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Research Article

Effect of Beach Sand and Curing on CBR and Compressive Strength of Expansive Soil

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Abstract

Expansive soil is a fine-grained clay that undergoes large volume changes as its moisture content fluctuates, which often produces differential settlement, cracking, and structural damage to the infrastructure built upon it. Improving such soil before construction is therefore essential. This study evaluates beach sand, a locally abundant granular material in Tarakan City, as a stabilizing agent for expansive soil, with particular attention to how curing time affects bearing capacity. Expansive clay sampled from Gunung Lingkas, Tarakan, was classified as high-plasticity clay. It was blended with beach sand at 20%, 40%, and 60% by weight and cured for 10, 20, and 30 days. Physical tests (sieve analysis, moisture content, unit weight, specific gravity, and Atterberg limits) and mechanical tests (compaction, California Bearing Ratio, and unconfined compressive strength) were carried out in the laboratory. Adding beach sand lowered plasticity to the point that several mixtures became non-plastic, while it markedly improved mechanical performance: the maximum dry density rose from 1.393 to 1.679 g/cm³, the bearing ratio increased from 9.59% to 25.47%, and the unconfined compressive strength grew from 0.0502 to 0.115 kg/cm². The most effective combination was 60% beach sand cured for 30 days. The results show that local beach sand is a promising granular stabilizer for improving the bearing capacity of expansive subgrade, although its low unconfined compressive strength and unverified mechanism call for further evaluation.

Introduction

Soil acts as the principal supporting medium in almost every civil engineering work, so its physical and mechanical behavior directly governs the stability and safety of the structures it carries. Among the soil types that routinely complicate construction, expansive clay is one of the most problematic. Because its mineralogy allows it to take up and release water, this soil swells when wet and shrinks when dry, and the repeated volume change drives differential movement that cracks pavements and damages foundations (Manoppo, 2013; Hardiyatmo, 2014).

In the Gunung Lingkas area of Tarakan City, expansive clay is widespread and limits the load-bearing performance of subgrade. Strengthening this soil before it carries traffic or building loads is therefore necessary, and stabilization, the deliberate alteration of soil properties through an added material, is one of the most practical approaches. A wide range of additives has been examined for this purpose. Chemical binders such as cement and lime, often combined with pozzolans, raise strength through cementation and pozzolanic reaction; for instance, lime and fly ash added to clay shale and allowed to cure substantially increased its California Bearing Ratio and reduced its plasticity (Harwadi, 2025), and similar pozzolanic treatments combining fly ash with fibre reinforcement have improved the strength of highway clay soils (Sengul et al., 2023). Polymer admixtures have likewise been shown to improve the bearing capacity of local soils (Dewi et al., 2022), and cement combined with sand has been reported to raise both CBR and unconfined compressive strength (Anwar, 2025), and cement–zeolite blends have markedly reduced the swelling of high-plasticity clay while improving its CBR (Umar et al., 2025).

Granular stabilization offers a simpler and lower-cost alternative. Mixing a clay with a course, low-plasticity material improves its gradation, fills inter-particle voids, and reduces the dominance of the active clay fraction, which in turn lowers plasticity and swelling while increasing density and bearing ratio (Ridwansyah, 2018; Fathonah et al., 2022; Novianto & Rochman, 2023; Amulya et al., 2023; Utkarsh & Jain, 2024). Marine sands are especially interesting because their dissolved salts promote flocculation of clay particles; sea sand has been found to raise the CBR and unconfined compressive strength of clay subgrade (Kusuma et al., 2017; Mina et al., 2017; Ghorbani & Hasanzadehshooiili, 2018), and it has also been applied to soft soils with encouraging results (Santoso, 2019).

Despite this body of work, the beach sand (locally known as pasir gusung) that is abundant along the coast of Tarakan has received little attention as a stabilizer for the city's expansive clay, and the role of curing time on the resulting bearing capacity has rarely been quantified for this material. This study addresses that gap. Its objective is to evaluate how the addition of Tarakan beach sand, at 20%, 40%, and 60% by weight, and curing for 10, 20, and 30 days, affect the physical properties and, in particular, the California Bearing Ratio and unconfined compressive strength of expansive clay taken from Gunung Lingkas. The novelty of the work lies in pairing a previously underused local marine sand with an explicit curing programme, offering a potentially practical and low-cost stabilization option for expansive subgrade in coastal Kalimantan that is here evaluated under laboratory conditions.

Research Method

The study was conducted experimentally in the soil mechanics laboratory to determine the influence of beach sand addition on the physical and mechanical behavior of expansive soil. Primary data were obtained from laboratory tests on the natural soil and on the stabilized mixtures, while secondary data, in the form of published literature and test standards, served as references for the procedures.

Study Area and Materials

The expansive clay used as the main sample was taken from Jalan Kuburan Cina, Gunung Lingkas, Tarakan City. The beach sand used as the stabilizing agent was collected from the Tanjung Pasir area, East Tarakan (coordinates 3°12′43.74″N, 117°38′03.22″E). Clean water was used for mixing and testing. Because the sand originates from a coastal environment, its salinity was measured to characterize the dissolved-salt content that can influence clay behavior.

Mixture Variations and Specimen Preparation

Three mixture proportions were prepared by replacing part of the dry soil mass with beach sand, as summarized below:

1. Mixture A: 80% expansive soil + 20% beach sand.
2. Mixture B: 60% expansive soil + 40% beach sand.
3. Mixture C: 40% expansive soil + 60% beach sand.

Each mixture was cured for 10, 20, and 30 days before testing so that the effect of curing duration on the stabilized soil could be evaluated.

The soil and beach sand were blended and compacted in a 9-mm plywood box lined with waterproof plastic to preserve the moisture condition of the specimens, and the mixtures were kept in this sealed condition throughout the 10-, 20-, and 30-day curing periods. Curing was carried out under ambient laboratory conditions at a room temperature of approximately 28–30 °C; the relative humidity was not monitored.

Testing Procedure

Physical-property tests were performed to characterize the soil and consisted of sieve analysis, moisture content, unit weight, specific gravity, and Atterberg limits. Mechanical-property tests were performed to assess the capacity of the soil to receive and resist load and consisted of standard compaction, the California Bearing Ratio (CBR), and the unconfined compressive strength (UCS) test. The same suite of tests was applied to the natural soil and to each stabilized mixture at every curing age, following established soil-testing references (Bowles, 1984; Das, 2010). The main laboratory equipment included a drying oven, a digital balance, a set of sieves, the Casagrande apparatus, a Proctor mould, a CBR testing machine, a UCS loading frame, a pycnometer, and sampling rings.

All tests followed the relevant Indonesian National Standards (SNI): grain-size and sieve analysis (SNI 3423:2008), moisture content (SNI 1965:2008), bulk unit weight (SNI 03-3637-1994), specific gravity (SNI 1964:2008), liquid limit (SNI 1967:2008) and plastic limit/plasticity index (SNI 1966:2008), standard Proctor compaction (SNI 1743:2008), California Bearing Ratio (SNI 1744:2012), and unconfined compressive strength (SNI 3638:2012).

The full programme covered three sand contents (20%, 40%, and 60%) tested at three curing ages (10, 20, and 30 days). For each mixture–curing combination, three specimens were tested and the value reported in this paper is the arithmetic mean of the three. Standard deviation and other dispersion statistics were not computed; only the mean of the three specimens is reported.

Data Analysis

The measured values were tabulated and compared between the natural soil and the stabilized mixtures, and trends were examined against both the proportion of beach sand and the curing duration. The combination giving the greatest improvement in mechanical properties was then identified as the most effective mixture.

Results and Discussion

Properties of the Natural Expansive Soil

Sieve analysis showed that 53% of the natural soil passed the No. 200 sieve, classifying it as a fine-grained soil. Combined with a liquid limit of 53.28% and a plasticity index of 28.28%, the soil falls into group CH (inorganic clay of high plasticity) under the Unified Soil Classification System, indicating a strong capacity to absorb water and a high swell–shrink potential. The grain-size distribution of the natural soil is shown in Figure 1.

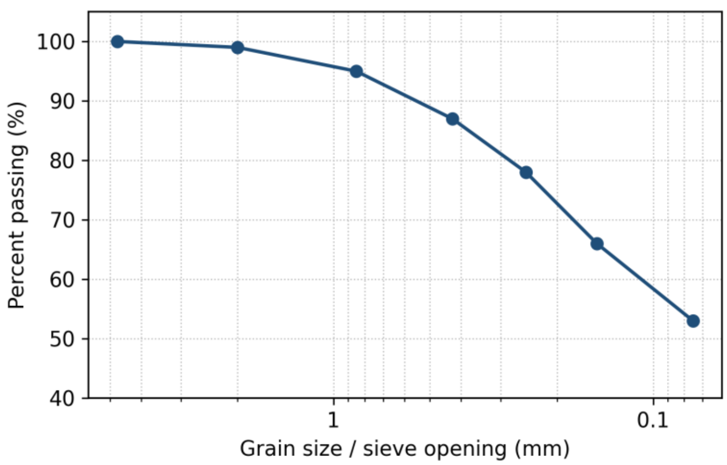

Figure 1. Grain-size distribution curve of the natural expansive soil

The moisture content of the natural soil was 87.87%, a very high value that confirms its strong affinity for water. Atterberg testing gave a liquid limit of 53.28%, a plastic limit of 25%, and a plasticity index of 28.28%; a plasticity index above 17% denotes a highly plastic, moisture-sensitive clay. The specific gravity averaged 2.237 and the bulk unit weight averaged 1.302 g/cm³, both consistent with a clay-dominated fabric containing relatively light minerals. A concise summary of the natural-soil properties is given in Table 1.

Table 1. Physical and mechanical properties of the natural expansive soil

Property	Unit	Value
Passing No. 200 sieve	%	53
Moisture content	%	87.87
Bulk unit weight	g/cm³	1.302
Specific gravity (Gs)	–	2.237
Liquid limit (LL)	%	53.28
Plastic limit (PL)	%	25.00
Plasticity index (IP)	%	28.28
USCS classification	–	CH
Optimum moisture content	%	24.05
Maximum dry density	g/cm³	1.393
CBR	%	9.59
Unconfined compressive strength	kg/cm²	0.0502

On the mechanical side, standard compaction gave an optimum moisture content of 24.05% and a maximum dry density of 1.393 g/cm³, the soil reaching its densest state while still retaining a relatively loose particle arrangement. The natural CBR of 9.59% reflects a moderate but sub-optimal subgrade capacity, lowered by the highwater content that softens the clay and allows it to swell. The unconfined compressive strength was only 0.0502 kg/cm²; because this lies below 0.25 kg/cm², the soil is classed as very soft, with a weak fabric, high water content, and low resistance to deformation (Hardiyatmo, 2017).

Properties of the Stabilized Soil

Salinity testing of the beach sand returned a value of 27 ppt across all three samples, placing it in the brackish range and confirming a meaningful dissolved-salt content. This salt content is relevant because dissolved salts can promote flocculation and aggregation of clay particles, a mechanism commonly associated with reduced swell potential and increased density. In this study the mechanism is inferred from the salinity level and the observed macro-scale behavior and was not verified by microstructural or chemical testing (see Limitations). The measured salinity is reported in Table 2.

Table 2. Salinity of the beach sand

Parameter	Sample 1	Sample 2	Sample 3	Reference range
Salinity (ppt)	27	27	27	Brackish: 0.5–30

Grain Size (Passing No. 200 Sieve)

Adding beach sand coarsened the mixture and reduced the fines fraction. The percentage passing the No. 200 sieve fell from 53% in the natural soil to 16.68% in the 60% mixture cured for 30 days. Both a higher sand content and a longer curing period reduced the fines, as flocculation and aggregation, promoted by the salt in the sand, bound fine particles into larger aggregates that no longer passed the sieve. The full results are given in Table 3 and illustrated in Figure 2.

Table 3. Percentage passing the No. 200 sieve of the stabilized soil (%)

Curing time	20% sand	40% sand	60% sand
10 days	44.78	32.11	21.29
20 days	41.30	29.98	18.13
30 days	37.97	28.32	16.68

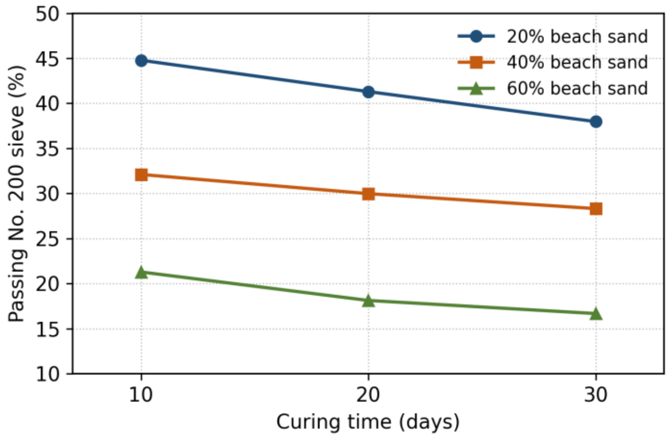

Figure 2. Effect of beach sand content and curing time on the percentage passing the No. 200 sieve.

Moisture Content

Moisture content decreased as both the sand proportion and the curing time increased. For the 20% mixture it dropped from 74.19% to 68.46%, for the 40% mixture from 50.71% to 46.66%, and for the 60% mixture, where the change was largest, from 32.41% to 27.61%. The added sand makes the fabric coarser and dilutes the water-hungry clay fraction, while the salt-driven aggregation during curing further reduces the soil's ability to retain water. The values are listed in Table 4.

Table 4. Moisture content of the stabilized soil (%)

Curing time	20% sand	40% sand	60% sand
10 days	74.19	50.71	32.41
20 days	69.55	47.83	30.77
30 days	68.46	46.66	27.61

Unit Weight

The bulk unit weight rose with both variables. It increased from 1.575 to 1.646 g/cm³ for the 20% mixture, from 1.791 to 1.854 g/cm³ for the 40% mixture, and most strongly from 1.862 to 2.093 g/cm³ for the 60% mixture. Sand grains filling the voids between soil particles produce a denser, more tightly packed fabric, and the accompanying loss of water and salt-induced bonding during curing further consolidate the structure. The results are presented in Table 5.

Table 5. Bulk unit weight of the stabilized soil (g/cm³)

Curing time	20% sand	40% sand	60% sand
10 days	1.575	1.791	1.862
20 days	1.629	1.812	1.957
30 days	1.646	1.854	2.093

Specific Gravity

The specific gravity of the natural soil, 2.237, reflects the dominance of relatively light clay minerals. After stabilization it rose progressively to 2.63 for the 60% mixture cured for 30 days, increasing from 2.40 to 2.55 for the 20% mixture, from 2.49 to 2.59 for the 40% mixture, and from 2.57 to 2.63 for the 60% mixture. The increase reflects the substitution of lighter clay with denser sand grains, while curing helps the particle arrangement settle and the water content decline. Table 6 gives the full results.

Table 6. Specific gravity of the stabilized soil

Curing time	20% sand	40% sand	60% sand
10 days	2.40	2.49	2.57
20 days	2.49	2.54	2.60
30 days	2.55	2.59	2.63

Atterberg Limits

Once stabilized, the mixtures could no longer be tested for liquid or plastic limit because they had lost their plastic character. Replacing part of the clay with coarse, cohesionless sand removed much of the fine fraction responsible for cohesion and plasticity, so the material became granular and non-plastic and no longer met the conditions required for the Atterberg tests. This loss of plasticity is itself a favorable indicator, as it implies a strong reduction in swell–shrink potential.

In standard terms, the stabilized material could not be rolled into a 3-mm thread without crumbling (SNI 1966:2008) and did not close the standard groove in the Casagrande cup under the prescribed blows (SNI 1967:2008); its plasticity is therefore reported as non-plastic (NP) rather than as a numerical plasticity index.

Compaction (Maximum Dry Density)

The maximum dry density of the natural soil, 1.393 g/cm³, indicates a fabric with large voids and a high proportion of fines. After stabilization it increased with both sand content and curing time, reaching 1.527 g/cm³ for the 20% mixture, 1.628 g/cm³ for the 40% mixture, and 1.679 g/cm³ for the 60% mixture at 30 days. Sand grains filling the soil voids tighten the particle packing, and the dissolved salts are thought to reduce the spacing between clay particles, making the soil more stable and easier to compact. The results appear in Table 7 and Figure 3.

Table 7. Maximum dry density of the stabilized soil (g/cm³)

Curing time	20% sand	40% sand	60% sand
10 days	1.478	1.579	1.589
20 days	1.484	1.593	1.650
30 days	1.527	1.628	1.679

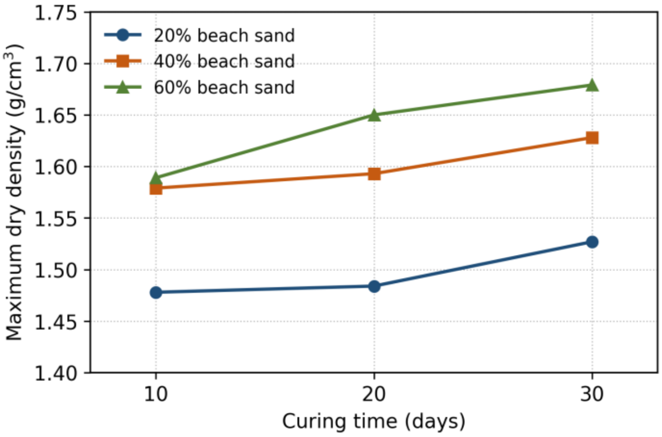

Figure 3. Effect of beach sand content and curing time on the maximum dry density

California Bearing Ratio (CBR)

The natural CBR of 9.59% reflects the low bearing capacity caused by the plastic, swell-prone clay. Stabilization raised the CBR for every mixture and curing age. At 30 days the value reached 15.48% for the 20% mixture and 16.48% for the 40% mixture, while the 60% mixture showed the largest gain, climbing to 25.47% — a 165.59% increase over the natural soil. Sand grains filling the voids create a denser, more stable fabric, and the dissolved salts are thought to thin the water films around the clay particles, making the soil stiffer and more load-resistant; longer curing continues to stabilize the structure, so the CBR keeps rising. The results are presented in Table 8 and Figure 4. The trend agrees with reports that marine sand improves the bearing ratio of clay subgrade (Kusuma et al., 2017).

Table 8. CBR of the stabilized soil (%)

Curing time	20% sand	40% sand	60% sand
10 days	11.79	12.79	15.48
20 days	13.49	14.79	20.08
30 days	15.48	16.48	25.47

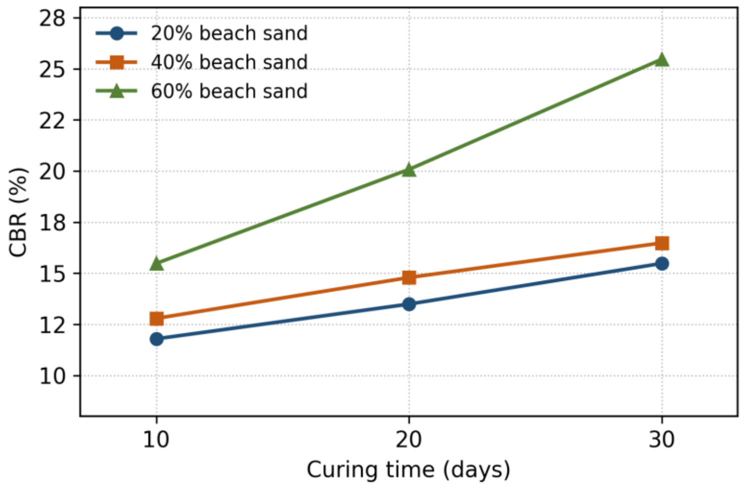

Figure 4. Effect of beach sand content and curing time on the CBR value

Unconfined Compressive Strength (UCS)

At a 10-day curing age the 20% and 40% mixtures gave UCS values slightly below that of the natural soil, because the sand–clay structure had not yet stabilized and the inter-particle bonds were poorly formed. As curing extended to 20 and then 30 days the UCS rose, the packing tightening, the moisture distributing more evenly, and the voids filling with sand. The 60% mixture showed the strongest gain, reaching 0.115 kg/cm² at 30 days, an increase of 129.08% over the natural soil. Here the abundant sand forms a dense, stable skeleton while the clay fills the voids between grains, and the reduced plasticity and swell potential translate into higher mechanical strength. In general, strength increased with both sand content and curing time. The results are given in Table 9 and Figure 5, and the link between density and unconfined strength is consistent with previous observations on expansive clay (Amran & Pradana, 2023) and with the improvement in unconfined strength reported for sand-stabilized subgrade (Fathonah et al., 2022; Mina et al., 2017).

Table 9. Unconfined compressive strength of the stabilized soil (kg/cm²)

Curing time	20% sand	40% sand	60% sand
10 days	0.036	0.049	0.083
20 days	0.043	0.058	0.085
30 days	0.049	0.062	0.115

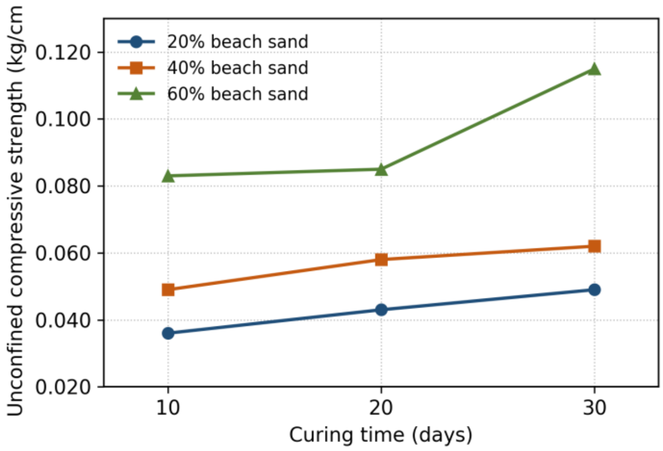

Figure 5. Effect of beach sand content and curing time on the unconfined compressive strength

Relationship Between Physical Changes and Strength Gain

The individual trends are mechanistically linked rather than independent. As the beach sand content and curing time increase, the fines passing the No. 200 sieve fall from 53% to 16.68% and the moisture content drops from 87.87% to 27.61%, so the active clay fraction that controls swelling and water retention is progressively diluted. The course, better-graded skeleton permits tighter packing, which is reflected in the rising bulk unit weight (1.302 to 2.093 g/cm³) and maximum dry density (1.393 to 1.679 g/cm³). This densification and the improved particle interlock are the principal reasons the CBR rises from 9.59% to 25.47%, because the bearing ratio is governed mainly by density, gradation, and frictional resistance rather than by cohesion.

The unconfined compressive strength behaves differently. Even for the optimum mixture it remains low in absolute terms (0.115 kg/cm²), because replacing cohesive clay with cohesionless sand reduces the very cohesion that the UCS measures; the modest gain in UCS therefore arises from denser packing and lower plasticity rather than from any cementing action. This contrast explains why the bearing ratio improves far more than the unconfined strength and indicates that, for this soil, beach sand acts primarily by improving density and frictional bearing capacity rather than cohesive strength.

Engineering Significance

From a design standpoint, the soil stabilized with 60% beach sand and cured for 30 days reaches a CBR of 25.47%, which comfortably exceeds the minimum CBR of about 6% commonly required for road subgrade (Bina Marga, 2017). On this basis the treated soil would be acceptable as subgrade fill in terms of bearing ratio. Its unconfined compressive strength, however, remains in the very-soft range (below 0.25 kg/cm²), so the material should not be relied upon where cohesive strength is critical. For context, earlier studies using sea sand on clay reported much higher unconfined strengths — for example an increase to 3.35 kg/cm² at 36% sand (Fathonah et al., 2022) and to 19.60 kg/cm² at 30% sand after 28 days of curing (Mina et al., 2017) — which highlights that the present beach sand improves performance mainly through densification rather than through the stronger cohesive or pozzolanic bonding observed with some marine sands.

Limitations

Several limitations should be acknowledged. The salt-induced flocculation invoked to explain the changes was not verified by mineralogical or microstructural testing (XRD, SEM), nor by pH or pore-water electrical-conductivity measurements, so the mechanism remains inferential. The reported values are means of three replicate specimens per mixture–curing combination, and a formal statistical evaluation (standard deviation, coefficient of variation, and significance testing) was not carried out, so small differences — such as those between the 10- and 20-day UCS values of some mixtures — should be interpreted with caution. Durability under wet–dry cycling, swelling-pressure measurement, curing beyond 30 days, cost analysis, and field validation were also outside the scope of this study.

Conclusion

Adding Tarakan beach sand improved the physical properties of the expansive clay. The fraction passing the No. 200 sieve fell from 53% to 16.68% and the moisture content from 87.87% to 27.61%, while the bulk unit weight rose from 1.302 to 2.093 g/cm³ and the specific gravity from 2.237 to 2.63. The stabilized soil could no longer be tested for Atterberg limits, having changed from a plastic fine-grained clay into a granular, non-plastic material — a direct sign of reduced swell–shrink potential. The treatment also enhanced the mechanical properties. The maximum dry density increased from 1.393 to 1.679 g/cm³ (about 20.53%), the CBR from 9.59% to 25.47% (about 165.59%), and the unconfined compressive strength from 0.0502 to 0.115 kg/cm² (about 129.08%). Although the 20% and 40% mixtures at 10 days of curing were initially weaker than the natural soil in unconfined strength, their strength recovered and rose as curing continued.

Overall, a 60% beach sand content was the most effective proportion for improving both the physical and mechanical behavior of the expansive clay, with the optimum result obtained after 30 days of curing. Under the laboratory conditions tested, local beach sand is therefore a promising granular stabilizer for improving the bearing capacity of expansive subgrade in Tarakan, the clearest benefit being the increase in CBR. Because cost, durability under wet–dry cycling, swelling pressure, statistical significance, and field performance were not assessed, and because the salt-related mechanism was not verified by mineralogical analysis, these aspects — together with longer curing and possible chemical admixtures — should be examined before any field application.

Author Contributions

Conceptualization, F.H and H.; Methodology, F.H and H.; Software, Q.B.R.; Validation, F.H and H.; Formal Analysis, F.H and H.; Investigation, H and Q.B.R.; Resources, H and Q.B.R.; Data Curation, F.H.; Writing – Original Draft Preparation, F.H.; Writing – Review & Editing, F.H.; Visualization, H.; Supervision, F.H.; Project Administration, H.

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Conflicts of Interest

The authors declare no conflict of interest.

Data Availability

The datasets generated during and/ or analyzed during the current study are available from the corresponding author on reasonable request.

Use of Generative AI

No generative AI was used.

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