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A review on treatment gypsum soil by using cement and lime

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Abstract

Gypsum soils, known for their high solubility and weak structural integrity, pose significant challenges in construction and agricultural applications. These soils tend to exhibit excessive settlement and reduced load-bearing capacity, particularly when exposed to moisture. Lime and cement stabilization has emerged as a promising solution to mitigate these challenges. By improving the soil mechanical properties through chemical reactions, Soil stabilization improves durability and strength, making it suitable for various engineering purposes. This paper reviews recent advancements, challenges, and opportunities associated with the application of lime and cement to gypsum soils, focusing on geotechnical performance and practical implications.

Keywords: Soil stabilization; Gypsum soil; Cement; Lime

1. Introduction

High levels of calcium sulfate dihydrate ($CaSO_4•2H_2O$) are a characteristic of gypsum soils, also known as gypsiferous soils. Due to their poor fertility, structural instability, and potential for dissolution under specific circumstances, these soils—which are found in dry and semi-arid regions—present particular difficulties. Depending on whether gypsum soil is being used for building or agricultural, different methods must be used for treatment. Combining soil amendments, proper irrigation, and stabilization techniques can significantly enhance the performance of gypsum soils.

In Iraq, Large tracts of land are now coated in gypsum soil as a result of Iraq's recent urbanization and growth. Although several were postponed due to concerns about constructing on gypsum soil, which can collapse when water travels through it, many critical projects have been finished in these locations. As a result, the high concentration of gypsum in many regions of the nation has motivated scientists to look into this specific soil type [14,15]. However, understanding the soil unique characteristics and careful management is essential for sustainable treatment outcomes [1].Gypsum soils often exhibit unique engineering challenges due to their solubility and low shear strength [2,3].Stabilization methods such as using lime, cement, or bitumen have shown promising results. These additives help in improving the soil's resistance to water-related damage and enhancing its structural stability. Various cement and lime treatments for gypseous soil, emphasizing reductions in collapsibility and improvements in strength by using optimal percentages and curing conditions for achieving effective stabilization [4,5].

In summary, gypsum can be found naturally in soil used for construction (referred to as gypseous, gypsiferous, or sulfate bearing soils) or it can be added in little quantities to non-gypsiferous soil to enhance its qualities or reduce the amount of gypsum-containing waste products that are dumped in landfills. As a result, numerous researchers worldwide have separately examined the effect of adding cement and lime to improve the soil properties. Accordingly, this paper covers the key findings obtained thus far in this field of study and highlights the efforts made in this area.

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2. Some of gypsum chemical and physical characteristics

Parallel layers of (SO4)2 groups firmly bound to (Ca)+2 make up the structure of gypsum. Sheets of (H2O) molecules having weak interactions between the H2O molecules in adjacent sheets divide these layers (Klein and Hurlbut, 1985), [6]. Gypsum is either colorless or can be white, gray, red, brown, or have different hues of yellow due to impurities[6]. Gypsum has a hardness of 2, making it easily scratched by fingernails. It's also crucial to remember that gypsum can be dissolved by the hot dilute (HCl). The initial monoclinic structure of gypsum single crystals could evolve into a hexagonal and eventually an orthorhombic structure during thermal disintegration (<200 °C) in a vacuum up to 1.33 Pa pressure, according to Kuznetsova and Lomovskii (1986) [7]. Gypsum has a specific gravity of 2.32, according to reports from Horta (1989) [8] and Klein and Hurlbut (1985).

3. Stabilization of Gypsum Soils for Construction

Gypsum-rich soils pose risks in construction due to their solubility and susceptibility to settlement. These unique properties make gypsum soils challenging to work with but also provide opportunities for improvement through stabilization methods. Stabilization techniques mitigate these risks:

3.1. Lime and Cement Stabilization

Lime reacts with soil to form calcium silicate hydrates, which bind soil particles together.Cement enhances strength and reduces permeability, making the soil suitable for roads and foundations Aldaood et al. (18).

3.2. Bituminous Coatings

Bitumen or asphalt emulsion layers act as waterproofing agents, preventing water ingress and gypsum dissolution.

3.3. Geotechnical Applications

- Placing impermeable layers under foundations reduces water movement and stabilizes the soil.
- In this review paper we focus on improvement the gypsum soil by using cement and lime.

4. Challenges in Gypsum Soil Treatment

4.1. Dissolution Risks

Excessive water can dissolve gypsum, leading to soil collapse. Controlled irrigation systems like drip irrigation are recommended Ahmed et al. (16).

4.2. Environmental Impacts

In desert regions, excessive gypsum treatment may result in secondary salinization.

4.3. Cost Considerations

Large-scale applications of stabilizers or amendments can be expensive. Optimizing the quantity of gypsum or using locally available materials (e.g., lime) can reduce costs.

5. Lime and Cement Stabilization

At first According to Smith and Roberson (1962, as referenced in FAO, 1990), the structure, texture, and water retention of soil are not substantially impacted by a gypsum level of less than 10%. On the other hand, a rise in the gypsum content (over 10%) seriously impairs the soil samples' geotechnical characteristics (Ahmed, 1985; Al-Dabbas et al., 2012) (9, 10).

Al-Obaydi et al. (11) observed that the combined additives of waste lime + cement have been evaluated and compared with those treated separately with waste lime or cement. Waste lime up to 8% and cement and waste lime additions in percentages of 4%+8%, 6%+8%, and 8%+8% have been applied to soil that contains 23% gypsum. Compared to the soil treated with waste lime, the cement-treated soil demonstrated greater strength. However, sulphate attack cement may have long-term effects. The percentage of stabilizers raises the pH values, and adding waste lime raises the value more than adding cement, as seen in the table below, which he investigated.

Table 1 Index properties and pH natural and treated soil

Property		**Natural Soil**	**Waste lime treated soil**				**Cement stabilized soil**			
			Waste lime %				Cement %			
			2	4	6	8	4	8	12	16
Atterberg limit %	L.L	41	37	35	33	Np	39	38	36	Np
	P.L	16	22	24	26	Np	28	31	33	Np
	P.I	25	15	11	7	------	13	6	3	-----
Linear shrinkage %		10.7	7.3	6.0	4	------	7.2	5.5	3	-----
Classification		CL	CL	CL-ML	Ml	------	Ml	Ml	Ml	-----
PH-value		8.43	9.88	11.20	11.99	12.14	9.95	11.33	11.54	11.63

Ahmed et al. (12) state that in order to enhance the mechanical and environmental qualities of the tested soil, recycled gypsum and lime were combined in various proportions and with varying contents. Since gypsum is a soluble substance, lime was utilized as a solidification agent for the gypsum-soil mixture. According to the test results, the strength and mechanical qualities of the tested soil were enhanced by the addition of this admixture. As the gypsum-lime admixture amount and ratio rose, so did its strength.

Aldaood et al. (13) studied the effect of add lime to gypsum soil, Different gypsum contents (0%, 5%, 15%, and 25%) were used to create soil samples, which were then treated with lime and evaluated at various temperatures and curing durations. The findings for untreated gypseous soil demonstrated that the addition of gypsum improves the swell potential and the unconfined compressive strength. The gypsum content and the curing conditions of the lime-treated gypseous soil both affect its geotechnical characteristics.

Hasan et al. (4) The optimal range of additions was between 8% and 12%, and cement was shown to be more effective than lime at improving the gypsum soils' engineering properties.

whereas hydrated lime is illustrated in Figure 1, An illustration of the Portland cement used in the study is shown in Figure 2.

Figure 1 The hydrated lime

Figure 2 cement

Alsafi et al. [17] evaluated the use of fly ash, Portland cement, and geopolymer binder to stabilize gypsum soil. According to the results, fly ash works better as a stabilizing agent than Portland cement. Fly ash differs from Portland cement due to its calcium-free composition, which may be the cause of its higher strength and sulfate resistance. Consoli et al. [19] found that adding cement to sandy soil at a weight percentage of up to 10% of dry sand significantly increased its maximal strength and stiffness, making the sand more technically brittle.

A study by Al-Hadidi et al. [22] was carried out on a sample of soil in the Karbala Governorate that contained 42.55% gypsum. The soil was mixed with varying amounts of cement (2, 3, 5, 8, 10, 13, and 15 percent by weight) and treated with soil cement. In order to perform collapse and settling investigations, the resultant mixture was compressed to a maximum density of 16.5 kN/m3 with an ideal water content of 12.8%. The studies were carried out in a flume with an average speed of 0.148 m/sec and 10% cement. After 28 days, the soil gypsum was constant, but the collapsibility decreased by 86.54%. Additionally, the study shows that a minimum of 14 days of treatment.

6. Discussion

Enhancing gypsum soil with cement and lime has been shown to significantly improve its engineering properties, addressing issues like low strength, high compressibility, and solubility in water. The following conclusions can be drawn based on research and practical applications:

6.1. Improved Strength and Stability

The addition of cement and lime increases the unconfined compressive strength and shear strength of gypsum soils as Hasan et al. (4) found and agreed with him Al-Obaydi et al. (11). Cement provides binding agents through hydration reactions, while lime induces pozzolanic reactions, stabilizing the soil matrix.

6.2. Reduced Swelling and Shrinkage

In terms of how gypsum concentration affects soil heaving and swelling, in general, the more gypsum added to the soil, the lower the free swell pressure of clay. The swell pressure brought on by the natural crystallization and development of gypsum inside the soil as a result of weathering and chemical reactions between the soil's constituent parts is not included in this observation, though. Kuttah D et al.(1). According to Kiliç et al. [21], adding gypsum might have been a more sensible choice. However, in a study that looked at how gypsum, lime, and lime-gypsum combinations affected the swelling and compression strength of highly flexible clays that were compacted under optimum conditions, lime turned out to be beneficial.

Lime helps in reducing the swelling potential of gypsum soils by reacting with clay minerals and gypsum to form more stable compounds.

6.3. Enhanced Durability

Several researchers have studied the effect of adding lime and cement on durability. Cement stabilization reduces the solubility of gypsum in water, enhancing the durability of the treated soil. Lime also contributes to long-term strength gain due to continued pozzolanic activity.

6.4. Improved Workability

Lime improves the plasticity and workability of gypsum soil, making it easier to handle during construction processes.

6.5. Optimal Dosage

The effectiveness of stabilization depends on the proportion of cement and lime used. Over-stabilization can lead to diminishing returns or excessive stiffness, so optimal dosages must be determined based on laboratory testing.

6.6. Economic and Environmental Considerations

While effective, the use of cement and lime involves environmental and economic costs. Alternative additives or combinations may further optimize the stabilization process. Hydrated lime consistently had a less impact than cement in each situation that was studied, although to varying degrees and at different addition levels [20].

7. Conclusion

In conclusion, cement and lime stabilization is a viable method for improving gypsum soil properties, making it suitable for construction projects. However, the approach should be tailored to site-specific conditions, and ongoing research is recommended to explore sustainable and cost-effective stabilization alternatives.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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