary objective is to evaluate the effectiveness of RCD in enhancing the mechanical properties of BCSs, including compaction characteristics, unconfined compressive strength (UCS), California bearing ratio (CBR) and shear properties. In the present study, two-types of black cotton soils (low and high-compressible clay soils) were collected and stabilized with RCD2 (with maximum size of 2.36 mm) and RCD3 (with maximum size of 4.75 mm) at a dosage of 0, 5, 10, 15, 20 and 25% by weight of soil. Further, the study evaluated the influence of potable water and bore-well water on the mechanical properties of these soils. The experimental outcomes from the CBR, UCS, and triaxial tests reveal that increasing amounts of recycled concrete dust (RCD2 and RCD3) notably improved the load-bearing capacity, unconfined compressive strength, and shear strength of both CH (highly compressible) and CL (low compressibility) soils. Using potable water generally provided superior results compared to bore-well water, indicating that water quality plays a role in further optimizing the stabilization process. These results underscore the potential of recycled concrete dust as an effective soil stabilizer, supporting the development of sustainable and robust infrastructure solutions for expansive and weak soils.

Keywords: Recycled concrete dust, stabilization, black-cotton soil, potable water, bore well water, strength, triaxial test, shear properties

1. Introduction

In India, expansive soils, commonly known as black cotton soils, cover nearly 800,000 square kilometres across the states of Madhya Pradesh, Andhra Pradesh, Maharashtra, Gujarat, Rajasthan, Telangana, and Jharkhand (Uppal and Chadda, 1967; Kumar et al., 2007). When the soil at a particular location is unable to offer the required stability and functionality for a proposed structure, designers have several remedial options to address the issue. These include: (a) avoiding the problematic site altogether; (b) modifying the foundation design to better accommodate the soil conditions; (c) removing the unsuitable soil and replacing it with a stronger, non-expansive material, such as murrum; or (d) improving the existing soil through ground modification techniques to enhance its properties, ensuring it can meet the structural performance criteria.

Black cotton soils, exhibit significant volumetric changes due to moisture variations, causing serious challenges for civil engineering and infrastructure projects. These soils dilate when exposed to moisture and shrink upon drying, a behavior typically driven by seasonal variations in climate. The volume instability in expansive soils arises from a combination of geotechnical and environmental factors, including mineralogical composition, clay content, soil fabric, moisture content, bulk density, pore water chemistry, and applied loading conditions (Seed and Lundgren, 1962; Nelson and Miller, 1997; Muttharam, 2000; Otcovska and Padevet, 2016). However, the presence of specific clay minerals, such as montmorillonite, is the primary cause of this expansive behavior (Katti, 1979).

Montmorillonite is a phyllosilicate mineral with two silica tetrahedral sheets sandwiching an alumina octahedral sheet. The tetrahedral and octahedral sheets generally share oxygen atoms and hydroxyl ions, forming a cohesive but reactive structure. The charge imbalance within the montmorillonite lattice and the weak Van der Waals forces between adjacent silica sheets allow for easy infiltration of water molecules and exchangeable cations into the interlayer spaces (Holtz et al., 1981). As water enters these spaces, the interlayer expands, resulting in significant swelling. Conversely, during drying, water exits the layers, leading to extensive shrinkage and settlement. The higher the clay content and montmorillonite proportion in the soil, the greater the degree of swelling and shrinkage. This cycle is particularly problematic in regions with distinct wet and dry seasons, where repeated swelling and contraction can severely compromise the structural integrity of overlying infrastructure.

The cyclic volume changes caused by moisture variations induce considerable stresses in the soil matrix, which are transmitted to overlying structures. This is especially problematic for lightly loaded structures or those with rigid foundations. Typical issues arising from expansive soils include cracking of walls, differential settlement, upheaval of floors, pavement heaving, fractures in slab-on-grade structures, and damage to critical infrastructure such as canal linings, irrigation networks, roads, railways, and underground utility systems (Chen, 1988; Ito and Azam, 2013). The repetitive nature of the damage requires frequent repairs and maintenance, often resulting in costs that far exceed the original construction expenditures. For example, Ito and Azam (2013) reported that an 850 km underground pipeline with a fracture rate of 0.27 breaks per kilometer per year can incur annual maintenance costs exceeding $2 million.

Past studies reported the damage caused by expansive soils which is equivalent to 0.15 billion dollars in the UK, 1 billion dollars in the USA, and over 4 million dollars in South Africa (Gourley et al., 1993). In Saudi Arabia, the swelling-related damage to buildings and pavements between 1977 and 1987 amounted to over $0.3 billion (Al-Rawas and Qamaruddin, 1998. Buhler and Cerato (2007) projected that in the USA, when adjusted for inflation and population growth, annual losses from expansive soils could exceed $15 billion. Jones and Holtz (1973) suggested that, in some years, the economic losses due to shrink-swell damage might surpass those from other natural disasters such as earthquakes, floods, tornadoes, and hurricanes which highlights the pervasive and often underestimated impact of expansive soils on infrastructure, as well as the enormous costs associated with their mitigation.

2. Objective

The chemical stabilizers such as lime, cement, calcium-based stabilizers can lead to high carbon footprint and increased stabilization cost, hence, it is necessary to employ sustainable stabilizers such as recycled concrete dust (RCD). It facilitates the utilization of waste material obtained through demolition of concrete structures. Further, the pre-processing or crushing of recycled concrete is not required the technical knowledge of stabilization. It is easy to separate the fines having more useful cementitious binder from the coarse recycled concrete. Further, no study is present is available on evaluating the black-cotton soils stabilized with RCD. Hence, the present study is focused on evaluating the index and mechanical properties of RCD stabilized black cotton soils.

Figure 1. Recycled concrete dust with a maximum size of 1.18 mm (left) and 2.36 mm (right)

3. Methodology

In the present study, it is proposed to evaluate the influence of recycled concrete dust as a stabilization agent on the mechanical properties of black cotton soils. Firstly, two types of expansive soils were collected and the corresponding index properties were evaluated. Secondly, the compaction characteristics such as maximum dry density (MDD) and corresponding optimum moisture content (OMC) of the collected soil samples mixed and compacted with potable water (PW) and bore-well water (BWW) and were evaluated as per Indian Standard codal provisions IS:2720 (part-8) 1983. In addition, the California bearing ratio (CBR) and unconfined compressive strengths of these two soil samples stabilized with recycled concrete dust with a maximum size of 1.18 mm and 2.36 mm (as shown in figure 1). The recycled concrete dust having maximum size of 0.6 mm was discarded and RC2 (< 1.18 mm) and RCD3 (2.36mm), was further used for the stabilization. A dosage of 0, 5, 10, 15, 20 and 25% by weight of soil sample was considered. The methodology used in the present article is illustrated in the figure 2. Finally, the shear properties of the stabilized soils were evaluated using monotonic tri-axial tests with a confining pressure ranging between 10-30 kPa.

Figure 2. Proposed methodology for evaluating the mechanical properties of RCD stabilized clayey soils

4. Soil Properties and Compaction Characteristics

Table 1 provides the geotechnical properties of two soil samples, soil-1 and soil-2. Soil-1 has a significantly higher liquid limit (61.8%) compared to Soil-2 (30.6%), indicating high compressibility. Similarly, the other index properties are also presented in the table 1. According to the Unified Soil Classification System (USCS), Soil-1 is classified as high plasticity clay (CH), whereas Soil-2 is classified as low plasticity clay (CL). These differences highlight that Soil-1 is more expansive and plastic, while Soil-2 has lower plasticity and swell potential**.**

Table 1. Basic Properties of collected soils

Soil Property	Soil-1	Soil-2
Liquid Limit (%)	61.8	30.6
Plastic Limit (%)	22.4	16.2
Plasticity Index (%)	39.4	14.4
Free-Swelling Index (%)	68.2	41.6
Soil-Class	CH	CL

Table 2. Moisture-Density Relation for soil-1 (CH)

S.No	Bore Well Water		Potable Water	
	Water content (%)	Dry Density (g/cc)	Water content (%)	Dry Density (g/cc)
1	14.6	1.668	14.3	1.671
2	19.3	1.691	19.6	1.696
3	24.6	1.723	24.6	1.729
4	29.6	1.747	28.5	1.759
5	34.6	1.726	33.6	1.731
6	39.1	1.672	39.4	1.686

Table 3. Moisture-Density Relation for soil-2 (CL)

S.No	Bore Well Water		Potable Water	
	Water content (%)	Dry Density (g/cc)	Water content (%)	Dry Density (g/cc)
1	4.7	1.696	4.8	1.722
2	9.8	1.733	9.7	1.739

3	14.3	1.768	14.1	1.789
4	19.3	1.719	19.7	1.728
5	24.6	1.661	23.7	1.681
6	29.4	1.603	28.9	1.621

Tables 2 and 3 show the moisture-density relationships for Soil-1 (CH) and Soil-2 (CL) using both bore well and potable water. For Soil-1, the dry density increases with water content, reaching a peak of 1.747 g/cc at 29.6% water content with bore well water, and 1.759 g/cc at 28.5% with potable water, before declining at higher water contents. Similarly, for Soil-2, the maximum dry density occurs at 14.3% water content with bore well water (1.768 g/cc) and 14.1% with potable water (1.789 g/cc), followed by a decrease in dry density as water content rises. In both soils, potable water consistently yields slightly higher dry densities than bore well water at similar moisture levels.

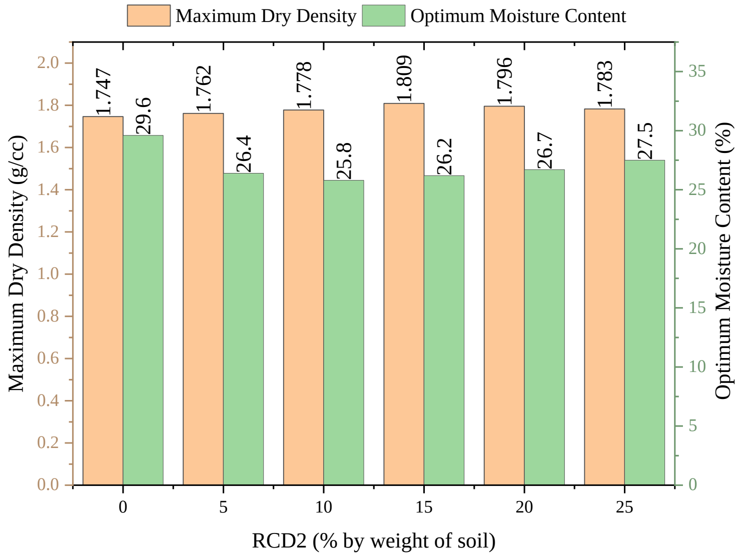

Figure 3. Influence of RCD2 dosage on compaction characteristics of soil-1 (CH) with Bore well water

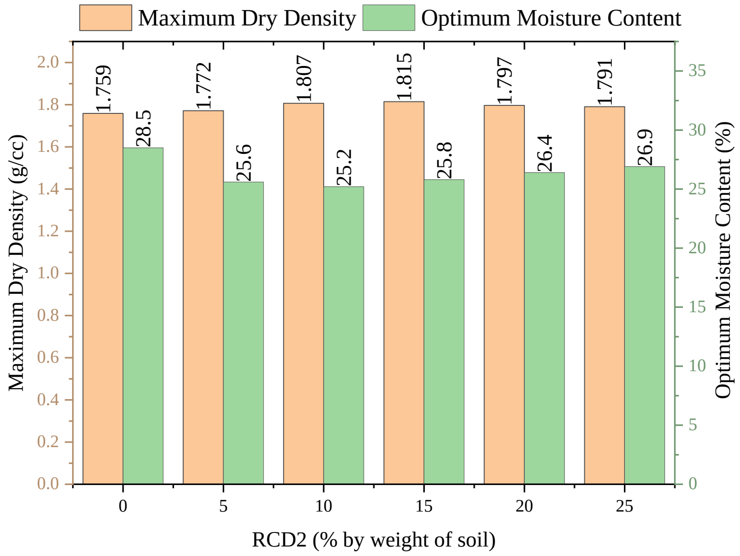

Figure 4. Influence of RCD2 dosage on compaction characteristics of soil-1 (CH) with potable water

Figure 3-6 illustrate a comparison of the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for soil samples treated with Recycled Concrete Dust with maximum size of 2.36 mm (RCD2) at varying percentages by weight of the soil, using two types of water: bore-well water and potable water. In this case, the MDD and OMC values increased with the RCD content up to 15%, after which they decreased. The use of bore-well water yielded slightly lower MDD values compared to potable water. However, the trends in OMC remained consistent between the two water types, with a general decrease in OMC as the RCD percentage increased. In the stabilized soil with RCD (particles <2.36 mm), the MDD values showed a more consistent increase as RCD content increased, while the OMC decreased in both water types. The differences between the impact of water types on MDD and OMC were minimal, suggesting that the addition of RCD improved soil compaction properties, regardless of the water source.

For high compressibility clay (CH), the MDD values started at 1.747 g/cc and increased up to 1.809 g/cc at 15% RCD, before slightly decreasing with higher percentages. The OMC values started high at 29.6% and generally decreased as RCD2 content increased, reaching 25.8% at 15% RCD. This pattern showed that CH soils had a higher moisture demand and lower maximum dry density, particularly at lower RCD2 contents. In contrast, low compressibility clay (CL) showed higher MDD values from the beginning, starting at 1.768 g/cc and reaching a maximum of 1.821 g/cc at 15% RCD2, followed by a slight reduction. The OMC values in CL soils started much lower at 14.3%, and consistently decreased as the RCD2 content increased, reaching as low as 12.6% at 15% RCD2. This indicated that CL soils, even with RCD2 treatment, had a lower moisture requirement and higher compaction potential compared to CH soils. In overall, CL soils achieved higher compaction and required less moisture, while CH soils retained more moisture and compacted to a lesser degree, showing a more pronounced effect of RCD2 treatment on CL soils.

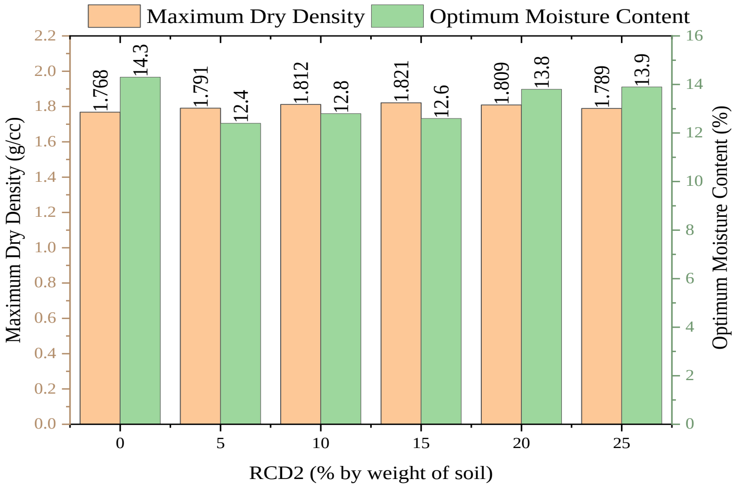

Figure 5. Influence of RCD2 dosage on compaction characteristics of soil-2 (CL) with Bore well water

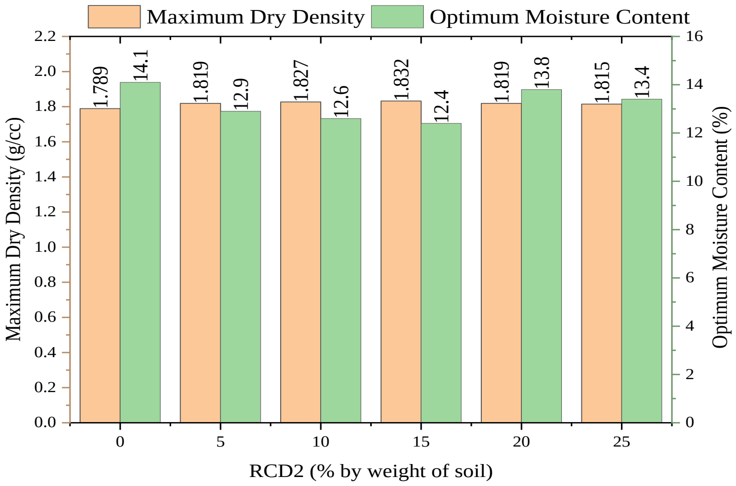

Figure 6. Influence of RCD2 dosage on compaction characteristics of soil-2 (CL) with potable water

The results (illustrated in figure 3-6) show that recycled concrete dust (RCD3) had a significant impact on the compaction properties of both high compressible clay (CH) and low compressible clay (CL). For CH soil, the MDD increased with RCD3 content, peaking at 15% RCD3 for both bore-well and potable water. MDD values reached 1.798 g/cc with bore-well water and 1.821 g/cc with potable water at 15% RCD3, after which they slightly declined at higher RCD3 contents. The OMC, however, decreased consistently as RCD3 increased, indicating that CH soils required less moisture as more RCD3 was added, with OMC values reducing from 29.6% to 25.2% (bore-well water) and 28.5% to 24.9% (potable water). This suggests that RCD3 optimized the compaction behaviour of CH soils by increasing their density and reducing moisture needs, but only up to a certain percentage (15%).

Similarly, CL soil responded well to RCD3 stabilization, with MDD peaking at 1.824 g/cc (bore-well water) and 1.843 g/cc (potable water) at 15% RCD3. The OMC also showed a consistent decrease as RCD3 content increased, dropping from 14.3% to 12.1% (bore-well water) and 14.1% to 12.1% (potable water). Overall, CL soils achieved higher MDD values and lower OMC compared to CH soils, indicating that they compacted better with less moisture. Potable water slightly improved the compaction results for both CH and CL soils compared to bore-well water, resulting in higher MDD and lower OMC. This demonstrates that CL soils benefited more from RCD3 stabilization, achieving higher compaction with lower moisture content, while CH soils required more moisture and reached lower densities.

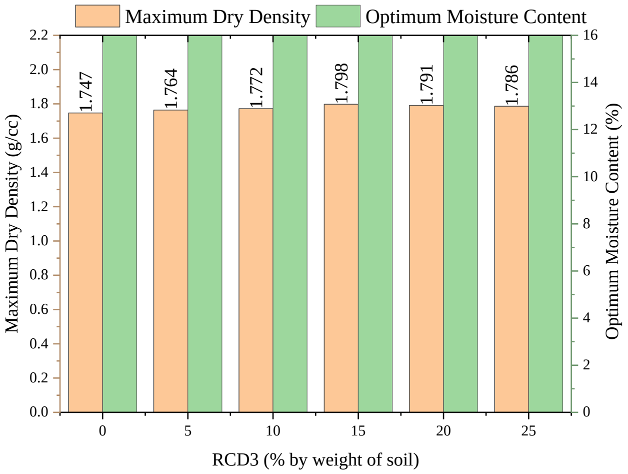

Figure 7. Influence of RCD3 dosage on compaction characteristics of soil-1 (CH) with Bore well water

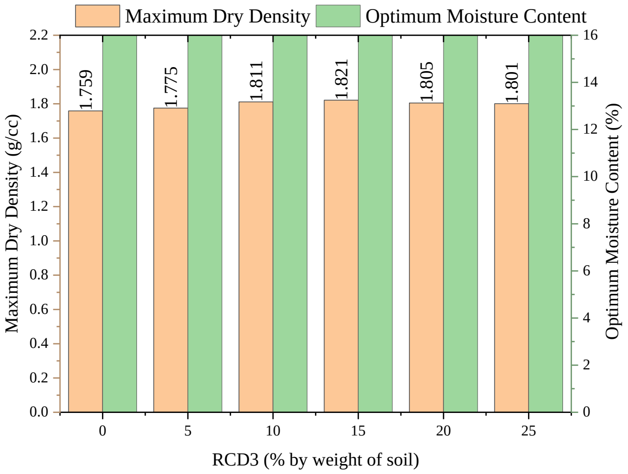

Figure 8. Influence of RCD3 dosage on compaction characteristics of soil-1 (CH) with Potable water

The effect of different percentages of Recycled Concrete Dust (RCD3) with a maximum aggregate size of 4.75 mm on the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of stabilized Soil-1 (CH) using both bore well and potable water is presented in figure 7-8. For bore well water, the MDD increased from 1.747 g/cc at 0% RCD3 to a peak of 1.798 g/cc at 15%, then slightly decreased to 1.786 g/cc at 25%. The OMC decreased from 29.6% at 0% to 25.2% at 15%, and raised again to 27.4% at 25%. Similarly, with potable water, the MDD raised from 1.759 g/cc at 0% to 1.821 g/cc at 15%, before dropping slightly to 1.801 g/cc at 25%. The OMC followed a similar trend, decreasing from 28.5% to 24.9% at 15%, and increasing to 25.9% at 25%. Overall, potable water yielded slightly higher MDD values than bore well water, with both water types showing improved density and reduced moisture content with increasing RCD3, attributed to enhanced compaction and changes in soil structure.

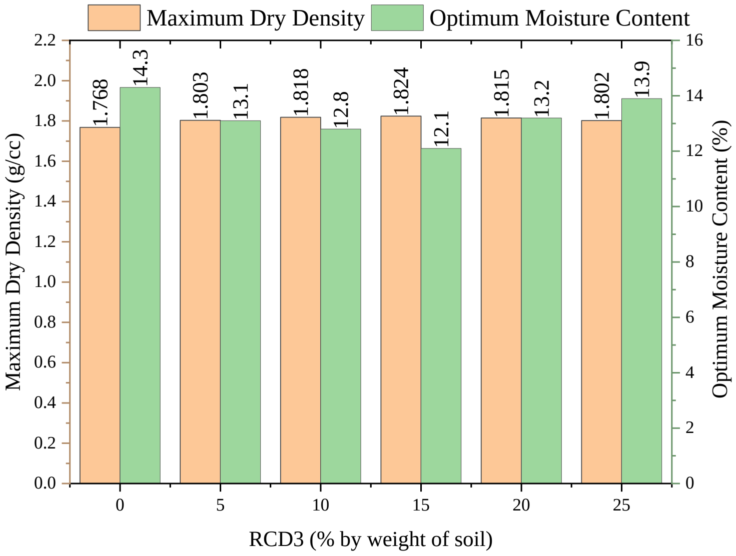

Table 9. Influence of RCD3 dosage on compaction characteristics of soil-2 (CL) with Bore well water

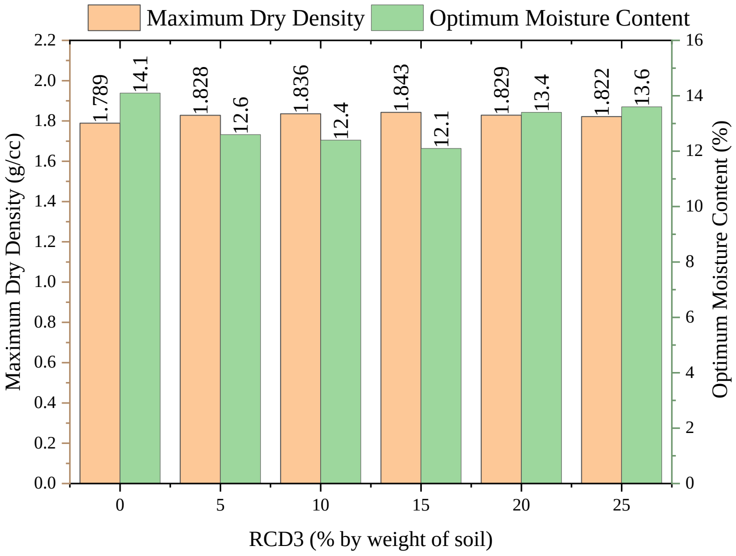

Figure 10. Influence of RCD3 on compaction characteristics of soil-2 with Potable water

For bore well water, the MDD initially increased from 1.768 g/cc at 0% RCD3 to a peak of 1.824 g/cc at 15%, then decreased slightly to 1.802 g/cc at 25%. The OMC decreased from 14.3% at 0% to 12.1% at 15%, before rising again to 13.9% at 25%. Similarly, when using potable water, the MDD increased from 1.789 g/cc at 0% to 1.843 g/cc at 15%, followed by a slight reduction to 1.822 g/cc at 25%. The OMC followed a comparable pattern, decreasing from 14.1% at 0% to 12.1% at 15%, and rising to 13.6% at 25%. Overall, the results showed that potable water led to higher MDD values than bore well water, with both water types reflecting improved density and reduced moisture requirements as RCD3 content increased, likely due to enhanced compaction and structural modification of the soil (figure 9-10).

5. California Bearing Ratio

This section presents the influence of RCD dosage on CBR of two soil samples prepared with RCD at a dosage of 0-25% with corresponding optimum water contents. Tables 4 and 5 show the effect of different dosages of Recycled Concrete Dust (RCD2) on the California Bearing Ratio (CBR) of Soil-1 (CH) using bore well water and potable water, respectively. In both cases, the CBR values for 2.5 mm and 5.0 mm penetration steadily increase as the RCD2 content is raised from 0% to 25%. For bore well water, the CBR starts at 1.5 and 1.4 at 0% RCD2, reaching 3.5 and 3.3 at 25%. Similarly, with potable water, CBR increases from 1.9 and 1.7 to 4.1 and 3.9 at the same dosages, showing a higher improvement with potable water. The key observation is that adding RCD2 improves the soil's strength, as reflected by the rise in CBR values. This is due to RCD2 filling the soil's voids and triggering pozzolanic reactions, forming cementitious compounds that enhance stability. Potable water yields slightly better results than bore well water, possibly due to fewer impurities affecting the stabilization process.

Table 4. Influence of RCD2 dosage on CBR of soil-1 (CH) with Bore Well Water

RCD2 (% by weight of soil)	Bore Well Water	
	CBR 2.5	CBR 5.0
0	1.5	1.4
5	2.2	2.1
10	2.4	2.2
15	2.8	2.6
20	3.2	3.1
25	3.5	3.3

Table 5. Influence of RCD2 dosage on CBR of soil-1 (CH) with Potable Water

RCD2 (% by weight of soil)	Potable Water	
	CBR 2.5	CBR 5.0
0	1.9	1.7
5	2.6	2.3
10	3.2	3.1
15	3.5	3.3
20	3.9	3.6
25	4.1	3.9

Table 6. Influence of RCD2 dosage on CBR of soil-2 (CL) with Bore Well water

RCD2 (% by weight of soil)	Bore Well Water	
	CBR 2.5	CBR 5.0
0	2.4	2.1
5	3.1	2.7

10	3.4	3.1
15	3.6	3.4
20	3.8	3.6
25	4.5	4.1

Table 7. Influence of RCD2 dosage on CBR of soil-2 (CL) with Potable water

RCD2 (% by weight of soil)	**Potable Water**	
	CBR 2.5	**CBR 5.0**
0	2.8	2.3
5	3.6	12.9
10	4.1	12.6
15	4.3	4.1
20	4.6	4.3
25	4.8	4.7

Tables 6 and 7 present the effect of Recycled Concrete Dust (RCD2) dosage on the California Bearing Ratio (CBR) of Soil-2 (CL) using bore well water and potable water. In both cases, increasing the RCD2 content from 0% to 25% led to a consistent improvement in CBR values for both 2.5 mm and 5.0 mm penetration. With bore well water, CBR increased from 2.4 to 4.5 (for 2.5 mm) and from 2.1 to 4.1 (for 5.0 mm). For potable water, CBR values were slightly higher, starting at 2.8 and rising to 4.8 for 2.5 mm, and increasing from 2.3 to 4.7 for 5.0 mm, indicating better soil strength when potable water was used.

Table 8. Influence of RCD3 dosage on CBR of soil-1 (CH) with Bore Well Water

RCD3 (% by weight of soil)	**Bore Well Water**	
	CBR 2.5	**CBR 5.0**
0	1.5	1.4
5	2.4	2.2
10	2.8	2.6
15	3.6	3.3
20	4.3	4.1
25	4.5	4.3

Table 9. Influence of RCD3 dosage on CBR of soil-1 (CH) with Potable Water

RCD3 (% by weight of soil)	**Potable Water**	
	CBR 2.5	**CBR 5.0**
0	1.9	1.7
5	2.9	2.7
10	3,4	3.1

15	3.9	3.6
20	4.2	3.8
25	4.4	4.1

Tables 8 and 9 illustrate the influence of varying dosages of Recycled Concrete Dust (RCD3) on the California Bearing Ratio (CBR) of Soil-1 (CH) when mixed with both bore well water and potable water. In Table 8, using bore well water, the CBR values increase from 1.5 for 0% RCD3 to 4.5 at 25% RCD3 for a 2.5 mm penetration, while the CBR for a 5.0 mm penetration shows a similar trend, starting at 1.4 and reaching 4.3. This indicates a substantial improvement in the soil's load-bearing capacity with the addition of RCD3. In Table 9, the same trend is observed with potable water, where the CBR begins at 1.9 and 1.7 for 0% RCD3 and rises to 4.4 and 4.1 at 25% RCD3, respectively. These results highlight the effectiveness of RCD3 in enhancing the strength of Soil-1 under both types of water, with slightly higher values observed when using potable water.

Table 10. Influence of RCD3 dosage on CBR of soil-2 (CL) with Bore Well Water

RCD3 (% by weight of soil)	**Bore Well Water**	
	CBR 2.5	**CBR 5.0**
0	2.4	2.1
5	3.4	3.2
10	3.7	3.5
15	4.2	4.1
20	4.5	4.3
25	4.8	4.5

Table 11. Influence of RCD3 dosage on UCS of soil-2 (CL) with Bore Well Water

RCD3 (% by weight of soil)	**Potable Water**	
	CBR 2.5	**CBR 5.0**
0	2.8	2.3
5	3.8	3.6
10	4.4	4.2
15	4.7	4.5
20	5.1	4.8
25	5.4	5.1

Tables 10 and 11 focus on the impact of RCD3 on Soil-2 (CL) with bore well and potable water, respectively. In Table 10, for Soil-2 mixed with bore well water, the CBR starts at 2.4 and 2.1 for 0% RCD3, showing a consistent increase to 4.8 and 4.5 at 25% RCD3 for 2.5 mm and 5.0 mm penetration levels. This signifies a notable enhancement in the soil's strength due to the incorporation of RCD3. In Table 11, the results for Soil-2 with potable water indicate that the CBR values improve from 2.8 and 2.3 at 0% RCD3 to 5.4 and 5.1 at 25% RCD3. Overall, the findings from both tables suggest that the addition of RCD3 significantly enhances the CBR of Soil-2, with potable water again resulting in higher strength improvements compared to bore well water. This reinforces the role of RCD3 as an effective stabilizing agent for both soil types, enhancing their load-bearing capacities under various conditions.

6. Unconfined Compressive Strength

The influence of recycled concrete dust on unconfined compressive strength of black-cotton soil is presented in the figure 11-12. For Soil-1 (CH), as the percentage of RCD2 increased from 0% to 25%, there was a notable enhancement in CBR values for both types of water. In the case of bore well water, the CBR for a 2.5 mm penetration rose from 1.5 to 3.5, while the 5.0 mm penetration increased from 1.4 to 3.3. Similarly, with potable water, the CBR values began at 1.9 and 1.7 for 0% RCD2 and climbed to 4.1 and 3.9 at 25%, indicating that the addition of RCD2 significantly improved the load-bearing capacity of Soil-1 (Figure 11).

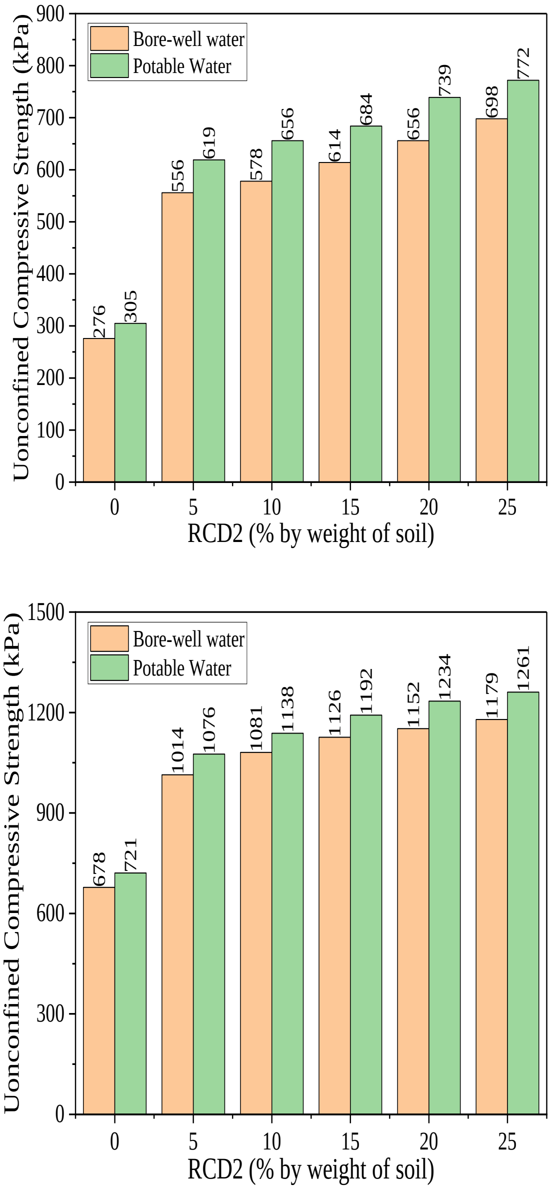

Figure 11. Influence of RCD2 dosage on UCS of soil-type of CH (left) and CL (right)

In the case of Soil-2 (CL), the trend remained consistent. The CBR values also rose significantly with increasing RCD2 dosage. With bore well water, the CBR increased from 2.4 and 2.1 for 0% RCD2 to 4.5 and 4.1 at 25% RCD2 for 2.5 mm and 5.0 mm penetrations, respectively. When using potable water, the CBR started at 2.8 and 2.3 and improved to 4.8 and 4.7 at the maximum dosage (Figure 12). The substantial improvements in CBR for both soil types confirmed that RCD2 was an effective stabilizing agent, enhancing the soil's strength and load-bearing capabilities regardless of the water type used. Notably, while both soil types showed improved performance, Soil-1 (CH) with potable water achieved the highest CBR values overall, indicating that the type of water used may have further influenced the effectiveness of RCD2 stabilization.

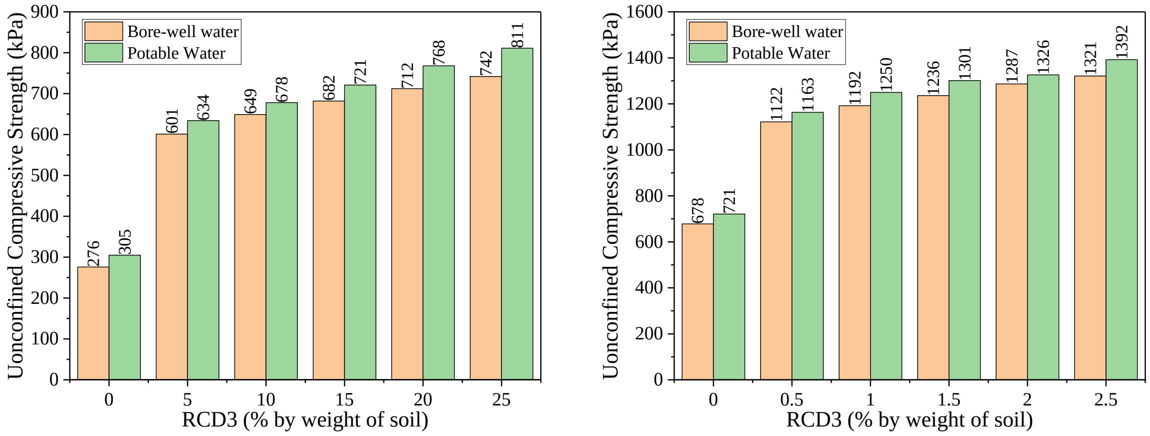

Figure 12. Influence of RCD3 dosage on UCS of soil-type of CH (left) and CL (right)

7. Triaxial tests on Recycled Concrete Dust stabilized black cotton soils

The results presented in Figure 13-14 illustrated the significant impact of recycled concrete dust (RCD2) on the peak deviatoric stress of both soil types, Clay soil (CH) and silty-clay soil (CL), under different confining pressures (σ_3) and using both bore well and potable water. For soil-1 (CH) with bore well water, the peak deviatoric stress values showed a marked increase from 291 kPa at 0% RCD2 to 832 kPa at 25% RCD2 for a confining pressure of 10 kPa. Similarly, the data for σ_3 at 20 kPa and 30 kPa exhibited comparable upward trends, reaching peak values of 869 kPa and 916 kPa, respectively. When using potable water, the peak deviatoric stress also increased substantially, starting from 346 kPa and attaining a maximum of 863 kPa at 25% RCD2 under σ3 of 10 kPa. The results indicated that the addition of RCD2 significantly enhanced the stress-bearing capacity of the soil, demonstrating improved performance under both types of water.

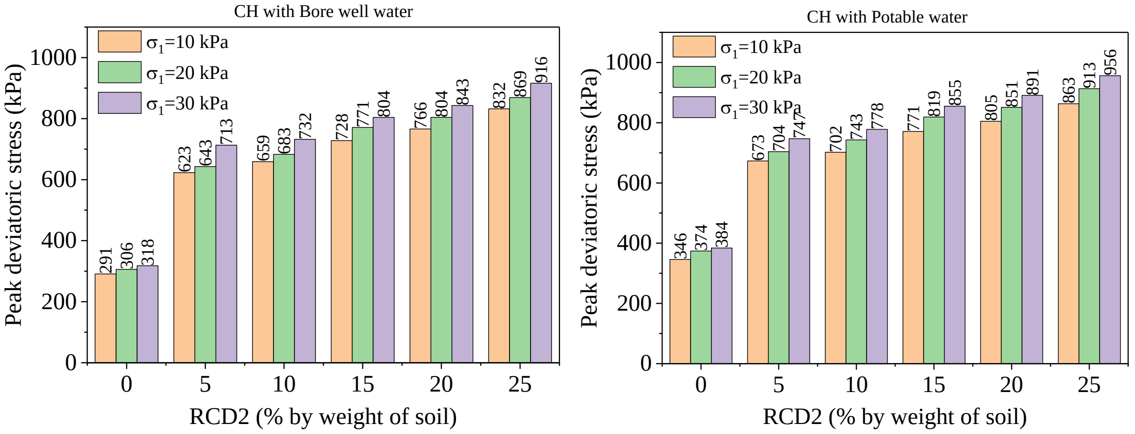

Figure 13. Influence of RCD2 dosage on Peak Deviatoric Stress of soil-1 (CH) with Bore Well Water (left) and Potable Water (right)

In the case of soil-2 (CL), the influence of RCD2 was even more pronounced, especially with bore well water, where peak deviatoric stress values escalated dramatically from 726 kPa at 0% RCD2 to 2422 kPa at 25% RCD2 under σ_3 of 10 kPa. Similar patterns were observed for the higher confining pressures, where stress values reached up to 2575 kPa. With potable water, the initial peak deviatoric stress of 781 kPa increased to 2372 kPa at 25% RCD2 for σ_3 of 10 kPa, with significant improvements at higher pressures as well. The results conclusively demonstrated that RCD2 served as an effective soil stabilizer, enhancing the load-bearing capacity and mechanical properties of both soil types. The substantial increases in peak deviatoric stress confirmed the potential for RCD2 to improve the performance of expansive soils, making it a valuable resource in geotechnical applications.

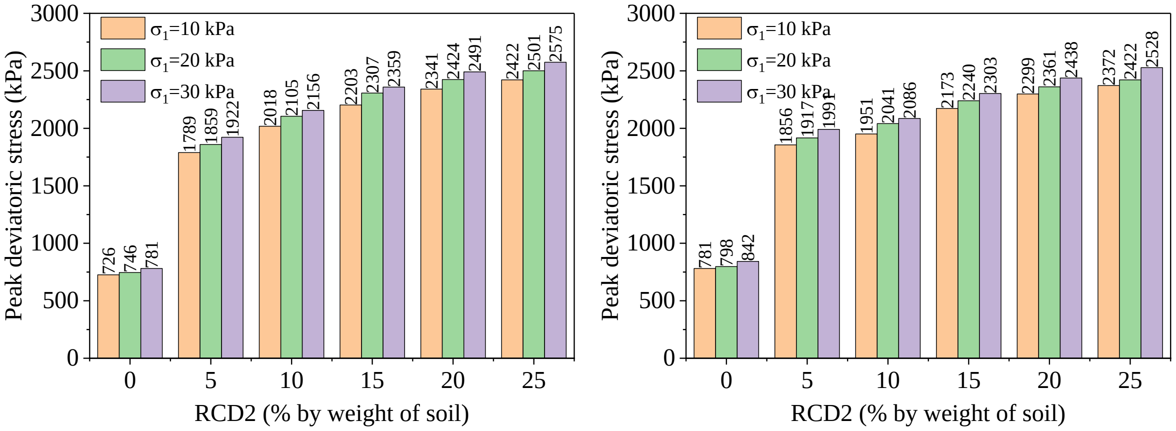

Figure 14. Influence of RCD2 dosage on Peak Deviatoric Stress of soil-2 (CL) with Bore Well Water (left) and Potable Water (right)

The results demonstrated a clear influence of RCD2 dosage on the shear properties of both CH (high compressibility clay) and CL (low compressibility clay) soils when treated with borewell and potable water. For CH soil with borewell water, the friction angle increased from 16.0° at 0% RCD2 to 21.9° at 25% RCD2, while cohesion also improved from 59.4 kPa to 76.6 kPa. Similarly, CH soil treated with potable water showed a rise in the friction angle from 17.1° to 22.4°, with cohesion increasing from 64.4 kPa to 72.7 kPa. These results indicate that the addition of RCD2 enhanced the shear strength of CH soil, with both friction angle and cohesion improving progressively as RCD2 content increased. Potable water slightly outperformed bore-well water in terms of increasing the friction angle and cohesion, suggesting that it helped optimize the stabilization effects of RCD2 on CH soil (Figure 15).

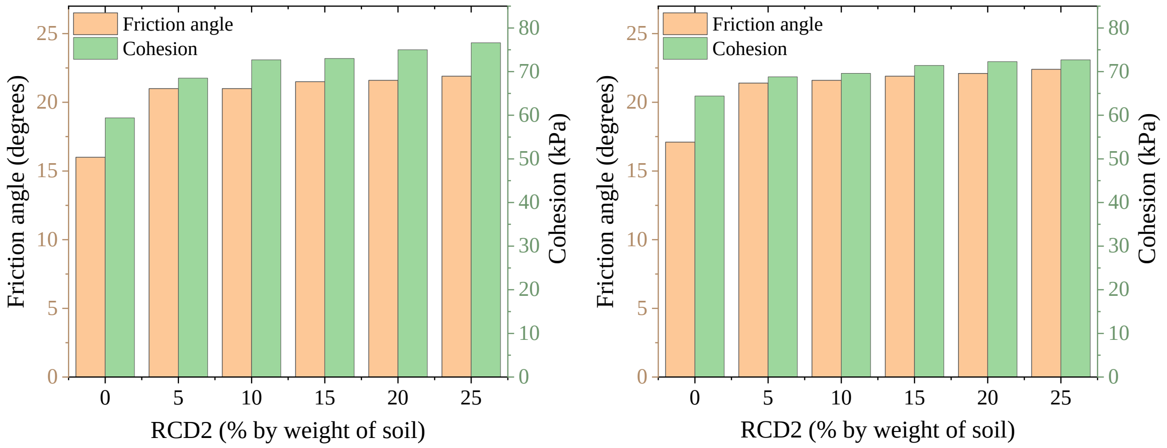

Figure 15. Influence of RCD2 dosage on shear properties of soil-1 (CH) with Bore Well Water (left) and Potable water (right)

For CL soil, a more significant improvement in shear properties was observed with both borewell and potable water. With borewell water, the friction angle increased from 19.8° at 0% RCD2 to 23.9° at 25% RCD2, while cohesion improved from 97.3 kPa to 135.8 kPa. CL soil treated with potable water showed a similar trend, with the friction angle rising from 19.8° to 23.6° and cohesion increasing from 105.4 kPa to 145.9 kPa as RCD2 content increased. These results confirmed that RCD2 substantially improved the shear strength of CL soil, with potable water leading to slightly higher cohesion values compared to borewell water. In conclusion, RCD2 dosage significantly enhanced the shear properties of both CH and CL soils, with CL soils exhibiting greater improvement in cohesion and friction angle. The use of potable water further optimized these enhancements, especially in CL soil, leading to higher shear strength values (Figure 16).

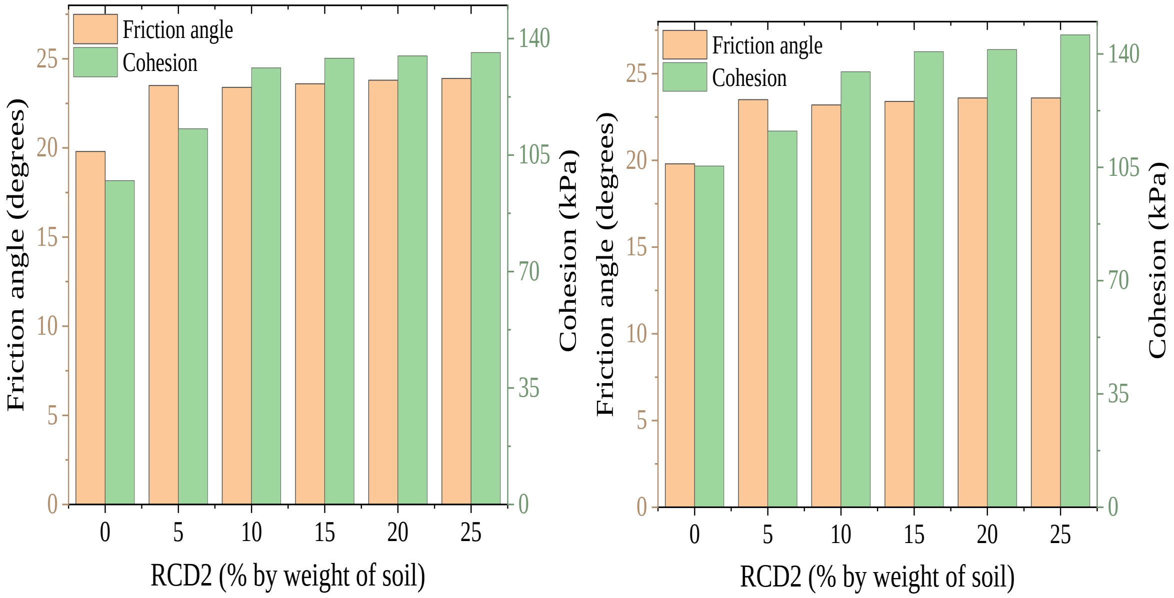

Figure 16. Influence of RCD2 dosage on shear properties of soil-2 (CL) with Bore Well Water (left) and Potable water (right)

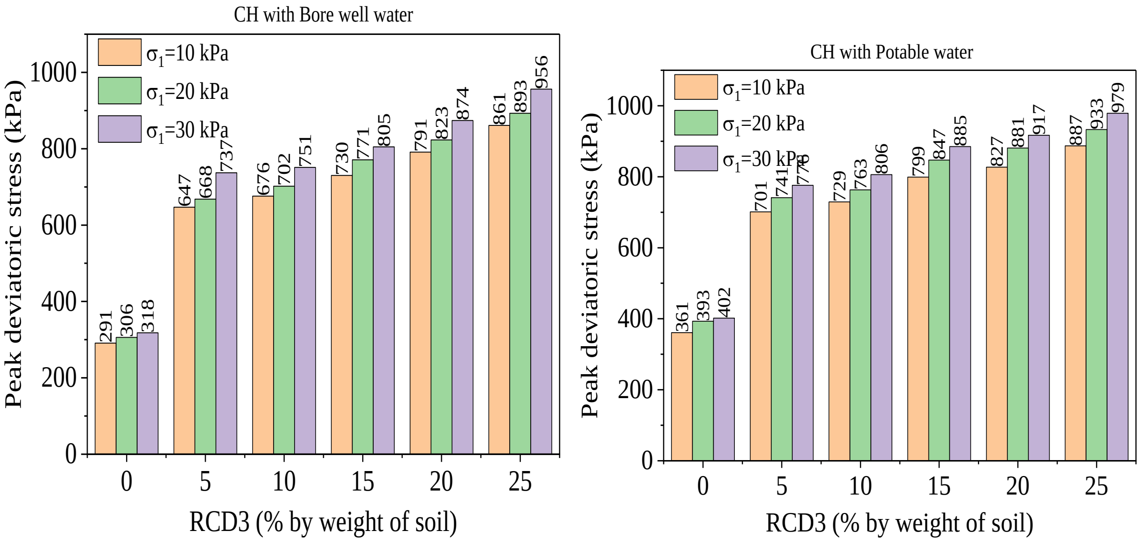

Figure 17. Influence of RCD3 dosage on Peak Deviatoric Stress of soil-1 (CH) with Bore Well Water (left) and Potable Water (right)

The results revealed that increasing RCD3 dosage had a significant effect on the peak deviatoric stress of CH (high compressibility clay) soil treated with both bore-well and potable water under varying confining pressures (σ_3 = 10, 20, and 30 kPa). For CH soil with bore-well water, the peak deviatoric stress at σ3 = 10 kPa increased from 291 kPa at 0% RCD3 to 861 kPa at 25% RCD3. A similar trend was observed at higher confining pressures, where the peak deviatoric stress rose from 306 to 893 kPa at σ_3 = 20 kPa and from 318 to 956 kPa at σ_3 = 30 kPa. In the case of potable water, the stress values were consistently higher compared to bore-well water. For instance, at σ_3 = 10 kPa, the peak deviatoric stress increased from 361 kPa at 0% RCD3 to 887 kPa at 25% RCD3. Similar improvements were noted for σ_3 = 20 and 30 kPa, where the peak deviatoric stress rose from 393 to 933 kPa and from 402 to 979 kPa, respectively (Figure 17). These results indicate that the addition of RCD3 substantially improved the deviatoric stress capacity of CH soil, with potable water producing slightly higher stress values compared to bore-well water.

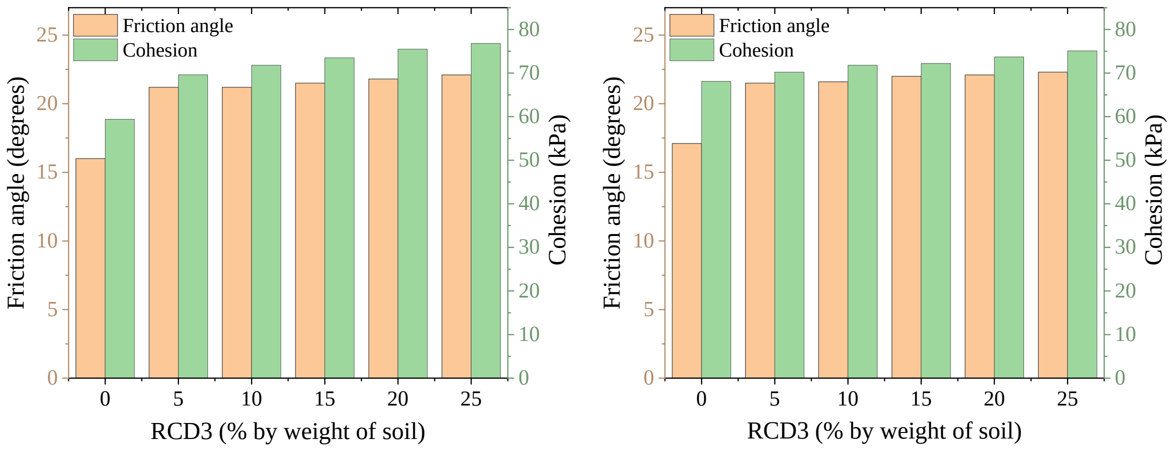

Figure 18. Influence of RCD3 dosage on shear properties of soil-1 (CH) with Bore Well Water (left) and Potable water (right)

The influence of RCD3 on the shear properties of CH soil was also evident in terms of friction angle and cohesion. For CH soil treated with bore-well water, the friction angle increased from 16.0° at 0% RCD3 to 22.1° at 25% RCD3, while cohesion improved from 59.4 kPa to 76.8 kPa. The trend was similar when potable water was used, where the friction angle increased from 17.1° to 22.3° and cohesion from 68.1 kPa to 75.1 kPa over the same range of RCD3 dosages (Figure 18). These results suggest that RCD3 improved the shear strength of CH soil, with both friction angle and cohesion showing steady increments as the dosage increased. Potable water had a slightly stronger effect on enhancing cohesion compared to bore-well water, but overall, both water types demonstrated that RCD3 addition significantly enhanced the shear properties of CH soil, particularly at higher dosages.

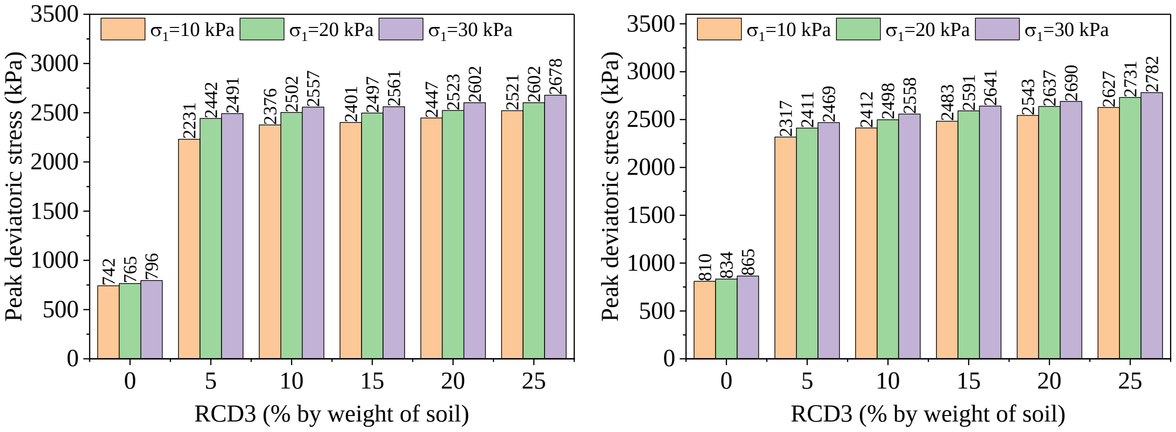

Figure 19. Influence of RCD3 dosage on Peak Deviatoric Stress of soil-2 (CL) with Bore Well Water (left) and Potable Water (right)

The results showed that increasing RCD3 dosage had a considerable effect on the peak deviatoric stress of CL (low compressibility clay) soil treated with both bore-well and potable water across various confining pressures (σ_3 = 10, 20, and 30 kPa). For CL soil with bore-well water, the peak deviatoric stress increased significantly from 742 kPa at 0% RCD3 to 2521 kPa at 25% RCD3 under σ_3 = 10 kPa. Similar patterns were observed at σ_3 = 20 kPa, where the peak stress increased from 765 to 2602 kPa, and at σ3 = 30 kPa, rising from 796 to 2678 kPa. Potable water produced slightly higher peak deviatoric stress values across all RCD3 dosages. For instance, at σ_3 = 10 kPa, the peak deviatoric stress increased from 810 kPa at 0% RCD3 to 2627 kPa at 25% RCD3, with similar increments observed at σ_3 = 20 and 30 kPa, where the stress rose from 834 to 2731 kPa and from 865 to 2782 kPa, respectively. These findings suggest that RCD3 significantly improved the deviatoric stress-bearing capacity of CL soil, with potable water consistently producing slightly better results compared to bore-well water (Figure 19).

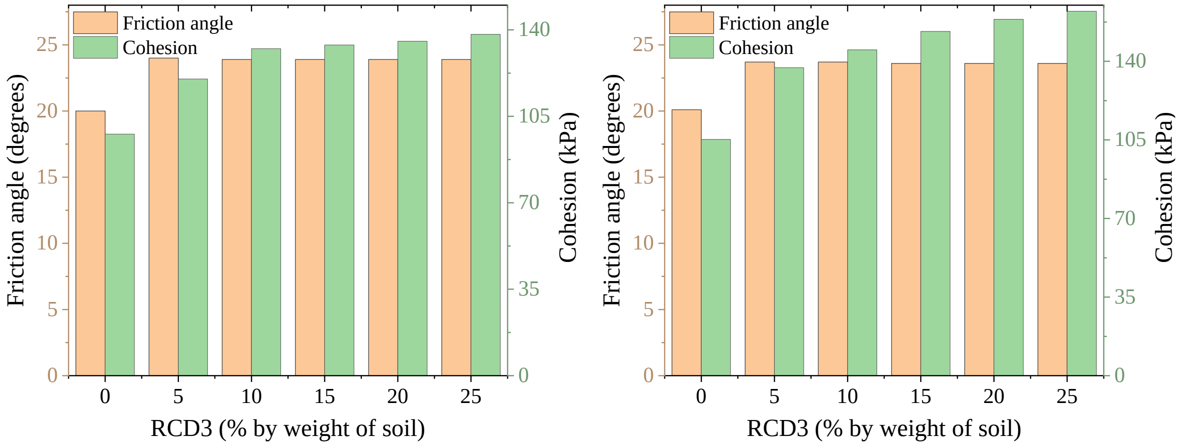

Figure 20. Influence of RCD3 dosage on shear properties of soil-2 (CL) with Bore Well Water (left) and Potable water (right)

In terms of shear properties, RCD3 dosage had a notable effect on the friction angle and cohesion of CL soil. For bore-well water, the friction angle increased from 20.0° at 0% RCD3 to 23.9° at 25% RCD3, while cohesion improved substantially from 97.8 kPa to 138.2 kPa over the same dosage range. With potable water, the friction angle showed a similar trend, remaining relatively stable around 23.7° to 23.6°, while cohesion increased from 105.2 kPa at 0% RCD3 to 162.3 kPa at 25% RCD3. The results indicate that RCD3 greatly enhanced the shear properties of CL soil, especially in terms of cohesion, with potable water yielding slightly higher cohesion values than bore-well water. Both water types demonstrated that increasing RCD3 dosage consistently improved the overall strength of the CL soil (Figure 20).

Conclusions:

The experimental results obtained from the CBR, UCS, and triaxial tests highlight those increasing dosages of recycled concrete dust (RCD2 and RCD3) significantly enhanced the load-bearing capacity, unconfined compressive strength, and shear strength of both CH (high compressibility) and CL (low compressibility) soils. Potable water generally yielded better results compared to bore-well water, suggesting that water quality may further optimize the stabilization process. These findings confirm the effectiveness of recycled concrete dust as a soil stabilizer, promoting sustainable and durable infrastructure solutions for expansive and weak soils.

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