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ORIGINAL CONTRIBUTION

# Strength and Index Properties Analysis of Thermally Generated Silica Fume (TGSF) Infused Organic Soil: Soil Swelling Behavior Treatment Breakdown

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***Abstract***— **This study includes an experimental investigation and dissemination of the stabilization of an expansive land from Nandipur, Punjab, Pakistan using silica smoke Thermally Generated Silica Fume (TGSF). The bright buildings are constantly exposed to structural loads; therefore, repairs and maintenance are due to the cyclic source drying of the underlying expansive floors, caused by watering and drying. There is a growing interest in using industrial waste to reduce soil swelling. In this study, in particular, the stabilizing materials were tested for their suitability as puzzles. After arguing that silica vapor TGSF is sufficiently active, it was used in ratios of 5% TGSF, 10% TGSF, and 15% TGSF, based on the soil dry matter. The physical properties and volume change behavior of the natural soil and the treated soil were investigated. After completing the test program, this includes the grain size distribution, the Atterberg limit, the specific weight, the relationship between moisture and dry density, the Unrestricted Compressive Strength (UCS), and the swell potential. It was concluded that there was a remarkable weakening, especially in the swelling and shrinking behavior. In the end, it was concluded that the addition of 5% TGSF was more effective. It is therefore recommended to mix and compact the expansive soils exposed to light loads such as sidewalks, streets and buildings with a maximum of two stories.**

***Index Terms***— **Soil Expansion, Silica Fume, TGSF, Stabilization, UCS, Specific Gravity, Battenberg Limits**

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## I. INTRODUCTION

The main source of the underlying issues is a large floor, often known as an absorbable inflated floor. These soils can alter in volume depending on the quantity of moisture in the soil. Such flooring, when used in essence, causes structures to rise when exposed to high moisture levels, while drying can cause shrinkage and, therefore compaction of buildings [1]. The major earthquake occurred resulting in the cracking and breaking of sidewalks, railways, highway kits, roads, building foundations, floor elements on the floor, lining of canals and reservoirs, irrigation systems, water pipes, and sewer pipes. As a result, if the moisture content of these soils can be stabilized, many of the most serious issues can be resolved. Stabilizers of many varieties are employed to solve this problem [2, 3].

In several nations, damage to major floor buildings has been recognized as the most costly natural hazard [4, 5]. Clay expansion damage is more than the average annual damage caused by floods, storms, earthquakes, and hurricanes in the United States [6]. Developing countries with much rice, such as India, Bangladesh, Malaysia and Iran, produce large quantities of ORS every year [7]. RHA's major features are good adsorption properties at first (due to the small particle size and large specific surface area) [8]. RHA is a good Pozzolanic substance because it can bind clay particles together and reduce water absorption by clay particles, as well as diminish swelling qualities in large soils and increase volume change [9]. Silica dust comes in extremely fine waste with a large specific surface area [10]. Silicon and ferroalloys produce it as a by-product. Large soils benefit from silica vapor.

Fig. 1. Cracks in (a) pavements and (b) buildings

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Unsaturated clay soils with high plasticity are extremely sensitive to water content changes and exhibit large volume fluctuations [11]. Large soils are those whose volume grows as the amount of water in the soil increases. Cracks in sidewalks, trails, sidewalks, foundations, and structures can be caused by these hard plastic floors as shown in fig. 1 [12].

These floors significant swelling and shrinking qualities frequently generate civil engineering issues. Large floors inflate when they come into contact with moisture and shrink when the moisture is removed, as shown in fig. 2 Many structural and substructure difficulties are caused by the amount of changes in soils [13, 14].


Fig. 2. (a) Shrinkage and (b) swelling of expansive soil

Large flooring can be found all throughout the world, wreaking havoc on roadways, walkways, and brightly colored structures. The movement of structures on large soils during the rainy and dry seasons has more possibility as shown in Fig 3

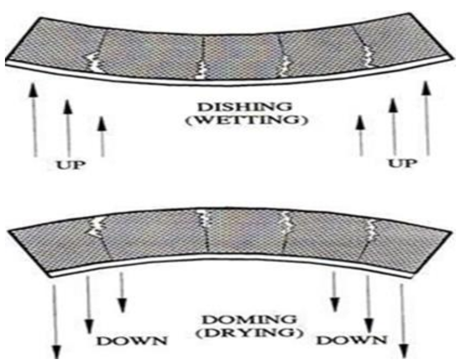


Fig. 3. Foundation movement resulting from seasonal moisture changes

When the water content of extensive soils varies, the volume fluctuates dramatically. Although it is plentiful in dry locations where conditions are favorable for the creation of smectite clay minerals or some types of illite, and these soil types are found all over the world [15]. They feature a small particle size, a big specific surface area, and a high capacity for cation exchange (CEC). The geological and technical properties of the soil, as well as local environmental circumstances, all have a role in the swelling of this form of clay. Soil moisture content, plasticity, and dry density are all technical considerations. The amount of clay fraction in the soil, the initial moisture conditions, and the boundary pressure is the most essential local environmental parameters to consider. It is critical to stabilize these soil types using additives since volume fluctuations in these soil types are the major source of natural catastrophes and cause significant damage to structures and infrastructure [16]. Damage to civil engineering infrastructure placed over vast swaths of land is projected to cost billions of pounds each year. As a result, it's critical to concentrate on enhancing the qualities of clay soils with low-cost approaches like the treatment of industrial waste with a cementitious value. In this study, industrial wastes such as silica vapor TGSF are used to improve the geotechnical properties of expansive soils[17].

Due to increasing economic growth and industrialization, a large amount of waste has to be disposed of, often leading to public health and the environment. Therefore, this waste must be disposed of properly [18]. Using these materials in their structures or basically as stabilizers can be a useful solution to this problem once they have properly developed their properties. It is particularly desired to treat soil with fixed stabilizers of industrial by-products. In many locations throughout the world, stabilized soils are frequently used in construction and foundation applications, especially when local natural/industrial resources are available [19]. To reduce volume changes and promote strength and cohesiveness, soil can be stabilized by mixing it with the correct stabilizers. Natural oils, vegetable fluids, animal drops, and bruised ant species have all been employed as stabilizers for millennia [20]. Chemical treatment is currently the most common approach for treating big soils, and the stabilizers employed are primarily lime, fly ash, cement, and other materials. Many scientists are currently looking into the effects of natural, manufactured, and extracted materials as stabilizers to replace fine-grained soils [21]. The stabilization of huge soils with lime and rice ash mixes, fly ash, and rice shells proved an effective strategy for addressing volume change issues. Pozzolana stabilizers can help to bind soil particles together and minimize clay particle water uptake [22]. Industrial by-products such as slag furnace, fly ash, rich shell, foundry sand, foundry slag, and cement furnace have been studied for their potential to stabilize clay soils [23]. Because of the presence of OH ions in pozzolans, the pH of the soil is raised to around 12.4. When Si and Al, which are part of the clay plate, dissolve and interact with the available $Ca_2+$, pozzolanic reactions occur, forming cement compounds such as calcium silicate hydrates (CSH) and calcium aluminate hydrates (CSH). These chemicals improve the soil's mechanical characteristics and expand it due to their cementing effect.

Following are the objectives of this research study:

- The main purpose of this study is to improve the volume change properties of large soils by using silica vapors as stabilizers and to determine the effect of curing on the effect of stabilization.
- To investigate the effect of the stabilizer on the physical properties of an expensive soil.
- To determine the qualities of stabilized soils in terms of swelling, shrinkage, and consolidation.
- To explore the effect of curing time on the properties of stabilized soils.

## II. MATERIALS AND METHODS

This study consists of characterization and stabilization of Nandipur soil using Silica Fume. All the laboratory tests were performed according to the ASTM standards. Tests were conducted at University of Engineering and Technology, Peshawar, Pakistan.

### A. Materials

Following are the material used in this research study described as under.

#### 1) Silica fume

TGSF Silica fume is indeed a chemical waste from industrial applications, but because of its effective properties it has become a valuable by-product among the Pozzolanic stabilizers [24]. The silica vapor used is available in the form of a suspension or in dry form. In both cases, silica fumes are very reactive with pozzolana due to their fine particles, large surfaces, and high silicon dioxide content. Silica dust originates in the manufacture of silicon metal in the form of very fine silica powder from a blast furnace and is used as a stabilizer to replace fine-grained soil considered as waste. The main effect of silica vapor on the soil is to increase cohesion [25]. More water is needed to wet the large surface area of the silica fumes, which increases the water content of the soil.

TABLE I
OXIDE COMPOSITION OF SILICA FUME USED

| TGSF composition | |
|---|---|
| Oxide | Concentration (%) |
| $Na_2O$ | 0.87 |
| $MgO$ | 4.36 |
| $Al_2O_3$ | 0.33 |
| $SiO_2$ | 69.25 |
| $K_2O$ | 7.18 |
| $MnO$ | 0.05 |
| $Fe_2O_3$ | 0.51 |
| $SO_3$ | 2.94 |

Fig. 4. Dry silica fume

## B. Methodology

The methodology of this research study includes the classification of the soil, the characterization of the Atterberg limits, the compressive strength, the compaction properties, and the swelling potential of large soils. A study was conducted on the effects of silica vapor, lime and an ideal or recommended mixture of silica vapor and lime on the soil properties. The effects and dose of additives were also assessed. A brief description of the methodology is given below.

### 1) Preparing expansive clayey soil

There are large areas in different parts of Pakistan, but this study focuses on large areas in Punjab, Nandipur region. As it has been noted that this floor causes several problems with lightly charged structures, e.g., one-story houses, streets, etc. In the Nandipur region, broad land was identified, and problems related to this land were highlighted. This research has been expanded to stabilize and cure a large amount of soils in this particular region.

### 2) Lab performances

Following are the tests done to evaluate the effect of TGSF in treating the expansive soil reducing swell properties.

- Soil classification by sieve analysis and hydrometer analysis
- Atterberg limits (LL, PL and PI)
- Specific gravity
- Compaction characteristics (Modified Proctor Test)
- UCS
- Swell Potential of Soil


Fig. 5. Google map location of Nandipur region of Pakistan

## III. RESULTS AND DISCUSSION

The first phase of the test program consisted of a TGSF reactivity test to determine the activity and physical properties of the selected expansive soil. The second phase contains volume change studies, which consist of swelling, shrinkage, and compressibility tests of the natural soil and their mixtures with 10% TGSF, 15% TGSF, and 20% TGSF.

Results of untreated and treated soil testing are discussed comprehensively in subsequent pages.

### A. Particle size analysis of soil

Particle size analysis is based on two tests from ASTM standards, a sieve analysis and a hydrometer analysis (ASTM D6913 and ASTM D422). ASTM D6913 sieve analysis was used to perform sorting, sand and fine particle analysis, and ASTM D422 densimeter analysis was used to perform fine soil assessment (clay and silt).

The classification curves of pure earth or black cotton soil and silica fumes are compared. Tone curves indicate that silica vapor contains an increasing amount of particle size particles. The table shows the percentage of particles of different sizes in pure soil and additives used during the research.

TABLE II
TEST RESULTS OF PARTICLE SIZE ANALYSIS OF PURE SOIL AND ADDITIVES

| Samples | Sand (%) | Silt Size Particles (%) | Clay Size Particles (%) |
|---|---|---|---|
| Pure Soil | 8 | 26 | 59 |
| Silica Fume | 0 | 69 | 23 |

The granulometric analysis of pure soil shows the percentage of the material as 9% sand, 28% silt and 63% clay, as the silica vapor in black cotton soil was partly changed by 10%, 10%, 15% and 20%. There is a 63% to 49% decrease in pitch size and an increase in sludge size particles of 28%. Table 2 shows the percentage of particles present in pure soil and in silica treated soil.

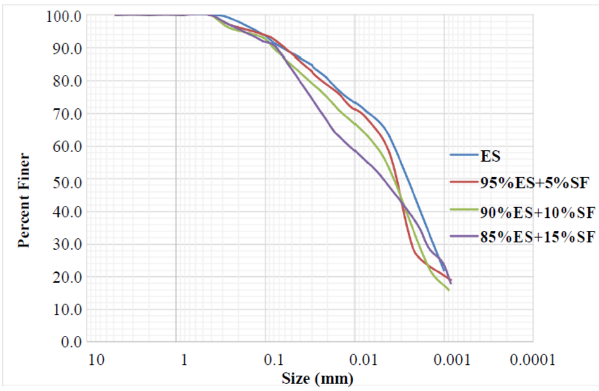


Fig. 6. Gradation curve of silica fume mixed soil and pure soil

TABLE III
TEST RESULTS OF PARTICLE SIZE ANALYSIS PURE SOIL AND SILICA FUME TREATED SOIL

| Samples | Sand (%) | Silt Size Particles (%) | Clay Size Particles (%) |
|---|---|---|---|
| Pure Soil | 8 | 26 | 59 |
| 95% ES + 5% TGSF | 7 | 32 | 55 |
| 90% ES + 10% TGSF | 10 | 33 | 50 |
| 85% ES + 15% TGSF | 9 | 37 | 48 |

### B. Specific gravity (Gs)

The specific gravity of the soil solids with the water pycnometer was performed on the untreated soil and processed according to the standard method specified in ASTM D854. The result of the specific gravity test showed the value of 2,710 through untreated soil (Fig. 7). During the partial substitution process of the soil, part of the untreated soil was replaced by silica fumes with different ratios, 5%, 10%, 15% and 20%. Table IV shows the variation of the value of the specific weight in relation to increasing percentages of additives.

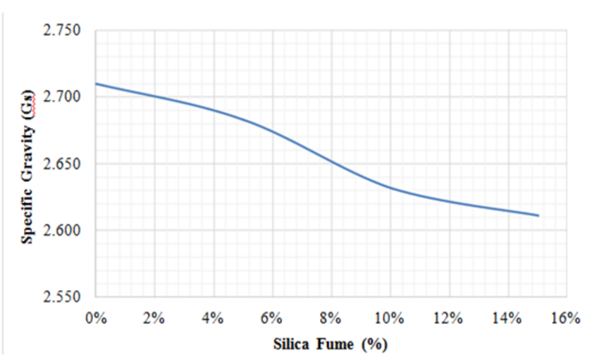


Fig. 7. Variation in specific gravity with an increasing percentage of silica fume

TABLE IV
TEST RESULTS OF SPECIFIC GRAVITY OF PURE SOIL AND TREATED WITH ADDITIVES

| Additives Percentage | Specific Gravity (Gs) |
|---|---|
| 0% | 2.710 |
| 5% | 2.683 |
| 10% | 2.632 |
| 15% | 2.611 |

### C. Atterberg limits

The Casa grande apparatus was used to determine the liquid boundary of the untreated floor, while 1/8 inch wires were made to control the plastic boundary of the floor. These tests were performed according to ASTM D4318-05. The results of the untreated soil test show that the liquid limit values are 45.81%, the plastic limit 36.63%, and the plasticity index 25.05%. Fig. 8 shows a relationship between the increased percentage of silica, partially replaced in black cotton soil, and the liquid boundary and the plastic boundary. The test results are shown in Table 4.6 if silica dust is present. Partially replaced by black cotton or broad earth, the liquid limit of the treated soil increases from 45.81% to 47.40%, the plastic limit from 36.63% to 36.01% and the plasticity index increased from 25.05% to 29.05%.

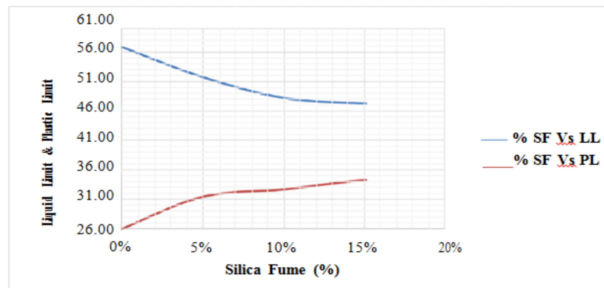


Fig. 8. Variation in LL & PL with an increasing percentage of silica fume

TABLE V
TEST RESULTS OF ATTERBERG LIMITS OF PURE SOIL AND SILICA FUME TREATED SOIL

| Samples | Liquid Limit (%) | Plastic Limit (%) | Plasticity Index (%) |
|---|---|---|---|
| Pure Soil | 45.81 | 36.63 | 25.05 |
| 95% ES + 5% TGSF | 43.83 | 36.96 | 26.86 |
| 90% ES + 10% TGSF | 43.73 | 34.65 | 25.90 |
| 85% ES + 15% TGSF | 47.40 | 36.01 | 29.05 |

### D. Soil classification

The classification of the soil according to the USCS classification system (ASTM D2487) and the AASHTO classification system (ASTM D3282) requires an analysis of both the particle size and the results of the Atterberg boundaries after cultivation. Untreated or black cotton flooring is classified as oily clay CH (USCS) and A - 7- 6 (AASHTO). If the black cotton floor is partially replaced by different silica steam floor classification percentages, the floor remains the same as CH and A - 7 - 6. If different lime percentages partially replace the soil, the soil classification changes from CH to ML (Schlick) and in the case of the AASHTO classification system from A - 7 - 6 to A - 7 - 5.

If the soil is partially replaced by a mixture of lime and silica vapors with different percentages, the soil classification changes from CH to MH (elastic silt) ML (silt), and in the case of the AASHTO classification system, it remains the same in A- 7 - 6.

### E. Unconfined compressive strength

The sample was prepared and tested according to ASTM D2216 to check the free compressive strength (UCS) of the untreated floor. Is 152 kpa Calculated resistance for untreated black cotton flooring. Change the unrestricted compression resistance of the soil treated with silica vapor to different doses of 5%, 10%, and 15%. When the silica fabric was partially replaced in a broad black cotton floor, the free compressive strength was increased to 160 kpa with a 5% change and then reduced to 15%. Table VI shows the results of the free compressive strength tests with an increasing amount of additives.

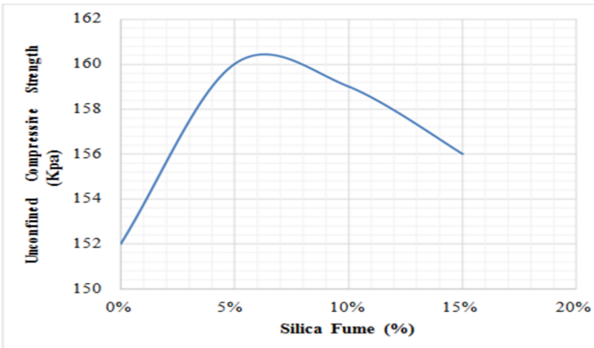


Fig. 9. Variation of unconfined compressive strength with increasing percentages of silica fume

TABLE VI
TEST RESULTS OF UNCONFINED COMPRESSIVE STRENGTH OF PURE SOIL AND TREATED SOIL WITH ADDITIVES PERCENTAGES

| Unconfined Compressive Strength (Kpa) | |
|---|---|
| Additives Percentages | Silica Fume |
| 0% | 152 |
| 5% | 160 |
| 10% | 159 |
| 15% | 156 |

## F. Swell test

Large soils have swelling properties under different conditions, and different stabilizers have been used to control these properties, and the results have been analyzed, silica smoke from the Nandipur region of large soils (which gives positive results to reduce the swelling potential in the soil). According to ASTM D4546, pure soil is subjected to a swelling test, which is a test to determine the swelling potential of the soil, the calculation shows 6.3% swelling. If the soil is partially replaced by silica vapor, the value of the calculated swell percentage decreases. Fig. 10 shows a change in the swell percentage with an increasing amount of silica vapor, showing a decrease of 6.3% to 0.7%. Table VII shows the test results of all partially modified additives in black cotton to calculate the swelling potential of the soil.

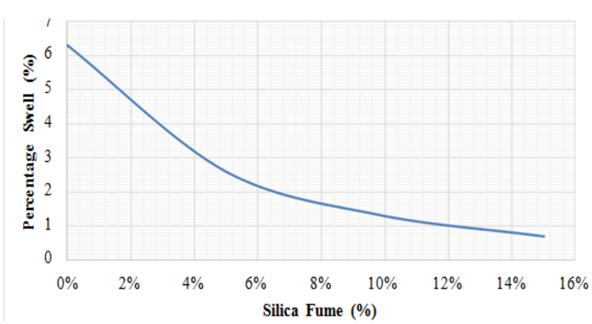


Fig. 10. Variation in swell percentage with an increasing percentage of silica fume

TABLE VII
TEST RESULTS OF SWELL POTENTIAL OF UNTREATED AND TREATED SOIL WITH INCREASING PERCENTAGES OF ADDITIVES

| Swell Percentage (%) | | |
|---|---|---|
| Additives (%) | Percentage | Silica Fume |
| 0 | | 6.3 |
| 5 | | 2.6 |
| 10 | | 1.3 |
| 15 | | 0.7 |

## G. Moisture-density relationship

A compression test was performed using a modified force. The results of this test show a maximum dry density (MDD) of 119.5 pounds/ft3 and Optimum Moisture Content (OMC) of 14.00 percent. ASTM D1557-12 was followed to perform compression tests. Fig. 11 shows a moisture-density ratio curve with an increasing percentage of silica dust. The test results are shown in Table VII and calculated from the moisture density ratio results. Partial replacement of additives with a constant decrease in MDD and an increase in OMC when the silica vapor is changed, the MDD decreases by 119.5 pounds/ft3 to 114.2 pounds/ft3, and the OMC is less than 14.00% 18.4%. Table VIII shows the maximum dry density values, and the optimum moisture content for each percentage of silica vapor added to the sample.

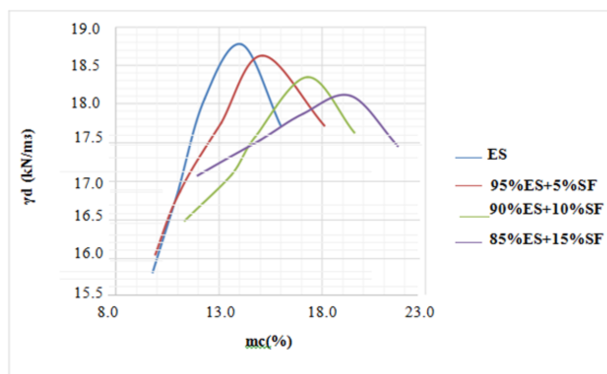


Fig. 11. Relationship between dry density and moisture content of silica fume mixed soil and pure soil

TABLE VIII
MDD VALUES OF PURE SOIL AND SILICA FUME TREATED SOIL

| Samples | Maximum Dry Density(%) | Optimum Moisture Content(%) |
|---|---|---|
| Pure Soil | 119.5 | 14.0 |
| 95% ES + 5% TGSF | 118.0 | 14.4 |
| 90% ES + 10% TGSF | 116.8 | 15.7 |
| 85% ES + 15% TGSF | 115.1 | 17.1 |

## H. Compaction characteristics

Modified Proctor tests were performed at different rates in natural soils and mixtures with TGSF. The results of the compression tests to evaluate the optimum water content and maximum dry density are shown in Fig. 11. A summary of the compression test results is given in Table IX. As can be seen, the additives usually reduced the maximum dry density while increasing the optimum water content.

TABLE IX
COMPACTION TEST RESULTS

| Sample | Optimum Water Content(%) | Maximum Dry Density (g/cm3) |
|---|---|---|
| 8% TGSF | 29 | 1.63 |
| 10% TGSF | 24 | 1.60 |
| 12% TGSF | 25 | 1.65 |
| 14% TGSF | 26 | 1.64 |
| 16%TGSF | 30 | 1.67 |

## IV. CONCLUSION

Following are the conclusion points of this investigation

- The soil of the Nandipur region has higher clay content in its composition, which leads to an increase in the swelling potential of the soil, while the additives are partially altered. It was concluded that he was there. A decrease in the size of the clay particles and an increase in the size of the silt particles were observed, which explains the decrease in the potential for swelling of the soil due to the decrease in the number of particles of the size. Clay.
- The Atterberg limit values were reduced by adding silica smoke, including liquid limit value, plastic limit value, and plasticity index. LL goes from 56.40% to 46.22%.
- The specific gravity of the natural soil is affected by replacement, and the results show a decrease in the value of the specific gravity.
- Soil classification adds the percentage of TGSF to the conclusion that soil classification ranges from CH to ML (USCS) and A-7-6 to A-7-5 (AASHTO).
- In any case, it is concluded that the partial exchange process reduces the maximum dry density and that the optimum water content for silica vapors is changed by up to 10%.
- A free compressive strength test determines that the soil mixed with silica fumes indicates a 15% increase in the maximum value of the UCS change by 5%.
- The mixed soil of silica fumes shows a decrease in the swelling value due to the increased value of particles in silt size. The swelling is reduced by 92.06%.

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## References

[1] D. Zarehaghi, M. R. Neyshabouri, M. Gorji, R. Hassanpour, and A. Bandehagh, ``Growth and development of pistachio seedling root at different levels of soil moisture and compaction in greenhouse conditions,'' *Soil and Water Research*, vol. 12, no. 1, pp. 60-66, 2017. doi: https://doi.org/10.17221/146/2015-swr

[2] E. Cokca, ``Use of class c fly ashes for the stabilizationof an expansive soil,'' *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 127, no. 7, pp. 568-573, 2001. doi: https://doi.org/10.1061/(ASCE)1090-0241

[3] R. H. Karol, *Chemical Grouting and Soil Stabilization*. Boca Raton, FL: CRC Press, 2003.

[4] K. Goltz, J. Yamori. (2020) Tsunami preparedness and mitigation strategies. [Online]. Available: https://bit.ly/3hRUD4t

[5] M. Attom, M. Kou, and N. Al-Akhras, ``Geo environmental utilization of iron-filing with cement in soil stabilization,'' *International Journal of Technology and Engineering Studies*, vol. 2, no. 2, pp. 32-37, 2016. doi: http://dx.doi.org/10.20469/ijtes.2.40001-2

[6] D. Hyndman and D. Hyndman, *Natural hazards and disasters Cengage Learning*. Boston, MA: Cengage Learning, 2017.

[7] K. E. Wiens, P. A. Lindstedt, B. F. Blacker, K. B. Johnson, M. M. Baumann, L. E. Schaeffer, H. Abbastabar Sr, F. Abd-Allah, A. Abdelalim, I. Abdollahpour *et al.*, ``Mapping geographical inequalities in oral rehydration therapy coverage in low-income and middle-income countries, 2000-17,'' *The Lancet Global Health*, vol. 8, no. 8, pp. 1038-1060, 2020. doi: https://doi.org/10.1016/S2214-109X(20)30230-8

[8] A. P. Vieira, R. D. Toledo Filho, L. M. Tavares, and G. C. Cordeiro, ``Effect of particle size, porous structure and content of rice husk ash on the hydration process and compressive strength evolution of concrete,'' *Construction and Building Materials*, vol. 236, pp. 1-9, 2020.

[9] Y. Zaika and E. A. Suryo, ``The durability of lime and rice husk ash improved expansive soil,'' *GEOMATE Journal*, vol. 18, no. 65, pp. 171-178, 2020. doi: https://doi.org/10.21660/2020.65.5539

[10] A. Mehta and D. K. Ashish, ``Silica fume and waste glass in cement concrete production: A review,'' *Journal of Building Engineering*, vol. 29, pp. 1-47, 2020. doi: https://doi.org/10.1016/j.jobe.2019.100888

[11] M. Y. Fattah and A. H. Al-Lami, ``Behavior and characteristics of compacted expansive unsaturated bentonite-sand mixture,'' *Journal of Rock Mechanics and Geotechnical Engineering*, vol. 8, no. 5, pp. 629-639, 2016. doi: https://doi.org/10.1016/j.jrmge.2016.02.005

[12] S. K. V. A. Bujang B.K. Huat, Arun Prasad, *Ground Improvement Techniques*. Boca Raton, FL: CRC Press, 2019.

[13] G. T. Demirkol, M. Ozcoban, and N. Tufekci, ``Removal rate of compacted clay soil in the batch and continuous reactors and its permeability,'' *Journal of Advances in Technology and Engineering Research*, vol. 3, no. 5, pp. 176-183, 2017. doi: https://doi.org/10.20474/jater-3.5.2

[14] D. K. Rao, P. Pranav, and M. Anusha, ``Stabilization of expansive soil with rice husk ash, lime and gypsum-an experimental study,'' *International Journal of Engineering Science and Technology*, vol. 3, no. 11, pp. 8076-8085, 2011.

[15] Q. Fang, H. Hong, T. J. Algeo, X. Huang, A. Sun, G. J. Churchman, J. Chorover, S. Chen, and Y. Liu, ``Microtopography-mediated hydrologic environment controls elemental migration and mineral weathering in subalpine surface soils of subtropical monsoonal china,'' *Geoderma*, vol. 344, pp. 82-98, 2019. doi: https://doi.org/10.1016/j.geoderma.2019.03.008

[16] J. Khazaei and H. Moayedi, ``Soft expansive soil improvement by eco-friendly waste and quick lime,'' *Arabian Journal for Science and Engineering*, vol. 44, no. 10, pp. 8337-8346, 2019. doi: https://doi.org/10.1007/s13369-017-2590-3

[17] F. S. Gutiérrez. (2016) Sinkhole hazards. [Online]. Available: https://bit.ly/3I0tJSj

[18] K. L. Thyberg and D. J. Tonjes, ``Drivers of food waste and their implications for sustainable policy development,'' *Resources, Conservation and Recycling*, vol. 106, pp. 110-123, 2016. doi: https://doi.org/10.1016/j.resconrec.2015.11.016

[19] V. M. Ramdas, P. Mandree, M. Mgangira, S. Mukaratirwa, R. Lalloo, and S. Ramchuran, ``Review of current and future bio-based stabilisation products (enzymatic and polymeric) for road construction materials,'' *Transportation Geotechnics*, vol. 27, pp. 1-56, 2021. doi: https://doi.org/10.1016/j.trgeo.2020.100458

[20] K. Cmiel and J. D. Peters, *Promiscuous Knowledge*. Chicago, IL: Chicago Press, 2020.

[21] L. Liu, W. Li, W. Song, and M. Guo, ``Remediation techniques for heavy metal-contaminated soils: Principles and applicability,'' *Science of the Total Environment*, vol. 633, pp. 206-219, 2018. doi: https://doi.org/10.1016/j.scitotenv.2018.03.161

[22] A. Behnood, ``Soil and clay stabilization with calcium-and non-calcium-based additives: A state-of-the-art review of challenges, approaches and techniques,'' *Transportation Geotechnics*, vol. 17, pp. 14-32, 2018. doi: https://doi.org/10.1016/j.trgeo.2018.08.002

[23] P. Cong and L. Mei, ``Using silica fume for improvement of fly ash/slag based geopolymer activated with calcium carbide residue and gypsum,'' *Construction and Building Materials*, vol. 275, pp. 1-16, 2021. doi: https://doi.org/10.1016/j.conbuildmat.2020.122171

[24] L. Benassi, A. Zanoletti, L. Depero, and E. Bontempi, ``Sewage sludge ash recovery as valuable raw material for chemical stabilization of leachable heavy metals,'' *Journal of Environmental Management*, vol. 245, pp. 464-470, 2019. doi: https://doi.org/10.1016/j.jenvman.2019.05.104

[25] J. K. H. Wong, S. T. Kok, and S. Y. Wong, ``Cementitious, pozzolanic and filler materials for DSM binders,'' *Civil Engineering Journal*, vol. 6, no. 2, pp. 402-417, 2020. doi: https://doi.org/10.28991/cej-2020-03091479