

# Improvement of Silts and Clays Soil Stabilized with Cement, Coarse Aggregate, and Chemical Additives from the Laboratory to the Field

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**Abstract** In many infrastructure projects, existing subgrade soils often fail to meet engineering standards, particularly silts and clays, which exhibit high swelling potential and low strength. To address these deficiencies, stabilization using cement, coarse aggregates, and chemical additives is necessary. This study investigates the combined effects of cement, coarse aggregate, and chemical additives on the improvement of soil properties, both in laboratory and field applications. The experimental program included California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), and swelling tests conducted under soaked and unsoaked conditions at 7 and 28 days. Two types of field trials were implemented: (1) cement and chemical additive combinations applied on a 25 m test section, and (2) extended road applications up to 19 km using varying dosages of cement, chemical additives, and coarse aggregates. The results indicate that cement and chemical additives significantly increased CBR and UCS values while reducing swelling potential. The findings demonstrate that cement combined with chemical additives can effectively replace coarse aggregates as a stabilizer, providing an economical and environmentally friendly solution for expansive soil stabilization.

**Keywords** Soil-Stabilization, Cement, Chemical-

Additive, Coarse-Aggregate, CBR, UCS, Swelling

## 1. Introduction

Soil serves as the foundation for various infrastructure projects, including buildings, bridges, highways, and dams. However, certain soil types, such as soft soils, expansive clays, and dispersive soils, pose significant geotechnical challenges due to their high swelling potential, differential settlement, and reduced shear strength upon water exposure [1], [2], [3]. These problems can compromise structural performance, increase maintenance costs, and reduce the long-term durability of infrastructure [4], [5], [6]. To address these challenges, stabilization techniques have been widely adopted, including the use of lime, fly ash, or cement, which are known to improve soil workability and strength [7], [8], [9]. Chemical stabilization, in particular, modifies soil characteristics by mixing additives with the soil to enhance durability, strength, and volume stability [10], [11]. Other approaches involve the use of industrial by-products and chemical additives that can further improve soil engineering properties and provide

sustainable alternatives [11], [12], [13]. Cement stabilization provides improved stiffness and compressive strength by filling voids and binding soil particles [14], [15].

Nevertheless, cement production presents serious environmental drawbacks, as it is highly energy-intensive and contributes significantly to greenhouse gas emissions, releasing approximately 1 ton of CO<sub>2</sub> for every ton of cement produced. This process also accelerates natural resource depletion and produces dust pollution from manufacturing plants [16], [17], [18]. Similarly, coarse aggregate stabilization, although effective in enhancing soil properties, faces sustainability concerns due to limited material availability, high transportation costs, and environmental degradation caused by quarrying and extraction activities [19], [20], [21]. These issues highlight the importance of exploring alternative and more sustainable stabilization methods.

This study, therefore, focuses on the combined use of cement, chemical additives, and coarse aggregates in stabilizing problematic soils. The primary objectives are threefold: (1) to evaluate the individual and combined performance of cement and chemical additives in improving soil strength and reducing swelling; (2) to assess whether cement–chemical additive combinations can serve as a viable substitute for coarse aggregates; and (3) to validate laboratory findings through field-scale applications to ensure practical feasibility. By addressing these objectives, the study not only contributes to the scientific understanding of soil stabilization mechanisms but also provides practical implications for achieving sustainable, cost-effective, and environmentally responsible solutions for infrastructure development.

## 2. Materials and Methods

### 2.1. Materials

The natural soil used in this study was classified as MH–CH under the Unified Soil Classification System (USCS). It consists of inorganic silts, micaceous or diatomaceous fine soils, and high-plasticity clays (fat clays). Table 1 summarizes the basic geotechnical properties of the soil.

**Table 1.** Properties of natural soil

Property	Value
Liquid limit (%)	63
Plastic limit (%)	30.27
Plasticity index (%)	32.73
Optimum moisture content (%)	19
Maximum dry density (g/cc)	1.70
USCS Group Symbol	MH–CH

Chemical additives consisted of polymer-based powder, while coarse aggregates were sourced locally from Riau, Indonesia. The materials used in this study, including the natural soil, Ordinary Portland Cement (OPC), and coarse aggregates, are illustrated in Figure 1.

### 2.2. Laboratory Tests

Nine mixtures (M0–M9) were prepared by varying cement and chemical additive contents (Table 2). Natural soil without additives (M0) was used as the control.

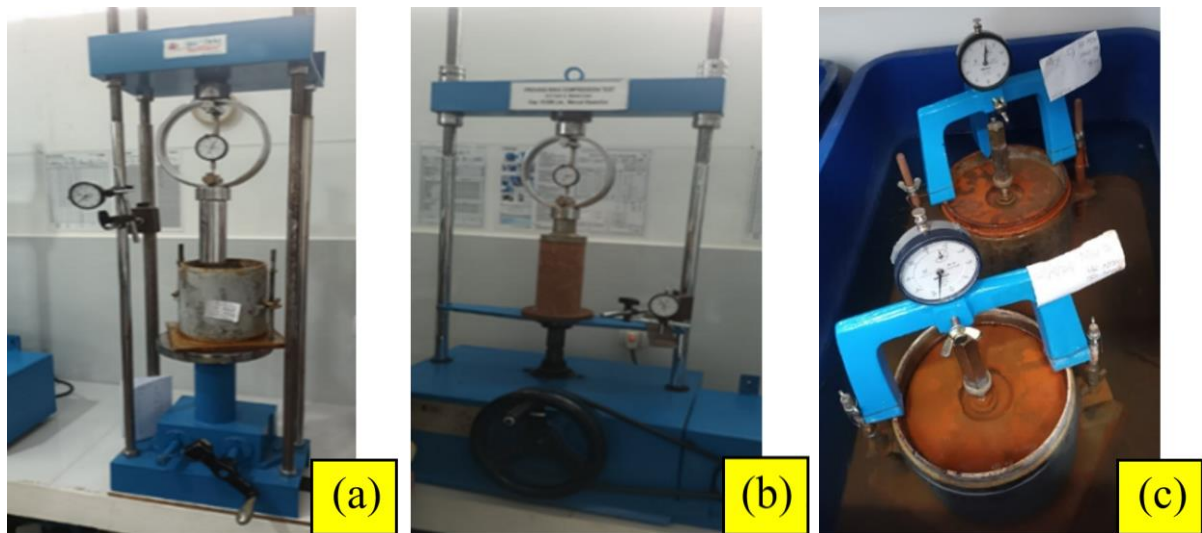
The laboratory testing program consisted of three main procedures. The California Bearing Ratio (CBR) test was conducted in accordance with ASTM D1883 for laboratory evaluation [22] and ASTM D4429 for field assessment [23]. Samples M0–M9 were examined under soaked and unsoaked conditions at curing ages of 7 and 28 days. In addition, the Unconfined Compressive Strength (UCS) test was carried out to determine the maximum compressive strength, Young's modulus, and Poisson's ratio of the stabilized soils, following the standard ASTM D2166 [24]. These tests were also performed on samples M0–M9 at 7 and 28 days under both soaked and unsoaked conditions. Furthermore, the swelling potential of the soil was evaluated to measure its expansion when in contact with water, in accordance with ASTM D5890 [25]. The swelling tests were conducted at curing periods of 7 and 28 days. The preparation and testing of soil samples for CBR, UCS, and swelling tests are shown in Figure 2.



**Figure 1.** (a) Existing Soil (OPC), (b) Ordinary Portland Cement (OPC), (c) Coarse Aggregate

**Table 2.** Mix proportions for laboratory testing

Code	Natural Soil (%)	Cement (%)	Chemical Additive (%)
M0	100	-	-
M1	96	4	-
M2	95	5	-
M3	94	6	-
M4	95	4	1
M5	94	5	1
M6	93	6	1
M7	94.5	4	1.5
M8	93.5	5	1.5
M9	92.5	6	1.5

**Figure 2.** Treated soil samples: (a) CBR test, (b) unconfined compressive strength, (c) in soaking condition**Table 3.** Job mix formula for field applications

Code	Natural Soil (%)	Ordinary Portland Cement (%)	Chemical Additive (%)	Coarse aggregate (cm)
Type 1				
L1	96	4	-	-
L2	95	4	1	-
Type 2				
L3	94	5	1	-
L4	94	5	1	7.5
L5	94	5	1	15

### 2.3. Field Applications

The field application was carried out in two types. In Type 1, two test sections were prepared: L1, consisting of existing soil mixed with Ordinary Portland Cement (OPC), and L2, consisting of existing soil mixed with OPC and a chemical additive. Each test section was 25 meters in

length, and the evaluation included CBR and UCS testing as well as visual observation over a monitoring period of four months (120 days). Type 2 involved larger-scale applications using the job mix formula presented in Table 3. These mixtures were applied directly in the field for three road sections: L3 with a length of 2.8 km, L4 with 7.8 km, and L5 with 19 km.

### 3. Results and Discussion

#### 3.1. California Bearing Ratio (CBR)

California Bearing Ratio (CBR) tests were performed on samples M0–M9 under both unsoaked and soaked conditions at curing periods of 7 and 28 days, as presented in Figure 3. For the natural soil (M0), the unsoaked CBR values were 6.06% at 7 days and 6.09% at 28 days. With the addition of 4% cement (M1), the CBR increased to 9.42% and 11.56%, representing improvements of 55.45% and 89.92%, respectively. For M2, containing 5% cement, CBR values of 11.67% and 14.39% were recorded, corresponding to increases of 92% and 136.29%. At 6% cement (M3), CBR values of 14.45% and 19.59% were obtained, showing increases of 154.95% and 221.67%. Further enhancement was observed in samples M4–M6, with CBR increases of 67.33%, 159.08%, and 171.95%, while M7–M9 achieved increases of 99.50%, 215.02%, and 290.59%.

Under soaked conditions, the improvements were also significant. Samples M1–M3 showed CBR increases of 37.5%, 80.36%, and 86.01% at 7 days, and 62.89%, 108.89%, and 179.56% at 28 days. For M4, M5, M6, CBR increased by 83.33%, 114.28% and 124.11% at 7 days and 58–352% at 28 days. The highest improvements were recorded in M6–M9, with increases ranging from 140.77% to 208.63%. These results confirm that cement substantially improves CBR values, while the addition of 1% and 1.5% chemical additives further enhances performance. The mechanism can be attributed to the flocculated structure produced by Ordinary Portland Cement (OPC), which fills soil voids, enhances bonding, and reduces destructive effects. Moreover, the chemical additive promotes precipitation of cementitious

compounds on soil particle surfaces, reducing surface activities and creating interconnected bonds that stabilize the soil [6], [26], [27]. Overall, the findings demonstrate that cement, particularly when combined with chemical additives, significantly increases the CBR of silty and clayey soils, with values continuing to improve over time.

#### 3.2. Swelling Test

Swelling tests were conducted on samples M0–M9 under soaked and unsoaked conditions at curing ages of 7 and 28 days, as illustrated in Figure 4. For the natural soil (M0), the swelling values were 0.31% at 7 days and 6.09% at 28 days under soaked conditions. With the addition of 4% cement (M1), the swelling decreased to 0.27% and 0.28%, corresponding to reductions of 12.90% and 12.50%, respectively. For M2, containing 5% cement, swelling values of 0.25% were obtained at both 7 and 28 days, representing reductions of 19.35% and 21.88%. In M3, with 6% cement, swelling decreased to 0.17% and 0.18%, showing reductions of 45.16% and 43.75%. Further decreases were observed in M4–M6, with values ranging between 0.13% and 0.16% at 7 days, and between 0.14% and 0.17% at 28 days, corresponding to reductions of 46.88–56.25%. The lowest swelling values were recorded in M7–M9, with reductions ranging from 61.29% to 74.19% at 7 days and 59.38% to 71.88% at 28 days.

These results clearly indicate that cement reduces swelling potential, and the addition of chemical additives further enhances this effect. The reduction in swelling is attributed to the hydration of cement particles and the chemical additive, which form agglomerates that occupy pore spaces and reduce water absorption capacity. Consequently, the soil becomes more stable with lower expansion potential when in contact with water [28], [29].

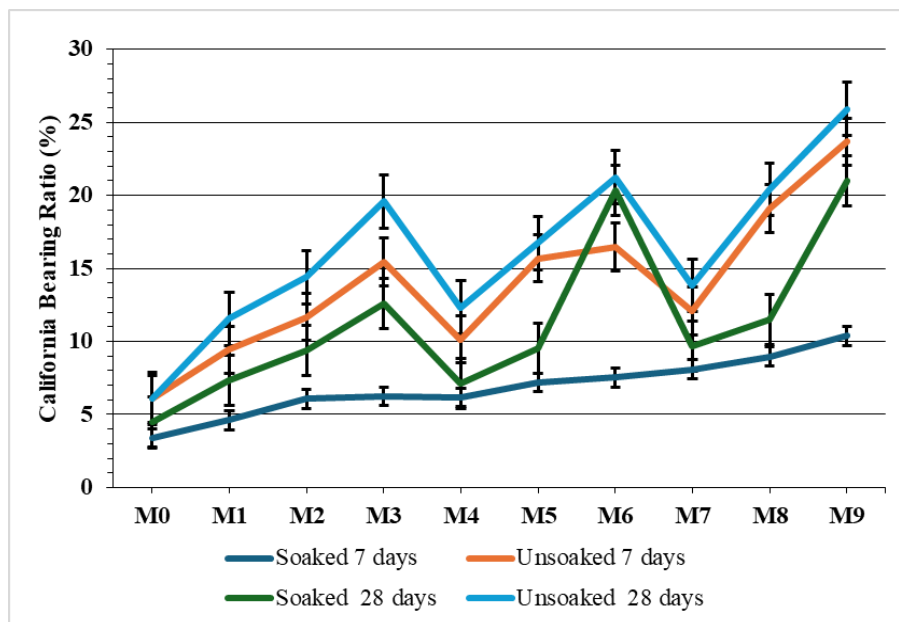


Figure 3. Results of CBR tests under soaked and unsoaked conditions at 7 and 28 days

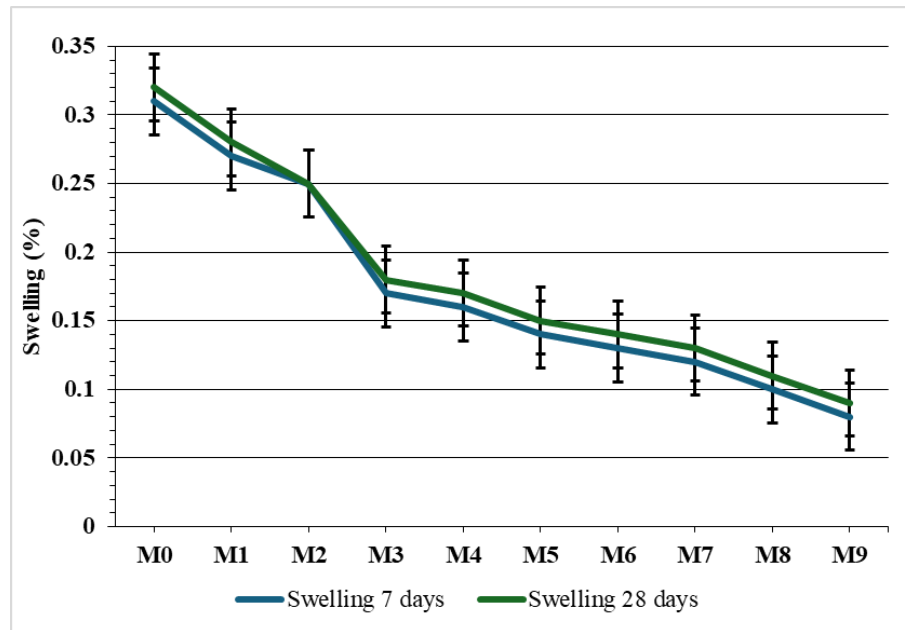


Figure 4. Results of swelling tests at 7 and 28 days under soaked conditions

### 3.3. Unconfined Compressive Strength (UCS)

Unconfined Compressive Strength (UCS) tests were carried out on samples M0–M9 under soaked and unsoaked conditions at curing ages of 7 and 28 days, as shown in Figure 5. For the natural soil (M0), UCS values were 0.63 MPa at 7 days and 0.734 MPa at 28 days. With the addition of 4% cement (M1), UCS increased to 0.97 MPa and 1.58 MPa, representing improvements of 53.97% and 92.06%, respectively. For M2, containing 5% cement, UCS values of 1.21 MPa and 1.741 MPa were achieved, corresponding to increases of 92% and 137.19%. At 6% cement (M3), the UCS rose to 1.61 MPa and 1.924 MPa, which equated to increases of 155.56% and 162.13%.

Further enhancements were observed in samples M4–M6, where UCS values reached 1.70 MPa, 2.006 MPa, and 2.10 MPa, with increases of 169.84%, 218.41%, and 233.33% at 7 days, and 190.05%, 201.63%, and 224.93% at 28 days. The highest improvements were recorded in M7–M9, which exhibited UCS increases of 219.05%, 255.56%, and 288.89% at 7 days, and between 235.01% and 293.05% at 28 days.

These results clearly indicate that cement significantly improves soil strength, and the addition of chemical additives further amplifies this effect. The combined action of cement hydration and chemical additive bonding produces a denser and more durable soil structure, resulting in substantial increases in UCS values compared to untreated soil.

### 3.4. Field Test Result

Field tests were conducted for Type 1 samples, namely L1 (existing soil mixed with OPC) and L2 (existing soil

mixed with OPC and a chemical additive). The visual performance of the stabilized sections is presented in Figure 6. The results showed that the soil stabilized with OPC alone (L1) achieved a CBR value of 26.06% and a UCS of 3.20 MPa. In comparison, the soil stabilized with OPC and a chemical additive (L2) exhibited higher performance, with a CBR of 28.75% and a UCS of 5.26 MPa.

These improvements demonstrate that the addition of chemical additives significantly enhances soil strength and bearing capacity. The enhancement is attributed to the chemical reaction between calcium hydroxide in the cement and the soil, which causes clay particles to flocculate into granular materials. This process reduces soil plasticity and lowers the swelling potential of expansive clays, consistent with findings from previous studies [30], [31]. Visual observations over a four-month monitoring period confirmed that the sections stabilized with chemical additives displayed greater durability and stability compared to those stabilized with cement alone.

The UCS tests for the field samples L3, L4, and L5 were conducted at curing ages of 7 and 28 days under both unsoaked and soaked conditions. The results showed that all samples achieved UCS values exceeding the minimum standard of 2 MPa. Moreover, as the curing time increased, especially under soaked conditions, a significant improvement in UCS values was observed. This indicates that Ordinary Portland Cement (OPC) combined with chemical additives, undergoes chemical reactions similar to those found in mortar and concrete, thereby enhancing the mechanical performance of the stabilized soil. These findings confirm that chemical additives can be effectively used for stabilizing expansive soils without the need for

coarse aggregates. The combined use of cement and chemical additives not only improves UCS and reduces swelling potential from high to low levels, but also

provides an economically advantageous and environmentally friendly alternative for soil stabilization [20], [28], [32].

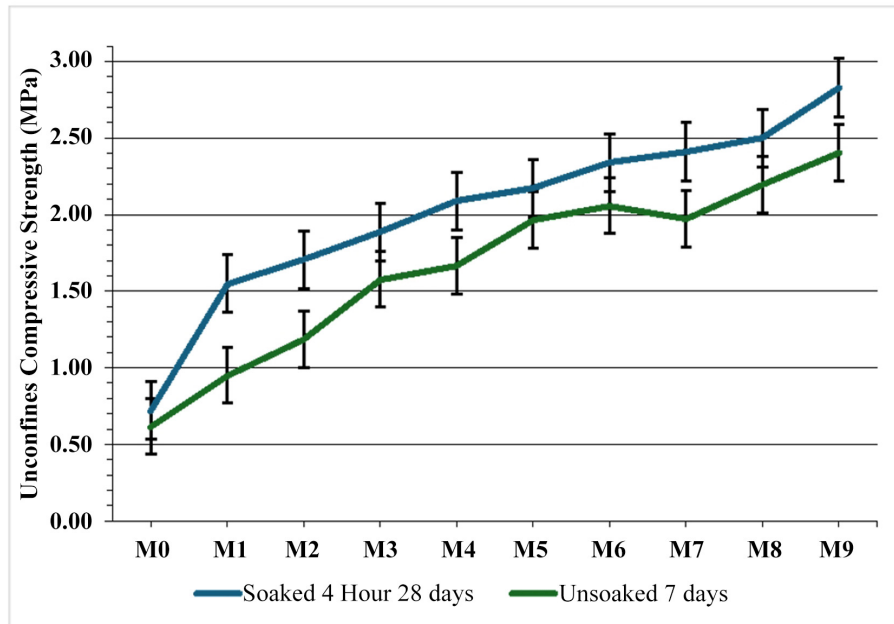


Figure 5. Results of UCS tests at 7 and 28 days



Figure 6. Visual results of field stabilization tests: (a) existing soil with OPC, (b) existing soil with OPC and chemical additive

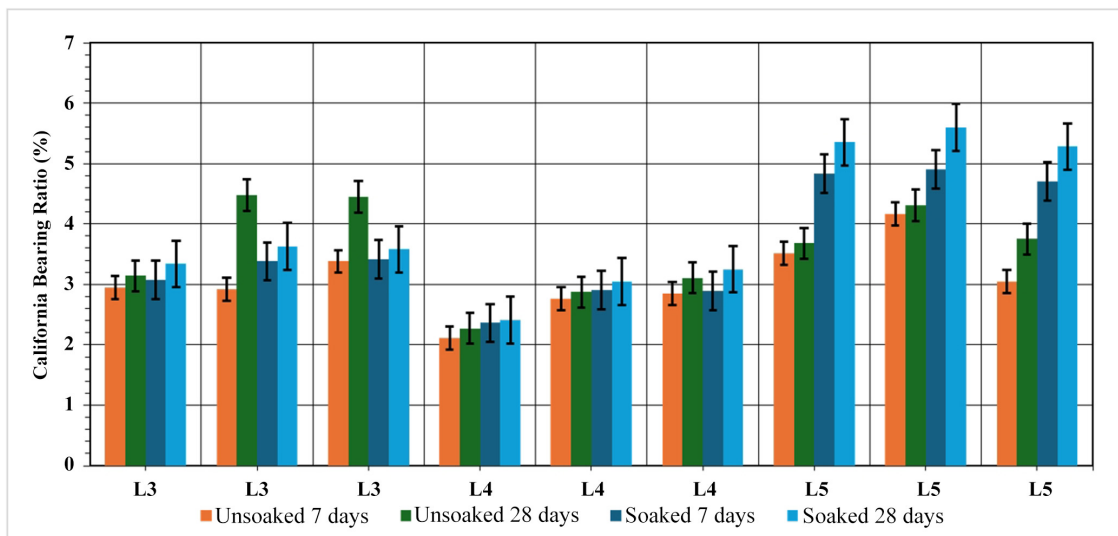


Figure 7. California Bearing Ratio (CBR) results of field applications (L3, L4, and L5) under soaked and unsoaked conditions at 7 and 28 days

Field test results for the extended applications (L3, L4, and L5) are discussed in the following section. The visual performance of the stabilized sections is presented in Figure 6, while the CBR values obtained from field applications (L3–L5) are summarized in Figure 7.

### 3.5. Visual Field Observations

Visual field observations were conducted to directly assess the physical condition of the stabilized road sections and to ensure compliance with the required construction standards. For the extended applications (L3, L4, and L5), photographic documentation was carried out before and after the stabilization works. The images illustrate clear improvements in the surface quality of the road sections

following treatment with cement and chemical additives. Prior to stabilization, the road surfaces exhibited cracks, unevenness, and signs of distress typical of expansive soils. After stabilization, the treated sections showed smoother and more uniform surfaces, with reduced cracking and deformation, indicating enhanced durability and performance of the stabilized soil. These visual findings further corroborate the laboratory and field test results, confirming the effectiveness of cement–chemical additive stabilization in improving both the mechanical properties and long-term performance of silty and clayey soils.

The surface improvements before and after stabilization are shown in Figures 8–10, which illustrate the effects of varying aggregate contents.



Before

After

**Figure 8.** Field condition of existing soil stabilized with 5% cement and 1% chemical additive (before and after treatment)



Before

After

**Figure 9.** Field condition of existing soil stabilized with 5% cement, 1% chemical additive, and coarse aggregate 7.5 cm (before and after treatment)



Before

After

**Figure 10.** Field condition of existing soil stabilized with 5% cement, 1% chemical additive, and coarse aggregate 15 cm (before and after treatment)

## 4. Conclusions

The key findings of this study can be summarized as follows:

1. The use of cement alone, at 28 days under soaked conditions, improved CBR values by 62.89–179.56% and UCS values by 115.26–162.13%. When combined with 1% chemical additive, CBR increased by 58–352% and UCS by 190.05–224.93%. Furthermore, the addition of 1.5% chemical additive resulted in CBR improvements of 115.56–366.67% and UCS enhancements of 235.01–293.05%.
2. Field applications demonstrated that cement, chemical additives, and coarse aggregates can be effectively utilized for soil stabilization. However, economic feasibility and environmental considerations must be taken into account during implementation.
3. The combination of cement and chemical additives alone can serve as an effective stabilizer for silty and clayey soils, offering a sustainable alternative to the use of coarse aggregates.

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