Jordan Journal of Civil Engineering, Volume **20**, No. **2**, **2026**
DOI: https://doi.org/10.14525/JJCE.v20i2.01

Jordan Journal of Civil Engineering

Journal homepage: https://jjce.just.edu.jo

Influence of Barite Powder as a Dual-purpose Stabilizer and Cushioning Material on the Performance of Expansive Soil

E. Ramanjaneya Raju[1)*], G. Sabarish[2)], S. Lakshmi Ganesh[2)], N.A.G.K. Manikanta [3)]

[1)] *Assistant Professor, Department of Civil Engineering SRKR Engineering College, Bhimavaram 534204, India and Coordinator, Centre for Research in Geotechnical and Transportation Engineering, S.R.K.R. Engineering College, Bhimavaram 534204, India. * Corresponding Author E-Mail: ramcivil06@gmail.com, err@srkrec.ac.in*

[2)] *Assistant Professor, Department of Civil Engineering, SRKR Engineering College, Bhimavaram 534204 India.*

[3)] *Assistant Professor, Department of Civil Engineering, Sri Vishnu Engineering College for Women (SVECW), Bhimavaram 534204, India.*

ARTICLE INFO

Article History:
Received: 14/4/2025
Accepted: 13/9/2025

ABSTRACT

Construction of civil engineering infrastructure in regions with significant deposits of expansive clay is generally challenging due to the volumetric changes of the soil's behavior. Moisture variations can cause expansive soils to become volumetrically unstable, which results in structural damage. Physical alteration and cushion techniques were the promising techniques for controlling the problems triggered by these soils. In the present study, barite powder, which is processed from barite mineral, was used as an additive to alter the behavior of expansive clay. The use of barite powder in the treatment of expansive clay is seldom explored. To assess the efficacy of barite powder as a stabilizer, free swell index (FSI), consistency limits, compaction parameters, unconfined compressive strength, hydraulic conductivity, California bearing ratio (CBR), heave and stress-settlement characteristics were determined on the unblended and blended samples. In all the tests, barite powder was added to expansive clay up to 30% in increments of 5%. As the amount of the barite powder increased, FSI, plasticity, and heave decreased, while the strength, CBR, and stress-settlement characteristics were improved. Further, CBR (soaked) tests were conducted on the untreated and treated clay beds cushioned with barite powder of 50-mm thickness. The CBR of the untreated and treated clay beds provided with barite powder cushion enhanced significantly. The test results revealed that the use of barite powder as a blended and cushion material can be a viable alternative for low-volume pavement sub-grades.

Keywords: Expansive clay, Barite powder, Physical alteration, Cushion techniques, Sustainability.

INTRODUCTION

The vulnerability of expansive soils to significant volume changes induced by fluctuations in moisture content renders them extremely problematic (Chen, 1988; Lu & Likos, 2004). The smectite mineral group, especially, montmorillonite, is mainly responsible for the swell-shrink behaviour of expansive clays in response to variations in water content (Rees & Thomas, 1993). Variations in moisture can render them volumetrically unstable, leading to structural damage. The universal issue of expansive soils threatening the sustainability of civil engineering structures has resulted in major financial losses in various nations (Nelson &

Miller, 1992: Snethan, 1979; Gourley, 1993; Petry & Little, 2002; Puppala, 2005; Ito & Azam, 2013).

The significant remedial measures, such as physical alteration (Satyanarayana, 1966; Phanikumar et al., 2012), mechanical alteration (Katti et al., 1969; Katti, 1978), chemical alteration (Cokca, 2001; Yadu & Tripathi, 2013; Fattah et al., 2015; Dash & Hussain, 2015; Gadouri et al., 2017; Phanikumar & Raju, 2020; Nagaraju & Prasad 2020; Ramanjaneya Raju et al., 2021; Al-Swaidani & Meziab, 2021; Vikas & Ramana, 2023; Hamid Gadouri, 2023; Salih et al., 2025; Driss et al., 2025) and special foundation techniques (Satyanarayana, 1966; Rao et al., 2007) were devised to alleviate the challenges brought by expansive soils. Among these available methods, physical alteration and mechanical alteration or cushion techniques have gained significance because of their efficacy, particularly in economic viability. In physical alteration, the expansive soil in the top layers was removed, pulverized and blended with non-expansive particles and then compacted. Heave decreased as non-expansive particles replaced the expansive particles. Investigations on sand-clay mixes revealed that both the rate and magnitude of heave reduced as the amount of sand in the mixes increased. Moreover, compressibility parameters such as a_v and c_c, decreased as the amount of sand in the mixes increased (Phanikumar et al., 2012). In sand-clay mixtures, the gradation of sand plays a key role in the behavior of the expansive soil. It was noticed that utilization of medium sand fraction is more effective for enhancing the strength of the clay (Nagaraj, 2016). When quarry dust (QD) is blended with expansive soil, the swell potential, and compressibility characteristics were consistently improved (Kennedy et al., 2019). The free swell index (FSI) and swelling pressure of the expansive clay significantly reduced with the addition of fine sand from 0% to 25% (Phanikumar et al., 2021). Adding 15% QD to the clay, the maximum dry density (MDD), unconfined compressive strength and CBR increases, which suggests the suitability of utilizing quarry dust to sustainable construction (Sudhakar et al., 2021), To achieve the required enhancement in the properties of expansive soils, it is advised to consider more than 30% of sand, which reduces soil suction and modifies the properties of the clay by decreasing permeability, heave and compressibility (Ammar et al., 2024). The addition of waste marble dust and fine clinker gravel effectively reduces the FSI, plasticity characteristics, optimum moisture content and significantly increases the MDD, unconfined compressive strength (UCS) and CBR (Belihu et al., 2024).

In mechanical alteration, the uppermost deposits of the expansive clay stratum are removed and replaced with non-expansive particles. These non-expansive particles are compacted to the required density to form the cushion. Cohesive non-swelling layers and sand cushions are coming under mechanical stabilization (Satyanarayana, 1966; Katti, 1969; Katti, 1978). Cement-stabilized fly ash cushion and cement-stabilized ground granulated blast furnace slag (GGBS) cushion can significantly reduce the heave of the clay beds (Rao et al., 2008; Sridevi, 2016). The heave/swelling of the clay was effectively reduced with chemically stabilised soil cushion (Murthy & Praveen, 2008). The use of lime-stabilized clay cushion increases the clay strength and durability (Sahoo & Pradhan, 2010). CBR of the clay enhanced with the inclusion of silicafume-stabilised lateritic soil cushion (Phanikumar et al., 2019). Copper slag cushion independently and in combination with lime can considerably decrease the heave of the clay beds (Lavanya & Kumar, 2022).

Barite is a naturally occurring barium sulfate ($BaSO_4$) mineral. It usually occurs as crystals in sedimentary rocks. It is usually of hydrothermal origin and found in sedimentary rocks as concretions. Barite powder is manufactured through the processes of crushing, grinding and purifying natural barite minerals. It is a multi-faceted mineral with numerous applications. Because of its high specific gravity, low solubility, and chemical inertness, it is essential in a wide variety of applications, like oil and gas industry, paints and coatings, construction, water purification systems and soil stabilization… etc. (Raghu, 1998). China and India are the leading makers of barite. The primary end-use sector for barite is the oil and gas industry, which drives most of the world's consumption at about 85% (Isabel et al., 2023). Barite powder is highly efficacious in reducing the FSI and enhancing the MDD and CBR of the clays (Santhosini et al., 2017). Barite powder can be used as a substitute for sand (Saidani et al., 2015). Barite powder content significantly influenced the UCS performance (Falciglia et al., 2016).

This research presents a laboratory study conducted to investigate the impact of barite powder on the performance of expansive clay. This work describes the influence of barite powder on the index and engineering characteristics of an expansive clay. The index properties, compaction behavior, unconfined compressive strength, hydraulic conductivity, CBR, heave and stress-settlement characteristics were determined at different barite powder contents. Further, CBR tests were performed on the barite powder-treated clay with and without barite powder cushion to make it suitable for pavement sub-grades.

EXPERIMENTAL INVESTIGATION

Materials

Expansive Soil: The soil used in the research was gathered from the village of Rayalam, Bhimavaram, A.P., India. From the laboratory investigation, the free swell index was observed as 130%, which indicates a high degree of expansion. The soil was categorized as *CH* according to the Unified Soil Classification System (*USCS)*, based on the consistency limits.

Barite Powder: The barite powder is collected from Sri Balaji Micro pulverizing mill, Dwaraka Nagar, Kadapa, Andhra Pradesh, India. It was classified as *SP*. Table 1 & Table 2 respectively depict the properties & chemical composition of the clay and barite powder. Figures 1 & 2 respectively show the location map and particle size distribution curve of the material used.

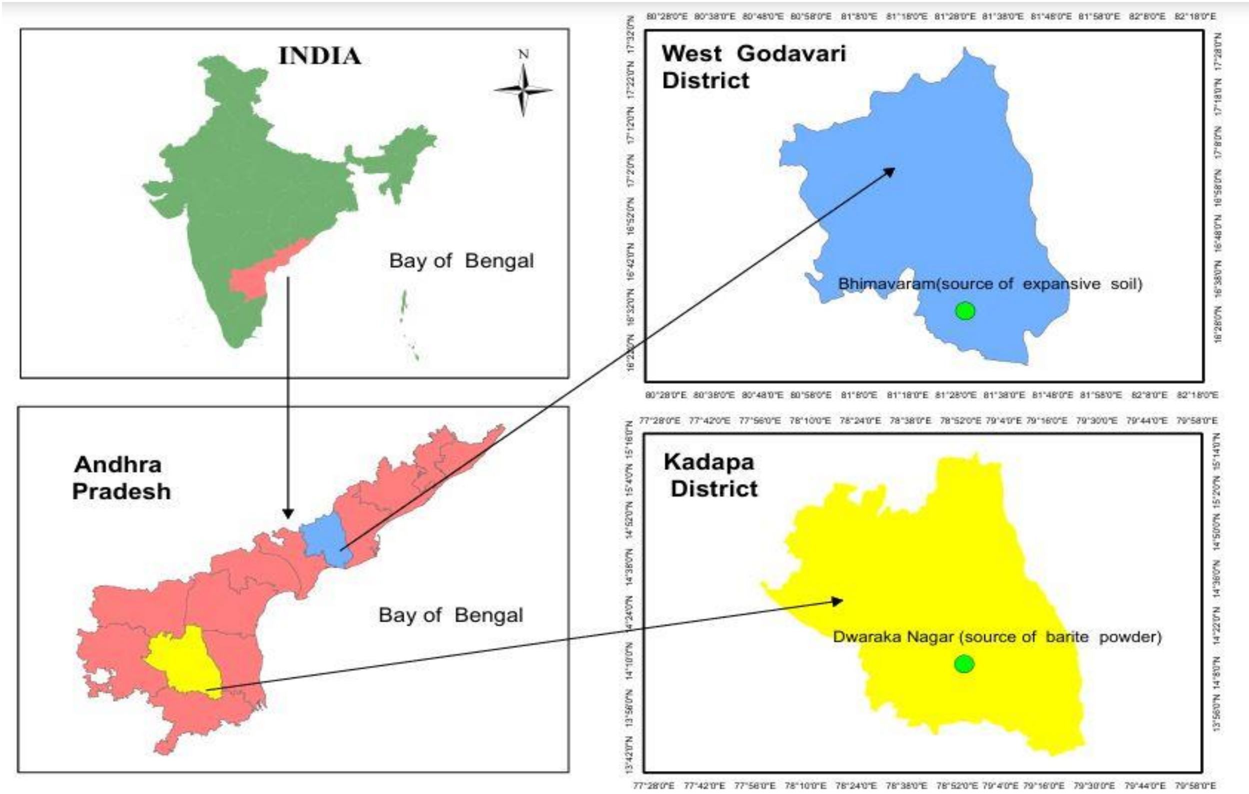


Figure 1. Geological location of the materials used

Experiments Conducted and Variables Studied

Liquid limit (LL), plastic limit (PL), free swell index (FSI), Standard Proctor compaction, unconfined compressive strength, hydraulic conductivity, California Bearing Ratio (CBR), and heave tests; plate load tests were performed on the clay beds treated with barite powder. In all the blends, barite powder content varies as 0, 5, 10, 15, 20, 25 and 30% by dry mass of the clay. The ASTM codes, such as ASTMD4318-00 for consistency limit tests, ASTMD5890-02 for FSI tests, ASTM 2000-D698a for compaction tests, ASTM 2000-D2166 for UCS tests, and ASTM D1833-05 for CBR tests, were followed for conducting the laboratory tests. Further, CBR tests were performed on the barite powder-treated clay with and without barite powder cushion to make it suitable for pavement sub-grades. Figures 3 & 4 respectively show the methodology flow chart and photographs of the experimental program.

Table 1. Properties of clay and barite powder

	Clay	**Barite powder**
Specific gravity, G	2.68	4.20
Gravel (%)	0	-
Sand (%)	2.0	83.5
Silt (%)	28.5	16.5
Clay (%)	69.50	-
Liquid limit, LL (%)	88	NP
Plastic limit, PL (%)	26	NP
Plasticity index, PI (%)	62	NP
Free swell index, FSI (%)	130	-
Soil classification	CH	SM
Optimum moisture content, OMC (%)	28.50	-
Maximum dry density, MDD (kN/m^3)	13.55	-

Table 2. Chemical composition of clay and barite powder

Component	**Quantity (%)**	
	Expansive clay	**Barite powder**
Silica (SiO_2)	63.00	3.20
Barium sulphate ($BaSO_4$)	-	95.0
Alumina (Al_2O_3)	21.50	0.70
Ferric oxide (Fe_2O_3)	4.50	0.80
Calcium oxide (CaO)	1.50	-
Magnesium oxide (MgO)	1.00	-
Potassium oxide(K_2O)	1.25	-
Sodium oxide (Na_2O)	7.00	-
Loss on ignition	0.25	0.30

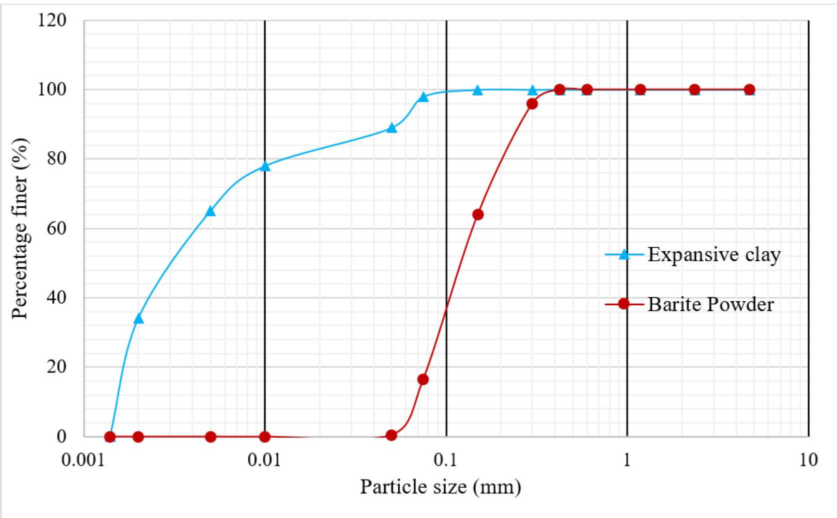


Figure 2. Particle size distribution curve of the expansive clay and barite powder

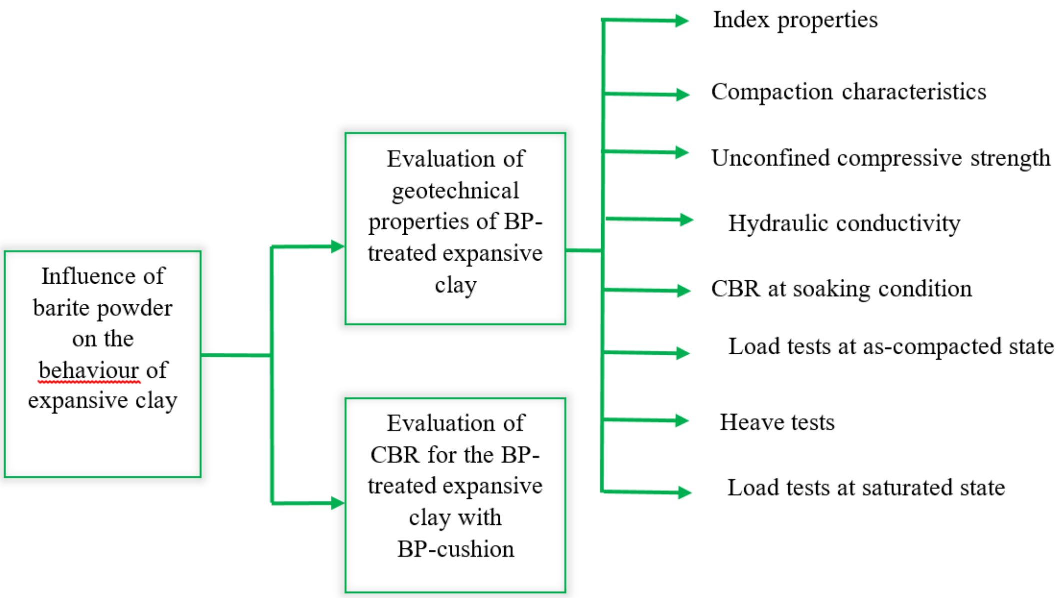
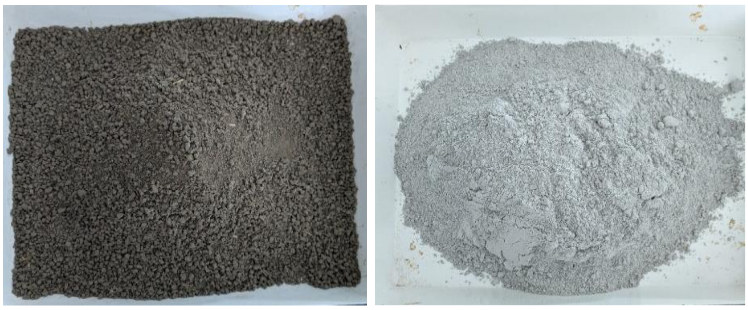


Figure 3. Methodology flow chart for the experimental program

Mixing Procedure: The sample preparation process entails initially pulverizing the dry soil samples, subsequently followed by sieving. After sieving, depending on the dosages of the additive and the dry weight of the soil, the amounts of barite powder are meticulously measured and blended with soil. To achieve uniform distribution of the barite powder in the soil, the barite powder was evenly spread on the prepared dry soil sample and accurately mixed by using a hand mixing technique. The mixing technique was executed with proper care to attain a uniform mix. Careful blending throughout the total process helps in achieving uniform mixing of barite powder in the soil.



a) Expansive soil b) Barite powder

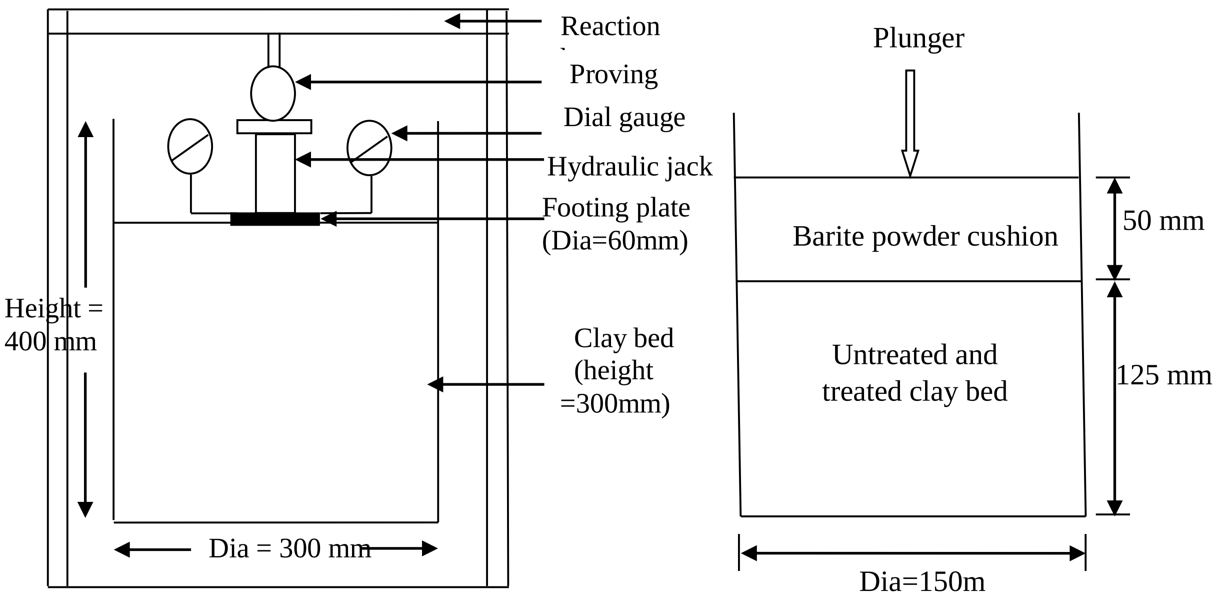
c) UCS test d) Hydraulic conductivity e) CBR test

Figure 4. Photographs of experimental program

Plate Load Tests: These tests were conducted in as-compacted (unsaturated) and saturated conditions. Tests were performed on the untreated clay bed and barite powder-blended clay beds with varying the barite powder content. In both conditions, the tests were performed using a reaction type of loading with a loading jack. Figure 5 (a) depicts the schematic view of experimental set-up. The clay beds were all compacted in a mould of 300-mm diameter and 400-mm height to their respective OMC and MDD and tests were conducted according to ASTM D 1196-93. By considering the undrained strength of the parent clay, every stress increment was chosen as 20kPa for all the clay beds and continued up to a maximum stress of 120kPa. Upon each stress increment of 20 kPa, the settlement of the clay beds was observed at intervals of time of 1, 2.25, 4, 6.25, 9, 16 and 25 minutes and thereafter at intervals of 1hour by using a dial gauge. With every stress increment, the settlement was monitored, and the next increment of stress was applied when the rate of settlement was less than 0.02mm/minute.

To conduct the load tests at saturation condition, clay beds were compacted corresponding to their OMC and MDD and the beds were perpetually saturated through the addition of water from the surface of the clay bed. During the saturation, clay beds were undergoing heave. Heave/swelling was monitored by placing a dial gauge on the weightless surface plate which was resting on the clay bed surface. At suitable intervals of time, the heave/swelling of the specimens was monitored. The saturation continued till the clay bed reached its equilibrium heave (5 days-from pilot studies). Once the clay beds attained saturation, the 2nd category of load tests were conducted by removing the surface plate and then considering the load test set-up as described in Figure 5. In this saturated condition also, the stress increment was considered as 20kPa and increased up to 120kPa. The rest of the procedure was the same as in as-compacted condition.

California Bearing Ratio (CBR) (soaked) tests were performed on the unblended clay beds and barite powder-blended clay beds without cushion and with barite powder cushion of 50-mm thickness. All the samples were compacted at their respective OMC and MDD in the CBR mould of 150-mm diameter and 175-mm height. Figure 5 (b) shows the schematic view of the test set-up. The CBR tests were conducted according to ASTM D1883-05. All the tests were conducted in laboratory conditions only.



(a) Plate load tests (b) CBR tests

Figure 5. Schematic representation of testing arrangement

DISCUSSION OF TEST RESULTS

Influence of Barite Powder on LL, PL, PI and FSI

Figure 6 depicts the variation of FSI with barite powder content. From the figure, it was observed that, with an increase in barite powder content from 0 to 30%, the FSI decreased from 130% to 52%, indicating a reduction of 60%, rendering the clay-additive blends almost non-swelling. The results are aligned with earlier research (Phanikumar et al., 2021; Ramanjaneya et al., 2021; Salih, 2025). The reduction in FSI can be attributed to the replacement of expansive clay particles with non-expansive barite powder particles. The FSI of the expansive clay particles was high due to the presence of smectite group of mineral montmorillonites. When the finer particles of clay are replaced with non-expansive large sized barite powder particles, the FSI goes down.

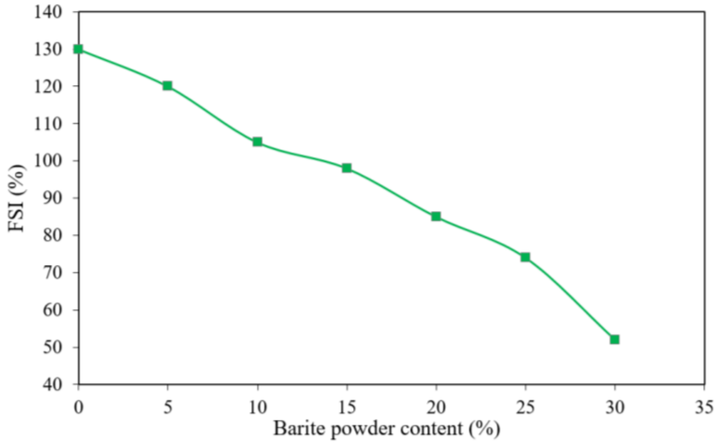


Figure 6. Influence of barite powder on FSI

Figure 7 depicts the influence of barite powder on plasticity characteristics of the clay. From the data, it was noticed that, as the amount of barite powder increased, LL decreased, and PL increased. The reduction in LL and increase in PL with increasing barite powder content resulted a decrease in the plasticity index (PI). LL reflects the water content at which clay behaves like a liquid. Clays having finer particles with larger surface area need a huge quantity of water, allowing the material to have a liquid-like behavior. When the silt-sized larger particles of barite powder added to the clay, the size of the particles increases, resulting in a reduction in LL. LL diminishes as the volume of water required for the blends with enhanced particle size to behave as a liquid decreases. When the barite powder content increased from 0 to 30%, LL decreased from 88% to 48%, indicating a reduction of 45%. PL shows an enhancement in barite powder-clay blends. As a result, PI decreased with increase in the barite powder are content. PI decreased from 62% to 15%, showing a reduction of 76%, rendering the blends low plastic. A similar trend was observed in earlier research (Al-Swaidani et al., 2021; Ramanjaneya et al., 2021).

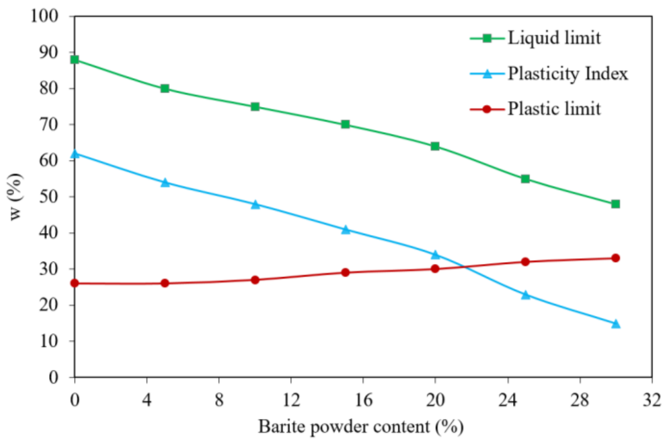


Figure 7. Influence of barite powder on index properties

Influence of Barite Powder on Compaction Behavior

Figure 8 depicts the compaction characteristics of the expansive clay treated with varied percentages of barite powder. The data demonstrated that the compaction curves moved to the left side and upward, revealing that the barite powder-treated clay blends stabilized and produced higher dry density values for prescribed water contents in comparison with untreated clay. MDD values increased as a result of this behavior, whereas OMC decreased. When the quantity of barite powder particles added to the clay increases, the resistance offered by the particles also increases, which results in higher densities. The variation in compaction parameters with the amount of barite powder is shown in Figure 9. The highest maximum dry density was observed for 30% barite powder-blended clay. The dry density values increase as the barite powder content increases. The addition of barite powder was restricted to 30%, because excess additive content may lead to the formation of new soil structures.

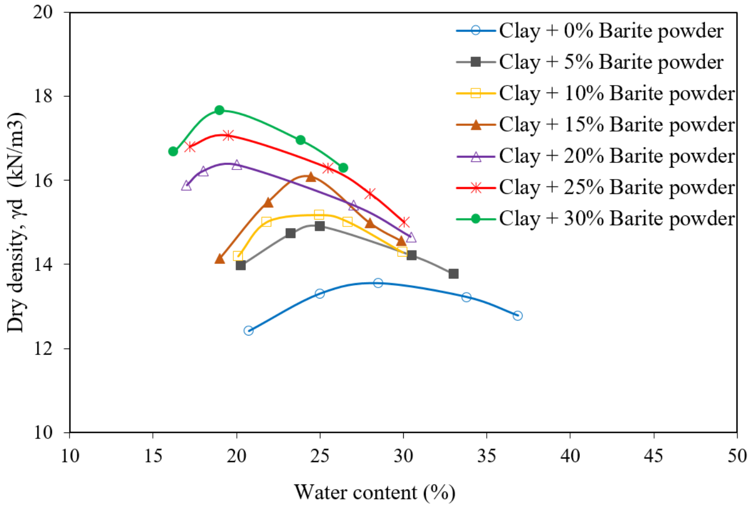


Figure 8. Influence of barite powder on compaction characteristics

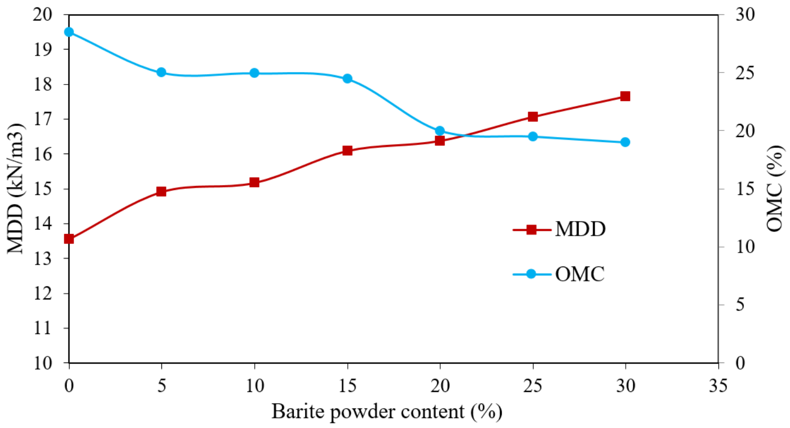


Figure 9. Influence of barite powder content on OMC and MDD of clay

Influence of Barite Powder on Unconfined Compressive Strength (UCS) and Hydraulic Conductivity (k) of the Clay

UCS tests were performed on the unblended and barite powder-treated clay beds corresponding to their OMC and MDD. From the experimental results, it was noticed that UCS or peak stress increased significantly with the addition of barite powder amount. The rise in peak stress is attributable to the increase in maximum dry density of the clay-additive blends. Addition of barite powder to the clay blends increases their resistance, which helps them better withstand applied axial compressive stresses. This increased resistance is contingent upon the quantity of additives used. The peak stress was respectively 148, 220, 255, 290, 345, 382 and 425 kPa at the barite powder contents of 0, 5, 10, 15, 20, 25 and 30%. A significant improvement of 187% in UCS was observed at 30% barite powder content. Thus, the 30% barite powder-treated specimen exhibits the highest resistance. A similar trend was observed in previous studies (Gadouri et al., 2017; Sudhakar et al., 2021; Al-Swaidani et al., 2021). It was observed in the UCS test samples that the failure pattern consists of inclined cracks observed from the top of the sample to the bottom of the sample or to the intermediate height of the sample. These cracks form with an inclination angle of 30^0-45^0 or 45^0-60^0 to the point of loading. The inclined crack path shows the shear strength under vertical compressive loading, with crack formation and propagation along the line of weakest shear plane within the soil sample.

The hydraulic conductivity tests were performed on the unblended and barite powder-blended clay beds corresponding to their OMC and MDD. Figure 10 shows the variation of hydraulic conductivity with barite powder content. The data indicates that hydraulic conductivity increases with an increase in the barite powder amount. The replacement of impervious clay particles with pervious barite powder particles is responsible for the enhancement in hydraulic conductivity. The hydraulic conductivity increases from 4 x 10^{-7} cm/sec to 9.00 x 10^{-5} cm/sec when the barite powder content is increased from 0 to 30%.

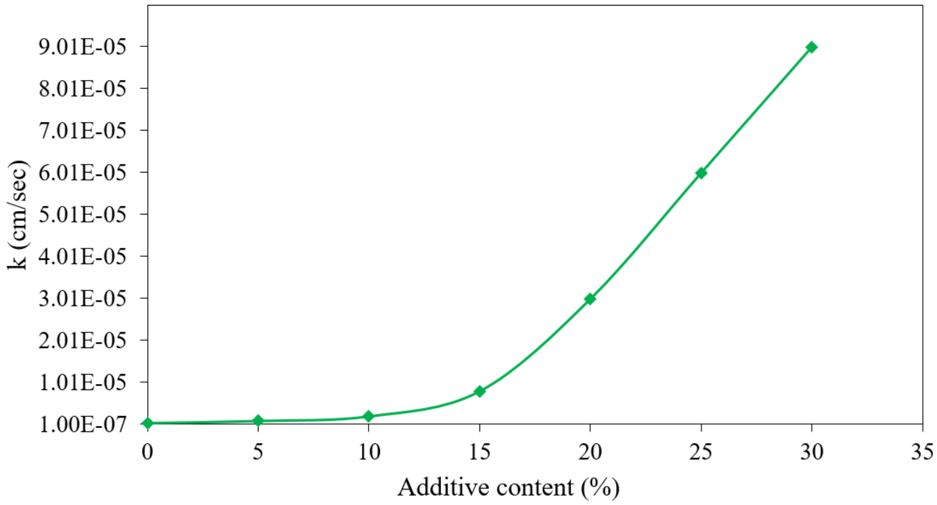


Figure 10. Influence of barite powder on hydraulic conductivity

Influence of Barite Powder on CBR of the Clay

CBR (soaked) tests were performed on the unblended and barite powder-blended clay beds at their respective OMC and MDD. Figure 11 depicts the load-penetration response of the unblended clay and barite powder-blended clay at different percentages. The load-penetration response of the clay-additive specimens increased with an increase in the barite powder amount. Hence, the CBR value increases with the addition of barite powder amount. The rise in CBR can be attributable to the increase in maximum dry density of the clay-additive blends. As the amount of barite powder increases, the resistance offered by the clay blends increases, which results in an improvement in load-penetration response. The increase in CBR can also be attributed to thhe reduction in the plasticity index. As the plasticity index decreases, the optimum moisture content decreases with an increase in maximum dry density, which results in higher CBR for the barite powder-treated clay beds. Figure 15 depicts the influence of barite powder on CBR. The data indicates that the CBR enhanced with increasing barite powder content. CBR increased from 1.12% to 5.65% when the barite powder content increased from 0% to 30%, showing an improvement of 404%. A similar trend was observed in previous studies (Phanikumar et al., 2019; Al-Swaidani et al., 2021, Ramanjaneya et al., 2021).

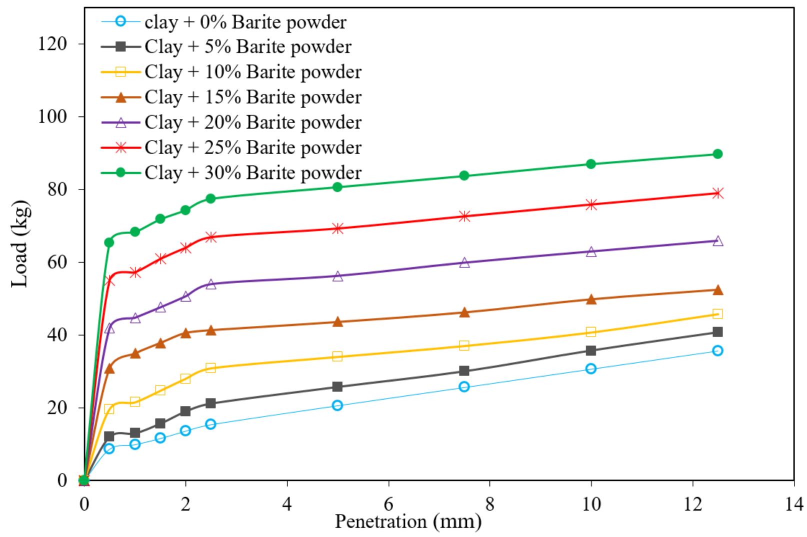


Figure 11. Load *vs.* penetration for clay with % variation in barite powder

Influence of Barite Powder on Stress-Settlement Behavior and Heave of the Clay

Load Tests at As-compacted Condition: The load tests were performed at the as-compacted (unsaturated) and saturated conditions of the clay bed. The untreated and barite powder-treated clay beds were compacted corresponding to their OMC and MDD. Figure 12 depicts the stress-settlement behavior of the untreated clay and barite powder-treated clay bed at as-compacted condition. The data indicated that stress-settlement behavior of the specimens improved with an increase in barite powder content. The stress needed for a particular settlement enhanced with the addition of barite powder. The barite powder-treated specimens exhibited enhanced resistance to applied axial stresses, owing to the increased dry densities with increased barite powder amount. At a settlement of 0.5mm, the required stress applied was 24 kPa, 30kPa, 32 kPa, 36kPa, 40kPa, 48kPa and 80kPa for soil treated with 0, 5, 10, 15, 20, 25 and 30% barite powder, respectively. For a settlement of 0.5mm, the enhancement in stress was 234% when the barite powder amount was increased from 0 to 30%. Hence, the stiffness of the samples increased with increasing barite powder content.

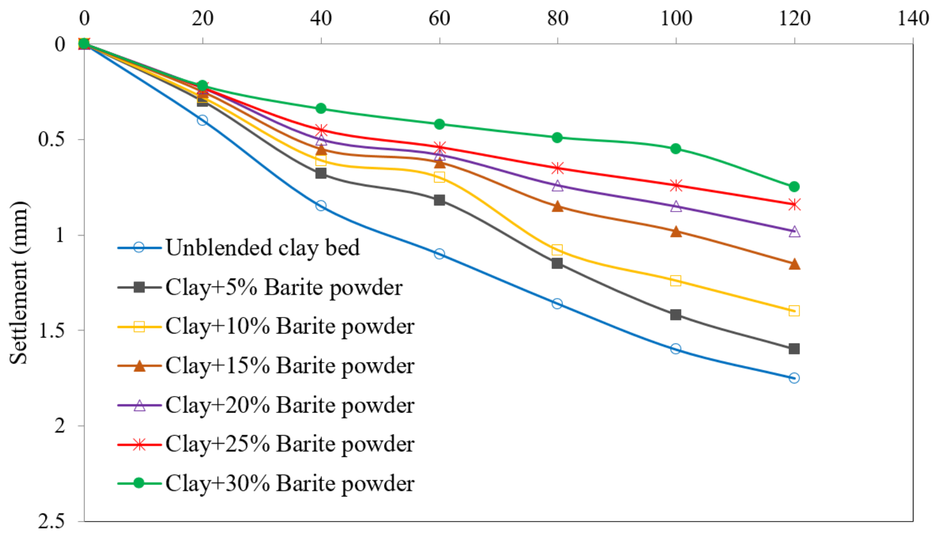


Figure 12. Stress-settlement behaviour of unblended and barite powder-blended clay at as-compacted state

Heave Characteristics: As previously stated, the untreated clay bed and barite powder-treated clay beds were allowed to free swell after being continuously saturated for a duration of 5 days. The heave was observed over various time periods until equilibrium heave was achieved. From the heave profiles of Figure 13, three phases in the heave development are observed. The three phases are the initial, primary and secondary phases. The initial phase develops at the macro-structural level and is generally related to smaller heave strains. The primary phase of heave occurs at the micro-structural level and advances alongside larger heave strains, as shown by the steep-inclined linear segment of the heave profile. The secondary phase of heave occurring at micro-structural level is again related to smaller heave strains. The asymptotic portion of the heave profile validates the equilibrium heave. Rate and magnitude of heave of the untreated soil and barite powder-treated clay beds are shown in Figure 13. The data indicates that the untreated clay beds attain a maximum heave of 39mm. When the clay bed is treated with barite powder, the rate and magnitude of heave/swelling decreased significantly. With the addition of barite powder from 0 to 30%, swelling/heave decreased from 39mm to 24mm, exhibiting a reduction of 38%. A similar trend was observed in previous studies (Rama Rao et al., 2007; Ramanjaneya et al., 2021). It was noticed that, as the amount of barite powder in the soil increases, both rate and magnitude of swelling/heave decreased significantly. The heave considerably decreases when finer clay particles are replaced with larger, non-expansive barite powder particles. The reduction in heave was more pronounced at higher barite powder contents.

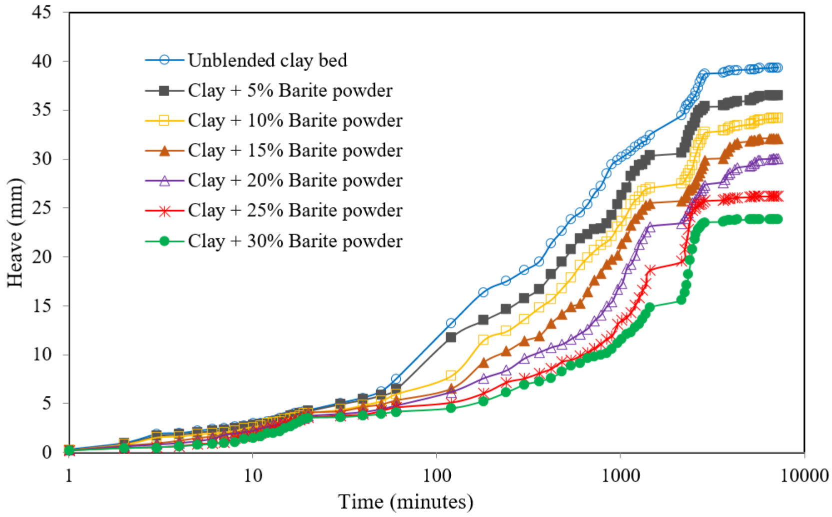


Figure 13. Rate of heave for untreated clay and barite powder treated clay

Load Tests at Saturated Condition: As previously stated, plate load tests were conducted at saturation conditions after heave attainment. Figure 14 shows the stress-settlement behavior of plain clay and barite powder-treated clay beds in saturated conditions. From the data, it was observed that stress-settlement behavior was increased with the addition of barite powder. The compressive load behavior for saturated clay beds is contingent upon their heave behavior. The soil which has the highest heave offers lower resistance to the applied compressive loads. Similarly, it offers higher resistance for the least magnitude of heave. Hence, 30% of barite powder-treated clay beds offers a higher compressive load response. For a settlement of 0.5mm, the required stress applied was 12kPa, 15kPa, 15kPa, 16kPa, 20kPa, 20kPa and 28kPa for the soil treated with 0, 5, 10, 15, 20, 25 and 30% barite powder, respectively. Previous studies support the present experimental results (Ramanjaneya et al., 2021). For a settlement of 0.5mm, the enhancement in the stress was 133% when the barite powder content was increased from 0 to 30%. Hence, the stiffness of the samples increased with increasing barite powder content. The clay beds lose their strength as they swell resulting in lower compressive load response than that in the as-compacted condition.

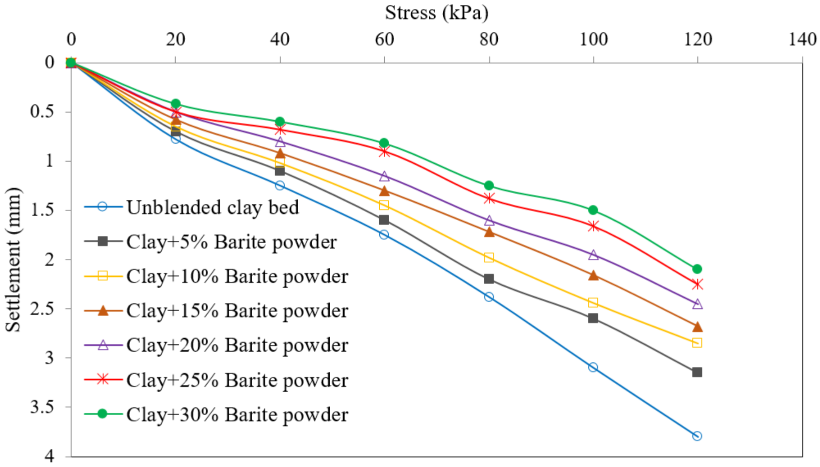


Figure 14. Stress-settlement behaviour of unblended and barite powder-blended clay at saturated condition

Influence of Barite Powder Cushion on CBR of the Barite Powder-reated Clay Beds

The crucial water content that develops *in-situ* is the saturated state. According to IRC:SP-72-2015, soaked CBR should be considered for low-volume road pavements due to their representation of severe condition. Considering this, CBR tests were performed at soaked conditions. Figure 15 shows the variation of CBR with and without barite powder cushion on the clay beds. The data indicates that the CBR of the untreated and treated clay beds without barite powder cushion enhanced with increasing barite powder content. CBR increased from 1.12% to 5.65% when the barite powder content increased from 0 to 30%, showing an improvement of 404%. The increase in CBR can be attributed to the increase in MDD of the clay-additive blends. CBR further increased with the provision of barite powder cushion on the untreated and barite powder-treated clay beds. The barite powder cushion offers higher resistance to penetration, resulting in higher values of CBR. By providing barite-powder cushions, CBR increased from 3.45% to 11.5%, when the barite powder content was increased from 0 to 30%, showing an improvement of 233%. The highest CBR was observed as 11.5% when 30% barite powder was added to the clay and 50mm of barite powder was used to cushion it. A similar trend was observed in previous studies (Phanikumar et al., 2019; Al-Swaidani et al., 2021, Ramanjaneya et al., 2021). From the experimental investigation, barite powder has proven to be an effective additive for expansive soil sub-grades that meet the requirements of sub-grade-S5 (IRC:SP-72-2015). The experimental findings demonstrate that the use of barite powder for stabilizing expansive soils is beneficial for sustainable construction.

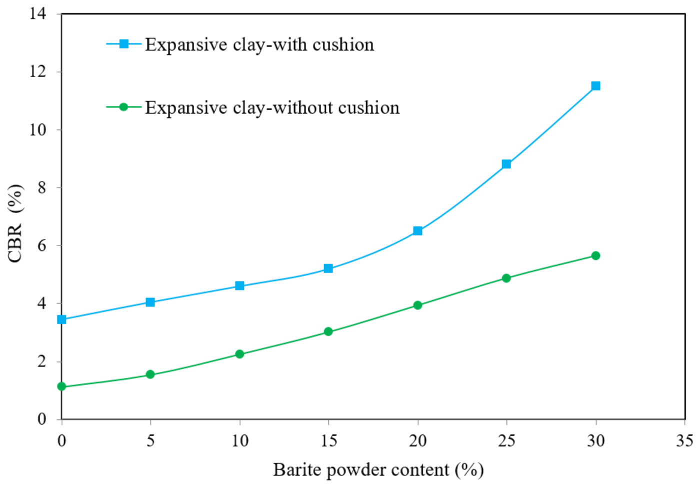


Figure 15. Variation of CBR for different % of barite powder

CONCLUSIONS

The conclusions can be drawn as:

1. FSI, LL and PI decreased significantly with increasing barite powder content. FSI, LL and PI decreased by 60%, 45% and 76%, respectively, at a barite powder content of 30%.
2. Compaction behavior shows improvement as OMC decreased and MDD increased with increasing the amount of barite powder.
3. The unconfined compressive strength increased from 148kPa to 425 kPa when the barite powder content increased from 0 to 30%, showing an improvement of 187%.
4. The hydraulic conductivity increases from 4 x 10^{-7} cm/sec to 9.00 x 10^{-5} cm/sec when the barite powder content increased from 0 to 30%.
5. The stress-settlement characteristics of the clay beds at both unsaturated and saturated conditions increased with increasing barite powder content. The stress needed for a given settlement increases with an increase in the barite powder content. With the addition of 30% barite powder, the unsaturated clay beds attain a stress of 80kPa, showing an improvement of 234% and the saturated clay beds attain a stress of 28kPa, showing an improvement of 133% corresponding to a settlement of 0.5mm.
6. Heave decreased with increasing barite powder content. The swelling decreased from 39mm to 24mm when the barite powder content increased from 0 to 30%, showing a reduction of 38%. As the amount of barite powder in the clay bed increases, both the rate and amount of heave decrease significantly.
7. The CBR of the barite powder-clay blends increased with increasing barite powder. Without barite powder cushion, when the barite powder content increased from 0 to 30%, CBR increased from 1.12% to 5.65%. By providing a barite powder cushion, when the barite powder content increased from 0 to 30%, CBR increased from 1.12% to 11.5%. The highest CBR was observed as 11.5% when 30% barite powder was added to the clay and 50mm of barite powder was used to cushion it.
8. The CBR value of barite powder treated soil satisfies the IRC: SP-72-2015 Sub-grade-S5 requirements for low-volume pavements, which suggests the suitability for low-volume pavements.

Suggestions for Field Validation

The present study was limited to laboratory experimentation only, conducted under controlled conditions to simulate the actual field conditions. Additionally, future studies should investigate the requirements of field conditions, like stress distribution, temperature, moisture fluctuations and durability. It was suggested to conduct pilot field tests based on the results of the present study.

REFERENCES

Alnmr, A., Alsirawan, R., Ray, R., & Alzawi, M.O. (2024). Compressibility of expansive soil mixed with sand and its correlation to index properties. *Heliyon, 10*(15), e35711. https://doi.org/10.1016/j.heliyon.2024.e35711

Al-Swaidani, A.M., & Meziab, A. (2021). Restriction of volume change and improvement of strength properties of problematic soils using nano-natural additives. *Indian Geotechnical Journal, 51*, 992-1010. https://doi.org/10.1007/s40098-021-00499-7

Belihu, J., Teshome, G., Geremew, A., & Fayissa, B. (2024). Experimental study on the stabilization of expansive soil with blended fine cinder gravel and waste marble dust: A case study of Jimma Town. *Jordan Journal of Civil Engineering, 19*(1), 128-144. https://doi.org/10.14525/JJCE.v19i1.10

Chen, F.H. (1988). *Foundations on expansive soils*. Elsevier Scientific Publishing Co., 18 Amsterdam.

Cokca, E. (2001). Use of class-C fly ash for the stabilization of an expansive soil. *Journal of Geotechnical and Geoenvironmental Engineering, 127*(7), 568-573.

Dash, S., & Hussain, M. (2015). Influence of lime on shrinkage behavior of soils. *Journal of Materials in Civil Engineering, 27*(7), 04015041. https://doi.org/10.1061/(ASCE)MT.1943-5533.000 1301

Driss, A.A.E., Harichane, K., Ghrici, M., & Mohammed, A.rS. (2025). Enhancing geotechnical properties of expansive clay with lime and natural pozzolana: Experimental and micro-structural analysis. *Arabian Journal for Science and Engineering*. https://doi.org/10.1007/s13369-025-09990-2

Falciglia, P.P., Romano, S., & Vagilisindhi, G.A. (2017).

Stabilisation/solidification of soils contaminated by mining activities: Influence of barite powder and grout content on γ-radiation shielding, unconfined compressive strength and 232Th immobilization. *Journal of Geochemical Exploration.* https://doi.org/10.1016/j.gexplo.2016.03.013

Fattah, M.Y., Al-Saidi, A.A., & Jaber, M.M. (2015). Improvement of bearing capacity of footing on soft clay grouted with lime-silica fume mix. *Geomechanics and Engineering, 8*(1), 113-132.

Gadouri, H. (2023). Behavior of natural pozzolana-lime-stabilized clayey soils artificially contaminated by sulfates. *Jordan Journal of Civil Engineering, 17*(4). https://doi.org/10.14525/JJCE.v17i4.07

Gadouri, H., Harichane, K., & Ghrici, M. (2017). A comparison study between $CaSO_4 \cdot 2H_2O$ and Na_2SO_4 effects on geotechnical properties of clayey soils stabilized with mineral additives to recommend adequate mixtures as materials for road pavements. *International Journal of Geotechnical Engineering, 13*(1), 61-82. https://doi.org/10.1080/19386362.2017.1320850

Gourley, C.S., Newill, D., & Schreiner, H.D. (1993). Expansive soils: TRL's research strategy. In *Proceedings of the 1st International Symposium on Engineering Characteristics of Arid Soils* (London).

IRC: SP-72-2015. (2015). *Guidelines for the design of flexible pavements for low volume rural roads* (IRC SP-72-2015). New Delhi, India.

Ito, M., & Azam, S. (2013). Engineering properties of a vertisolic expansive soil deposit. *Engineering Geology, 152*(1), 10-16.

Katti, R.K. (1978). Search for solutions to problems in black cotton soils. *Indian Geotechnical Journal, 9*(1), 1-80.

Katti, R.K., Kulkarni, S.K., & Kate, J.M. (1969). Experimental investigation on cohesive non-swelling soil layer as intercepting media for footing on expansive soil. In *Proceedings of the 2nd International Research and Engineering Conference on Expansive Clay Soils* (pp. 323-327). Texas, USA.

Lavanya, C., & Kumar, N.D. (2022). Effect of lime-stabilised copper slag cushion on swelling behaviour of highly plastic clay. *Geotechnical Research, 9*(1), 15-22. https://doi.org/10.1680/jgere.21.00006a

Lu, N., & Lykos, W. (2004). *Unsaturated soil mechanics*. Wiley, New York.

Murty, V.R., & Praveen, G.V. (2008). Use of chemically stabilized soil as cushion material below light weight structures founded on expansive soils. *Journal of Materials in Civil Engineering, 20*(5), 392-400.

Nagaraj, H.B. (2016). Influence of gradation and proportion of sand on stress–strain behavior of clay–sand mixtures. *Geo-Engineering, 7*(19). https://doi.org/10.1186/s40703-016-0033-8

Nagaraju, T.V., & Prasad, C. D. (2020). Swarm-assisted multiple linear regression models for compression index (C_c) estimation of blended expansive clays. *Arabian Journal of Geosciences, 13*, 331. https://doi.org/10.1007/s12517-020-05287-w

Nelson, J.D., & Miller, D.J. (1992). *Expansive soils: Problems and practice in foundation and pavement engineering*. John Wiley & Sons.

Onyelowe, D.B.K., Van, K. et al. (2019). Sorptivity, swelling, shrinkage, compression and durability of quarry dust–treated soft soils for moisture bound pavement geotechnics. *Journal of Materials Research and Technology, 8*(4), 3529-3538. https://doi.org/10.1016/j.jmrt.2019.06.029

Penaloza, I., Tita, A., McNew, E., & Chu, P. (2023). Barite resources, production and recovery using froth flotation: A review. *Minerals Engineering, 203*, 108327. https://doi.org/10.1016/j.mineng.2023.108327

Petry, T.M., & Little, D.N. (2002). Review of stabilization of clays and expansive soils in pavements and lightly loaded structures—History, practice, and future. *Journal of Materials in Civil Engineering, 14*, 447-460.

Phanikumar, B.R., & Ramanjaneya, R.E. (2020). Compaction and strength characteristics of an expansive clay stabilised with lime sludge and cement. *Soils and Foundations, 60*(1), 129-138. https://doi.org/10.1016/j.sandf.2020.01.007

Phanikumar, B.R., Dembla, S., & Yatindra, A. (2021). Swelling behaviour of an expansive clay blended with fine sand and fly ash. *Geotechnical and Geological Engineering, 39*, 583-591. https://doi.org/10.1007/s10706-020-01480-6

Phanikumar, B.R., Jagapathi, R.M., & Ramanjaneya, R.E. (2019). Silica fume stabilization of an expansive clay subgrade and the effect of silica fume-stabilized soil cushion on its CBR. *Geomechanics and Geoengineering*. https://doi.org/10.1080/17486025. 2019.1620348

Phanikumar, B.R., Malini, C.A., & Karthika, R. (2012). Swell-consolidation characteristics of artificial sand–clay mixes. *Geomechanics and Geoengineering, 7*(1), 69-74.

Puppala, A.J., Intharasambat, N., & Vempati, R.K. (2005). Experimental studies on ettringite-induced heaving in soils. *Journal of Geotechnical and Geoenvironmental Engineering, 131*, 325-337.

Raghu, V. (1998). Barytes. *Resonance, 3*, 59-61. https://doi.org/10.1007/BF02837615

Ramanjaneya Raju, E., Phanikumar, B.R., & Heeralal, M. (2021). Effect of chemical stabilization on index and engineering properties of a remoulded expansive soil. *Quarterly Journal of Engineering Geology and Hydrogeology, 54*. https://doi.org/10.1144/qjegh2020-142

Ramanjaneya Raju, E., Phanikumar, B.R., & Heeralal, M. (2021). Heave and load-settlement behaviour of a chemically stabilised expansive clay bed. *Geomechanics and Geoengineering, 17*(6), 1887-1904. https://doi.org/10.1080/17486025.2021.1980232

Rao, A.S., Phanikumar, B.R., Dayakar Babu, R., & Suresh, K. (2007). Pullout behavior of granular pile-anchors in expansive clay beds in situ. *Journal of Geotechnical and Geoenvironmental Engineering*, 531-538.

Rao, M.R., Rao, A.S., & Babu, R.D. (2008). Efficacy of cement-stabilized fly ash cushion in arresting heave of expansive soils. *Geotechnical and Geological Engineering, 26*, 189-197. https://doi.org/10.1007/s10706-007-9156-1

Rees, S.W., & Thomas, H.R. (1993). Simulating seasonal ground movement in unsaturated clay. *Journal of Geotechnical Engineering*, *119*(7), 1127-1143.

Sahoo, J.P., & Pradhan, P.K. (2010). Effect of lime stabilized soil cushion on strength behaviour of expansive soil. *Geotechnical and Geological Engineering, 28*, 889-897. https://doi.org/10.1007/s10706-010-9332-6

Saidani, K., Ajama, L., & Ben, M.O. (2015). Barite powder as sand substitution in concrete: Effect on some mechanical properties. *Construction and Building Materials, 95*, 287-295. https://doi.org/10.1016/j.conbuildmat.2015.07.140

Salih, N.B., Mohammed, F.O., & Hasan, R.A. (2025). Cement kiln dust for improving properties of soil. *Jordan Journal of Civil Engineering, 19*(2), 316-329. https://doi.org/10.14525/JJCE.v19i2.09

Santhoshi, G.D.N., Prasad, D.S.V., & Raju, G.V.R.P. (2017). A study on geotechnical properties of expansive soil stabilized with barite powder and aluminium chloride. *IOSR Journal of Engineering, 7*(9), 66-71.

Satyanarayana, B. (1966). *Swelling pressure and related mechanical properties of black cotton soils* (PhD thesis). Indian Institute of Science, Bangalore.

Snethen, D.R. (1979). *An evaluation of methodology for prediction and minimization of detrimental volume change of expansive soils in highway subgrades* (Vol. 1). Federal Highway Administration.

Sridevi, G. (2016). Efficacy of cement-stabilized GBS and GGBS cushions in improving the performance of expansive soils. *Jordan Journal of Civil Engineering, 10*(4), 529-542.

Sudhakar, S., Duraisekaran, E., Vignesh, D. et al. (2021). Performance evaluation of quarry dust treated expansive clay for road foundations. *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, *45*, 2637-2649. https://doi.org/10.1007/s40996-021-00645-4

Vikas, K., & Ramana, G.V. (2023). Viability of bulk utilization of granite sludge powder (GSP) to enhance the geotechnical behavior of expansive soil. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2023.04.574

Yadu, L., & Tripathi, R.K. (2013). Effects of granulated blast furnace slag on the engineering behaviour of stabilized soft soil. *Procedia Engineering, 51*, 125-131.