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A Case Study on Stabilizing Kathmandu Valley Lacustrine Silt with Stone Dust and Sand

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ABSTRACT. High-plasticity soils, like those in the Kathmandu Valley, present significant construction challenges because of their high compressibility, low shear strength, and notable settlement behavior. By evaluating changes in geotechnical properties and shear strength parameters, this study explores the stabilization potential of stone dust and sand in enhancing the geotechnical behavior of lacustrine silt, a common high-plasticity soil type in the Kathmandu Valley. A number of laboratory tests were performed on natural soil samples that were collected from the area close to the Bagmati River. Different proportions of stone dust (10–40%), sand (10–40%), and a combination of the two were used to modify the soil. Assessments were made of parameters like cohesion, internal friction angle, maximum dry density (MDD), and optimal moisture content (OMC). Sand and stone dust increased the internal friction angle and dry density while decreasing cohesion and OMC. It was discovered that the combination of sand and stone dust was especially useful for strength improvement without being overly expensive. According to the study, sand and stone dust are both practical, locally accessible stabilizers that can greatly increase the bearing capacity and lessen the settlement of high-plasticity soils, particularly for shallow foundations used in low-rise buildings.

Keywords: Kathmandu Valley, Lacustrine Soil Stabilization, Silt, Stone dust, Sand.

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1. Introduction

The Kathmandu valley lies above an ancient dried-up lake, and most of the soil in this area is lacustrine and fluvio-deltaic deposits [1]. In some areas within the valley, construction projects face significant challenges due to weak soil conditions[2]. Due to their extremely low strength and stiffness, some of the difficulties encountered when dealing with weak soil in construction projects are instability, bearing capacity failure, or excessive settlement[3][4]. Such soils are not suitable for supporting structural loads without stabilization because of their high compressibility, low shear strength, and significant volumetric changes with moisture fluctuations. Common examples of traditional ground improvement techniques are using stabilizing chemicals or mechanical compaction. Alternative stabilizers, like sand, marble dust, limestone dust, stone dust, and quarry dust, have been investigated recently, though, because of their affordability, accessibility, and environmental advantages. These materials are frequently waste byproducts of the mining and stone crushing industries, which further encourages their sustainable use. The individual and combined effects of sand, and stone dust on the geotechnical behavior of Kathmandu's weak soils have, however, not been thoroughly studied in many studies. To identify the ideal mix proportions, appropriate for real-world applications, it is necessary to assess the compaction properties and shear strength parameters of such stabilized soils.

Broadly, stabilization can be classified into chemical and physical stabilization. Chemical stabilization is a technique that involves the use of chemicals, such as cement, lime, fly ash, or polymer-based binders, to improve the soil properties or aggregate materials for construction[5]. One can either add stabilizing material to an undisturbed soil deposit and allow it to interact by allowing it to permeate through soil voids, or one can mechanically mix and compact the natural soil and stabilizing material together to create a homogeneous mixture[6]. Other common methods used to make weak soil more stable by increasing strength and stiffness are by cementation, grading and compaction, soil replacement, artificial consolidation, by use of chemicals, geosynthetics, grouting, and by use of waste materials: rock dust, rubber dust, eggshell powders, kiln slag, waste geopolymers[3, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19].

Prior studies on using sand and stone dust have shown effective results in the stabilization of weak soil. A study found that adding non-plastic fines increased the Maximum Dry Density (MDD) and California Bearing Ratio (CBR) value of soil types, while decreasing the OMC (Optimum Moisture Content) [20]. As numerous studies have shown, the addition of stone-based additives greatly enhances the geotechnical characteristics of expansive or weak soils. A study found that the addition of stone dust to soil results in a decrease in plasticity index (PI), increased MDD, reduced OMC, and increased Unconfined Compressive Strength (UCS) [14]. Parallelly, laboratory test results from another study showed a significant strength increase when sand was added to soil, with improvements observed at sand percentages up to 60% by soil weight [21]. It has been demonstrated that adding sand or stone dust to weak soils improves the shear strength parameters (cohesion c and internal friction angle ϕ) while lowering compressibility, swelling pressure, and plasticity.

As shown in Table 1 and Table 2, previous studies have explored the use of stone dust and sand, respectively, for improving the geotechnical properties of various soil types. These tables give a comparative overview of the efficacy of stone dust and sand in enhancing the geotechnical qualities of weak soils. Although a number of studies have examined the stabilizing effects of sand or stone dust separately, not many have examined how these

Table 1. Effects of Stone Dust Addition on Soil Properties: Summary of Previous Studies

Ref.	Soil Type	Additives	Key Findings
[22]	Laterite	Graphite Nanoparticles (GN)	↓ Swelling pressure beyond 1% GN; ↑ Shear strength; ↑ Impermeability; improved soil strength and reduced volume change
[23]	Expansive Shale	Marble Dust	↓ Plasticity index; ↑ Permeability; reduced dry density; effective in altering plasticity and improving sustainability
[24]	Lateritic Soil	Micro-sized Quarry Dust	↓ Plasticity index; ↑ UCS, MDD, CBR; micro-filler action enhanced strength and compaction
[25]	Fine-Grained Soil	Stone Dust	↓ LL, PL, PI, and OMC; ↑ MDD and UCS up to 50% stone dust; effective in reducing plasticity and improving strength
[26]	Expansive Clayey Soil	Natural Zeolite	↑ UCS (+21% with zeolite); ↓ Swelling slightly; strength significantly improved with optimized CKD and zeolite blend
[27]	Expansive Soil	Quarry Dust	↓ LL, PI; ↑ PL, SL, cohesion, ϕ, OMC; ↑ MDD with quarry dust; reduced plasticity and improved compaction; optimum strength at 5% lime
[28]	Expansive Soil	Limestone Dust	↑ UCS, CBR; ↓ Swelling pressure and shrinkage strain; effective strength gain and swell reduction; suitable for subgrade and landfill liner applications
[29]	Expansive Soil	Stone Dust	↓ Swelling and plasticity; ↑ UCS and compaction; best results with equal proportions of stone dust and fly ash
[14]	Weak Soil	Stone Dust	↑ UCS after 28 days curing; ↑ MDD and ↓ OMC with stone dust; combined use improved the strength of weak Kathmandu soil

two substances work together to affect the strength properties of high-plastic soils that are unique to Kathmandu.

The stabilization of lacustrine high plastic soils from Kathmandu valley using different ratios of sand, stone dust, and their combination is the main focus of this study. In order to determine how these stabilizers affect compaction and strength behavior, the scope of the study includes analyzing the index properties of the natural soil and altering it. Prior to and following modification, cohesion, internal friction angle, maximum dry density (MDD), and optimal moisture content (OMC) are measured. The principal aim is to determine the ideal ratio of sand, stone dust, or both for the successful stabilization of weak soils unique to this area. Particularly for small-to medium-sized infrastructure projects, the results are intended to provide insights on the performance and feasibility of these locally accessible materials for ground improvement. This study builds on earlier research by analyzing the effects of separate stabilizers, such as sand and stone dust, as well as the shear strength properties that arise from applying them together. This approach provides a workable and affordable solution for sustainable soil stabilization in the Kathmandu Valley.

TABLE 2. Effects of Sand Addition on Soil Properties: Summary of Previous Studies

Ref.	Soil Type	Additives	Key Findings
[30]	Swelling soil	Dune Sand	↓ Swelling pressure
[31]	Soil	River sand	Sand is suitable for subgrade stabilization
[21]	Expansive soil	Sand	↓ LL, PL, Shrinkage, OMC; ↑ MDD; UCS ↑ until 60% sand, then ↓
[32]	Expansive soils	Dune Sand	↓ Swelling pressure & potential, ↑ Shear strength, Economic stabilization
[33]	Swelling Clays	Sand	↓ Swelling
[34]	Expansive soils	Dune sand	Stabilization is effective for ¿30% sand
[35]	Clayey soil	Sand & fly ash	30% sand → ↑ MDD, ↓ OMC, ↑ CBR; Beyond 30%, ↓ MDD
[36]	Cohesive Soil	Sand	↓ LL initially, ↓ OMC, ↑ MDD, ↑ CBR significantly
[37]	Clayey Soils	Sand	Bearing Capacity (3.7× untreated soil); 60% sand = optimal for pavements
[38]	Expansive soil	Beach Sand	↓ Consistency parameters, ↓ Swelling; Sand fineness affects plasticity
[39]	Clay	Sand	↓ Swelling, ↓ Consistency limits, ↓ Compressibility, ↑ Dry density
[40]	Laterite	Sand	↓ Atterberg limits, ↓ Shrinkage, ↑ MDD, CBR (irregular trend)
[41]	Swelling Soil	Sand	↓ Swelling pressure; 50% sand = significant ↓ LL & ↓ Free swell
[42]	Clay	Sand	↑ Permeability, ↑ CBR, ↑ UCS up to 40% sand
[43]	Black cotton	Sand & coir	↑ CBR, ↑ Compaction
[44]	Swelling Soil	Geofoam & Sand	↓ Swelling, ↓ LL, ↓ OMC, ↑ Dry density
[45]	Sandy Clay	Dune Sand	↑ Strength at 2-4% sand; ↓ Strength at 6%

2. Methodology

The high-plasticity soil was collected from Kupondole, a location close to the Bagmati River in the central Kathmandu Valley. The site location close to the Bagmati River and the representative sample of lacustrine silt used in this investigation are shown in Figure 1. Samples of bulk soil were taken from shallow depths (0–1.5 m), sealed in plastic bags, air-dried, ground up, and then sieved through a 425-micron sieve to guarantee consistency. The soil was characterized using basic index properties such as Atterberg limits and grain size distribution.

Stabilizers for this study, stone dust (D) and river sand (S), were obtained from a quarry at Dhading, an area close to the Kathmandu Valley. The stone dust was sieved through 425 microns, and was used in varying proportions (10%, 20%, 30% and 40% by dry weight of soil). Similarly, the sand passing through 1 mm was used in varying proportions (10%, 20%, 30% and 40% by dry weight of soil). Both stone dust and sand were also combined at varying proportions (5D-5S%, 10D-10S%, 15D-15S%, and 20D-20S% by dry weight of soil). The framework of the study is depicted in Figure 2. The basic properties of the mix were tested, and following IS 2720 (Part 7), Standard Proctor compaction tests were performed to ascertain each soil mix's MDD and OMC. Furthermore, a set of stabilized samples was subjected to Direct Shear Tests in accordance with IS 2720 (Part 13) in order to ascertain the shear strength parameters, specifically cohesion (c) and angle of internal friction (ϕ). The test results are all based on individual trials for each soil mix.

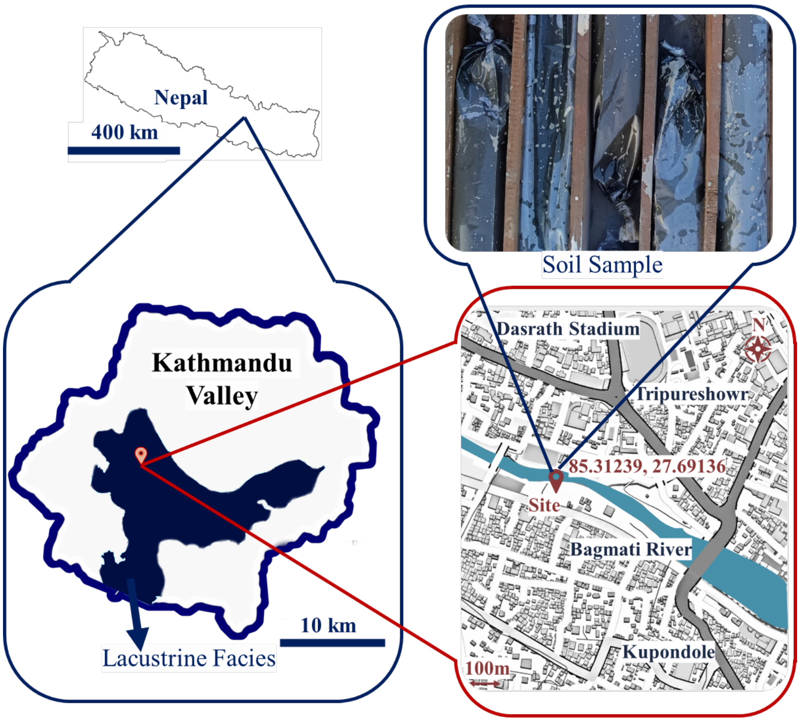

FIGURE 1. Representative sample of lacustrine silt from the study area near the Bagmati River within the Kathmandu Valley, Nepal.

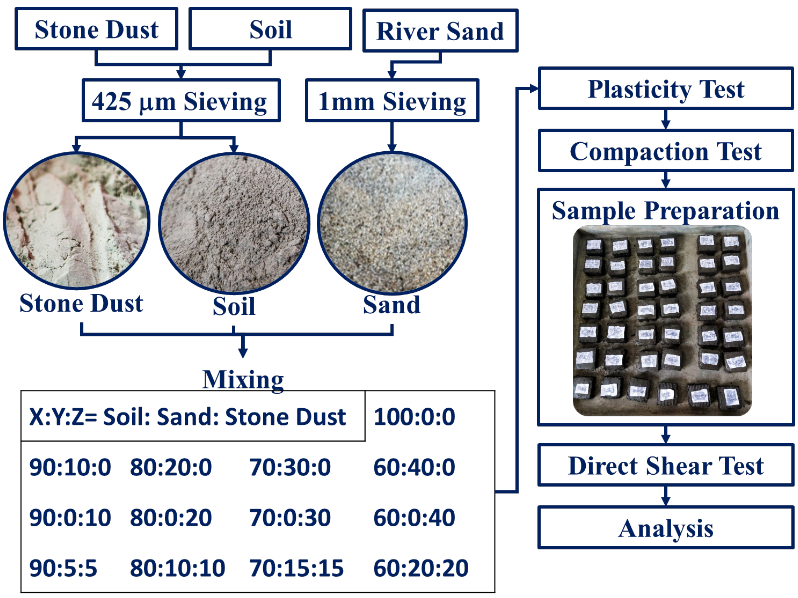

FIGURE 2. Methodological framework of the study.

The number of compositions examined in this study presented practical time and resource constraints, even though multiple repetitions would offer statistical strength and enable uncertainty quantification. The findings are therefore interpreted, emphasizing general

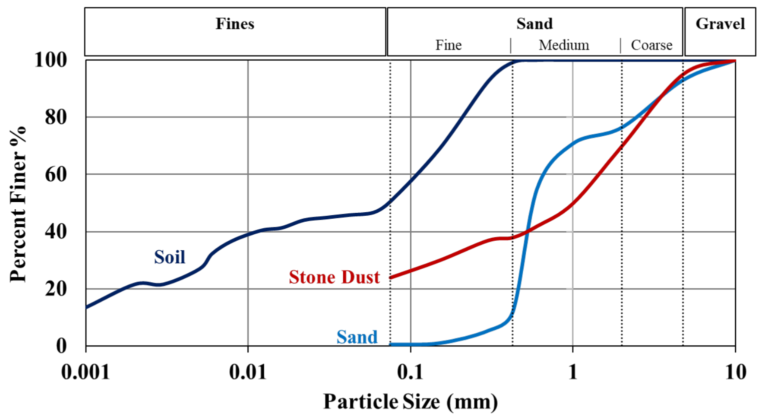

FIGURE 3. Grain size distribution curves for the natural soil, stone dust, and sand used in the stabilization.

behavioral patterns among various stabilizer kinds and contents rather than statistically averaged values.

3. Results and Discussion

3.1. **Index Properties of Natural Soil and Stabilizers.** Prior to stabilization, the classification characteristics of the natural soil from Kupondole, Kathmandu, were determined. The particle size distribution curves for natural soil, sand, and stone dust are shown in Figure 3. The natural soil curves substantially, with a large percentage of particles smaller than 0.075 mm, suggesting that fine-grained particles (clay and silt) predominate. Atterberg limit test demonstrates the soil's high plasticity. The liquid limit is 83.14%, and the plastic limit is 43.44%, resulting in a plasticity index of 39.69%. The liquid limit after oven drying is 69.92%, and the ratio of the liquid limit after oven drying to that before drying is 0.84—above the threshold of 0.75—indicating the soil is inorganic. Therefore, the soil is classified as inorganic MH according to the Unified Soil Classification System. Parallelly, sand is primarily coarse, with the majority of particles lying between 0.075 mm and 4.75 mm, whereas stone dust has a flatter curve with a mixture of fine to medium particles (range from silt to fine sand sizes). The coarser gradation, like sand and stone dust, indicates their ability to improve the structure of the soil by improving interparticle friction, decreasing flexibility, and diluting the fine clay percentage [27, 29].

3.2. **Effect of Stone Dust and Sand on Atterberg Limits.** The Atterberg limits of the stabilized and natural soil mixtures were analyzed to determine the plasticity behavior. The Unified Soil Classification System (USCS)-based plasticity chart is shown in Figure 4, which plots the plasticity index (PI) against the liquid limit (LL) for different soil combinations. With a plasticity index of 39.697 and a liquid limit of 83.137, the natural soil (100:0:0) lies below the A-line and is categorized as a high-plasticity silt (MH). The downward and leftward movement of data points in Figure 4 shows that the addition of sand and stone dust significantly lowers the plasticity index and liquid limit. These patterns are indicated by the arrows, which show how well both stabilizers work to reduce plasticity. For example, the LL and PI are decreased by the mixture containing stone dust. The mixture containing sand also produces a similar reduction, getting closer to the

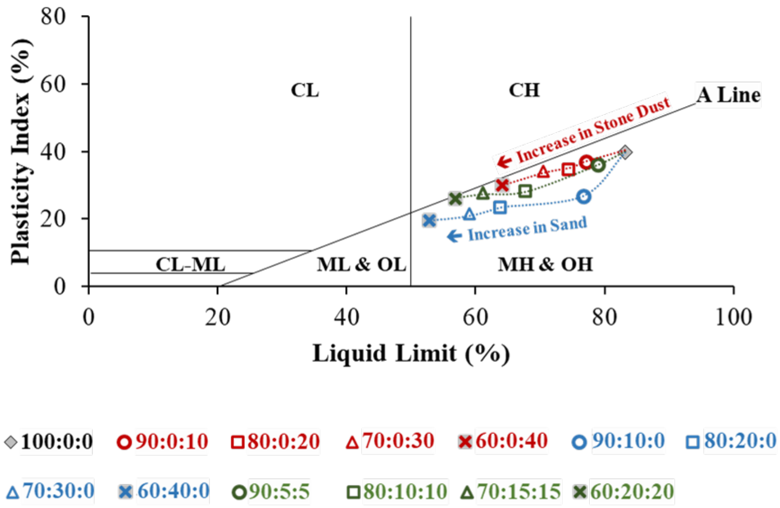

Figure 4. Plasticity chart showing the impact of different ratios of sand and stone dust on the Atterberg limits of Kupondole's high-plasticity soil.

ML (low-plasticity silt) zone. The effect of combined mixes is also noticeable, significantly lowering the LL and PI. The non-plastic properties of sand and stone dust dilute the clay content and reduce the soil's capacity to hold water, which lowers the LL and PI. This is the reason for the decrease in plasticity. This is consistent with earlier studies that found that coarse materials lower the plasticity index and swelling potential of expansive soils [27, 29]. The use of sand and stone dust together has a synergistic effect, resulting in appreciable decreases in plasticity. These findings support the materials' suitability for stabilizing Kupondole's high-plasticity soils, especially for small- to medium-sized building projects, by reducing the unfavorable volume change behavior of the native soil.

3.3. **Compaction Test Results.** As shown in Figure 5, when the stone dust content rises from 0% to 40%, the Optimum Moisture Content (OMC) gradually decreases, starting at 38.46% and ending at roughly 34.70%. The OMC, however, decreases down to roughly 34.88% as the amount of sand in the soil mix grows from 0% to 40%, following a similar decreasing trend. However, the Maximum Dry Density (MDD) of soil increases significantly from 11.99 kN/m^3 to 13.803 kN/m^3 with the percentage of stone dust in the soil mixture, from 0% to 40%. The MDD also grows steadily with the addition of sand, reaching 13.398 kN/m^3 when 40% of the soil is replaced with sand. The MDD rises by above 11%, while the OMC falls by nearly 9% when sand content is increased from 0% to 40%. In contrast, increasing stone dust in the same amount results in a nearly 15% rise in MDD and over 9% decrease in OMC.

The presence of both sand and stone dust in soil leads to significant changes in the compaction properties; however, stone dust was found to be more effective than sand. The maximum dry density (MDD) increases due to the angular and varying sizes of these particles, which occupy void spaces between larger soil particles, resulting in improved particle packing. However, the optimum moisture content (OMC) decreases as the percentage of sand and stone dust increases. The reduced porosity of these particles reduces the amount of water that can be held within the soil, reducing the amount of water needed for optimal

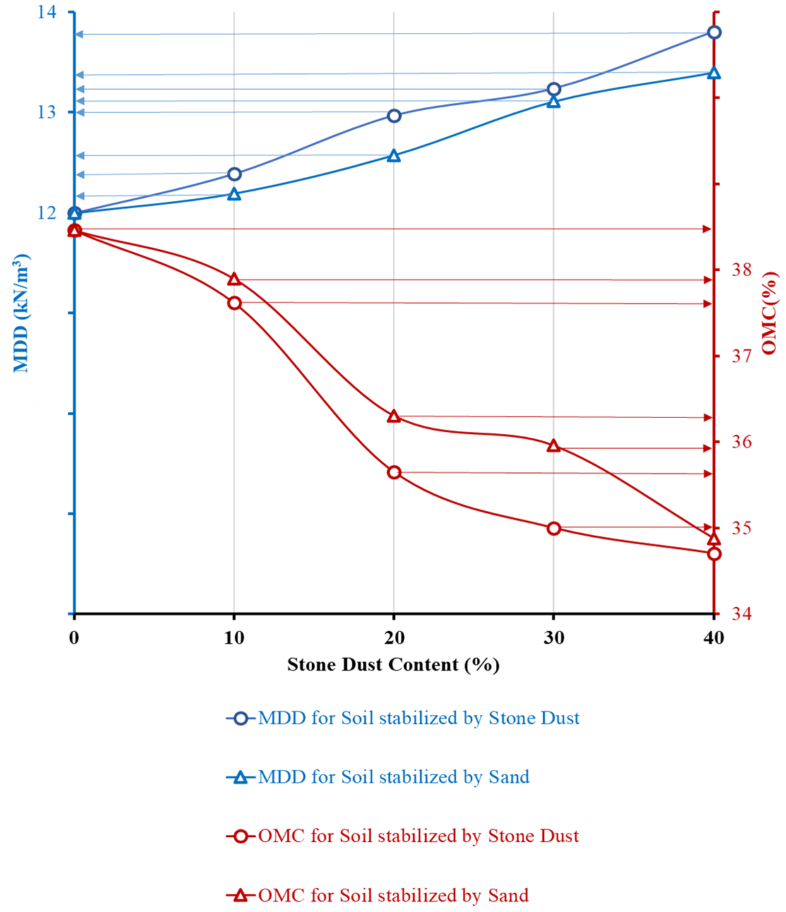

FIGURE 5. Comparison of Compaction Properties (OMC and MDD) for sand and stone dust.

compaction. This can be beneficial in construction projects, as it allows earth to be compacted with less water, potentially saving costs and reducing post-construction settlement risk. This also reduces the likelihood of soil shrinkage or expansion.

4. Direct Shear Test Results

As shown in Figure 6, as percentages of sand, stone dust, or a combination of both were added to the soil mixture, the data showed a steady rise in the friction angle. With no addition of admixtures in the soil, the friction angle was around 20.44 degrees. However, the friction angle reached 34.90 degrees when the sand content rose to 40% and it reached 36.8 degrees when the stone dust content rose to 40%. The friction angle increased to roughly 40.02 degrees when both sand and stone dust were mixed together at a percentage of 40%.

Unlike the friction angle, the cohesiveness of the soil mixtures showed a divergent pattern of improvement with the addition of sand and stone dust. As the percentages of sand, stone dust, or both were raised in the soil mixture, cohesion, which is a measure of the soil's intrinsic strength, rapidly reduced. For instance, cohesiveness reduced from 23.39

kN/m^2 to roughly 7.18 kN/m^2 when 40% sand was added to the soil and to approximately 7.12 kN/m^2 when 40% stone dust was added. Cohesion decreased to 5.42 kN/m^2 when both sand and stone dust were mixed together at a percentage of 40%.

The friction angle rises by above 70%, while the cohesion falls by nearly 69% when sand content is increased from 0% to 40%. In contrast, increasing stone dust in the same amount results in a nearly 80% rise in friction angle and over 69% decrease in cohesion. However, the friction angle rises by above 95%, while the cohesion falls by nearly 77% when both sand and stone dust are combined and the percentage by weight is increased from 0% to 40%.

Cohesion was found to decrease noticeably as stabilizer content increased, while the internal friction angle increased as well. The substitution of non-cohesive granular stabilizers for fines explains this behavior. The addition of coarser particles also improves interparticle interlocking, which raises frictional resistance. The soil structure changes from a clustered and plastic matrix to a more granular and friction-dependent framework as the stabilizer content rises [46]. This change causes the components of shear strength to be redistributed, increasing the frictional strength while decreasing the cohesive contribution.

So, sand and stone dust significantly impact soil behavior in geotechnical engineering applications. Sand is a stabilizer, increasing soil stability by improving resistance to shear deformation. Stone dust enhances soil stability by increasing its capacity to withstand shear stresses. As more stone dust is added, the friction angle rises, indicating improved shear resistance. However, the trade-off between cohesiveness and shear strength is important. With the addition of sand or stone dust, the friction angle increases, but the soil's cohesiveness decreases, indicating increased shear resistance. This allows for modification of soil compositions to meet specific project needs, improving soil performance in situations where shear deformation is crucial.

5. Conclusion

The study assessed weak soil's geotechnical properties, examined how sand, stone dust, or a combination altered compaction characteristics, and identified stabilized soil's shear strength parameters, providing valuable insights into poor soil behavior. The lacustrine soil from Kupondole was inorganic, high plastic silt. The laboratory testing of the soil resulted in MDD of 12.0 kN/m^3, OMC of 38.46%, friction angle of 20.44 degrees, cohesion of 23.39 kN/m^2, and specific gravity of 2.36. Meanwhile, sand and stone dust added coarser particles to improve the soil's gradation.

The results demonstrate the effectiveness of sand and stone dust to improve the plasticity characteristics of the lacustrine MH, with combined mixes showing noticeable reductions in LL and PI. Similarly, when mixing sand and stone dust in the soil, the compaction tests showed a significant increase in MDD and a decrease in OMC, enhancing compaction properties in weak soil, with 40% content showing the best results. Likewise, both stabilizers significantly improved the lacustrine soil's shear strength. Particularly, the friction angle of stabilized soil increased with the addition of sand and stone dust. For both sand and stone dust, the greatest improvements in the friction angle were consistently observed at the 40% content level. However, the addition of the stabilizers led to a decline in cohesion, emphasizing the importance of balance between increased friction angle with decreased

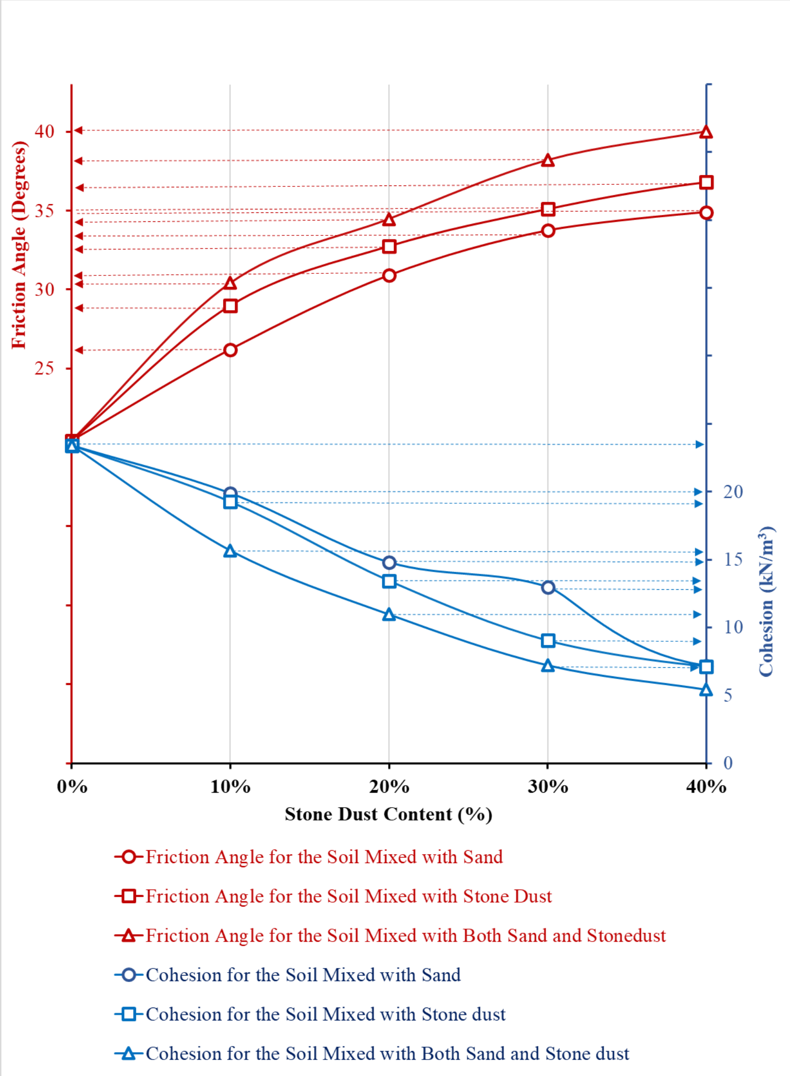

FIGURE 6. Comparison of cohesion and friction angle for soil stabilized with sand, stone dust, and the combination of both.

cohesiveness in the shear strength of soil.

On comparison, the 40% addition of the stone dust in the weak soil resulted in around a 15% rise in MDD and an 80% rise in friction angle, which was more effective than sand. When comparing the compaction and shear strength parameters between the sand and stone dust individually in stabilization of weak soil, it is clear that stone dust is a more effective stabilizer than sand. However, the impacts of the combined mix (both sand and stone dust) from 0% to 40% result in nearly a 1.96 times increase in friction angle when compared to untreated (natural) soil condition, indicating that the combination acts as an efficient stabilizing agent. So, sand and stone dust are cost-effective, long-lasting materials to reinforce weak soils and address engineering and environmental concerns [1, 14, 21, 27, 29, 46].

From a practical standpoint, incorporating 30–40% stone dust emerged as the most effective and economical strategy for enhancing weak soils in Kathmandu Valley. This method is particularly suitable for use in shallow foundations, road subgrade layers, and fill materials in small- to medium-scale infrastructure projects. Moreover, the approach promotes the reuse of local quarry by-products, aligning with sustainable construction practices and cost efficiency [20, 27, 29].

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