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# Understanding and mitigating settlement in gypseous soils: A comprehensive study on the role of saturation and soil stabilization techniques

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**Abstract:** This study examines the influence of saturation levels and soil additives on the load-settlement properties of gypseous soils, a significant geotechnical concern in regions like Iraq. The study analyzes the deficiencies of conventional oedometer testing, which often fail to adequately represent the true unsaturated conditions prevalent in these soils. The research investigates the impact of varying matric suction (Ψ) values on the compressibility of untreated, cement-treated, and CKD-treated gypseous soils. A modified oedometer apparatus, engineered to control and quantify matric suction, was used to replicate diverse moisture conditions. The experimental program investigated soils with varying gypsum contents (8.8%, 12.66%, and 30%), reflecting the diversity of gypseous soils seen in the field. The findings demonstrate that increased saturation levels significantly enhance settling in gypseous soils. As matric suction increases, settlement is markedly reduced due to elevated soil suction pressure and enhanced effective stress. The findings underscore the importance of unsaturated conditions in improving the load-bearing capacity of these soils. The study illustrates the advantageous impacts of cement and CKD treatments in reducing settling. The effectiveness of these methods is particularly apparent in partially saturated environments, emphasizing the need of including matric suction into design considerations. This research improves understanding of the complex behavior of unsaturated gypseous soils. The findings have practical importance for geotechnical engineering, including foundation design, ground improvement methods, and the development of effective solutions for settlement issues in areas with high gypsum concentrations.

***Keywords:*** *Gypsiferous Soils, Matric Suction, Soil Amendments, Subsidence, Unsaturated Soils.*

## 1. Introduction: Examining the Behavior of Unsaturated Gypseous Soils from Al-Najaf, Iraq

Geotechnical engineers might see the assumption of either fully saturated, dry, or any two extreme states of soil as a helpful approach in making calculations and modeling, but such an assumption is rather too ideal to represent the real complexity of the scenarios. One of the most common soils in nature, the saturated soils, which have both water and air in the soil pores, behave differently from the saturated soils as well. Such a difference is essential for the case of gypsum soils, which not only have a high concentration of gypsum in it but also undergo a large volumetric change and instability when saturated. The present work studies the properties of unsaturated gypsum soils in Al-Najaf, Iraq, a specific area that is known to have large deposits of gypsum soils. [9].

Soil mechanics textbook follows the definition of water table as a horizontal boundary line which divides soils into two zones, stating below this line the effective stress is active in modifying soils behavior, and above it unsaturated conditions are to be found. Such an argument is overly simplistic since the behavior of the unsaturated soils, particularly that of gypsum soils, is dependent on various


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constituent interactions [1]. [2] There are effective non-zero values of matrix suction (ψ), the negative value of pore water pressure in the unsaturated soils, and for unsaturated soils it is an important quantity for their strength, stability, and volumetric change characteristics. It is necessary to carefully pinpoint and fully understand the effects of matrix suction in order to anticipate the gypseous soils behavior when utilized in construction.

This study aims to evaluate the limitations posed by conventional oedometer tests that are particularly performed on saturated soils, thus neglecting the role of matrix suction in the behavior of unsaturated gypsum soils. In this study, a modification of the oedometer with suction control properties was tested to achieve necessary variations in matrix suction so as to simulate various moisture conditions. This helps to gain a better understanding of resistant-settlement behaviour of gypsum soils under different environmental conditions.

Soil samples from three diverse sites were collected in Al-Najaf, Iraq, verifying in this way the unreliability in terms of the precipitation gypsum content in the area. The gypsum content for the samples G1, G2, and G3 were 8.8%, 12.66%, and 30% respectively. These varying gypsum concentrations represent low, medium and high classification according to the Gypsum soil classification system in Iraq. These various samples have been selected in order to help not only test the various characteristics of gypsum soils but also their resultant geotechnical behaviour.

The city of Al-Najaf was focused on for this research for the sole purpose that this particular area has experienced high levels of historical geotechnical troubles stemming from the presence of gypsum soils.

When Al-Saoudi and Al-Shakerchy (2010) did their geotechnical studies in Al-Najaf, they were able to isolate two major zones, the old city region and the new outgrowth area [10]. Their investigation indicates the presence of gypsum soils in the zone and highlights the importance of understanding their properties before coming across challenges related to construction and infrastructure.

The research investigates the effects of saturating levels and stabilizing additives on the load-bearing and settlement characteristics of gypsum soils. Cement and calcined clay dust, inexpensive materials, are proposed as suitable techniques for enhancing the geotechnical properties of gypsum soils and mitigating settlement issues. The study aims at investigating the effectiveness of various combinations of aggregates in both saturated and unsaturated conditions in the aspiration of determining appropriate treatment procedures for various concentrations and moisture percentages of gypsum.

This research assists in enhancing the understanding of the complex behavior of the unsaturated gypsum soils and is an important progress in the search for effective and environmentally sustainable geotechnical solutions for the regions afflicted with these particular soil types.

## 2. Materials Used and Samples Preparation

The soil used for this research was collected from Al-Najaf city in Iraq which is known for its content of gypsiferous. We aimed to determine the variability in gypsiferous concentration by collecting from three different locations. The gypsum content of every soil sample was determined in accordance with the standard ASTM C25-99. Three different levels of gypsum content were studied: G1: 8.8% (low), G2: 12.66% (medium) and G3: 30% (high).

Size distribution analysis of the clay fraction was employed in order to determine the soil type of the collected samples. The examination was carried out as required by ASTM C136. Three samples were taken from three different points of a depth of 0.5 meters.

Based on the sieve analysis results, all the three soil samples, G1, G2 and G3, were in the category of well-graded poorly sand (SP) using the Unified Soil Classification System USCS. Following this, Proctor compaction tests were undertaken to reveal the maximum dry density and optimum moisture content of each soil type. This study adhered to ASTM D698-00a standards. Certain gravity tests were carried out to evaluate the ratio of the density of water to that of solid soils. Testing procedures followed in this instance were according to ASTM D854-14.

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For oedometer testing, soil samples of the dimensions, diameter 5 cm and height 2 cm were created. All the samples created bore 90% of their respective field densities. A total of sixty-six remolded soil samples were made for the said testing procedure, which were then divided into three groups according to their gypsum concentration content of G1, G2 and G3. Further, each of the gypsum content categories was subdivided into two categories for both saturation and unsaturation oedometer testing.

This investigation studied the possibility of using cement Ce and calcined clay dust CKD as soil amendment materials in the stabilization of gypseous soils.

In exploring the best additive ratio for both cement and CKD, we performed saturated oedometer tests with different ratios (1%, 3%, 5% 7%) for each workability determinant. U was used for the unsaturated oedometer examinations.

**Table 1.**
Proctor test results.

| Test description | Test details | G1 | G2 | G3 |
|---|---|---|---|---|
| Max. dry density according to proctor test, gr/cm$^3$ | ASTM D698-00a | 1.77 | 1.68 | 1.55 |
| The Optimum water content from, % | ASTM D698-00a | 9.89 | 21.95 | 14.5 |
| Void Ratio | - | 0.49 | 0.43 | 0.53 |
| Porosity, n | - | 0.33 | 0.30 | 0.35 |

## 3. Experimental Program

The soil used in this research work was collected from Al-Najaf city in Iraq which is known to have high concentration of gypsum. So as to determine the differences in gypsum content variation, samples were collected from three different locations. Gypsum content of every sample of soil was determined following the guidelines set forth by ASTM C25-99. Three different levels of gypsum concentration were tried: G1: 8.8% (low), G2: 12.66% (middle), and G3: 30% (high). The aim of this test was to determine the particle size distribution of the collected soil samples to establish the soil type. This test was carried out in line with procedures outlined in ASTM C136. Samples were collected at depth of 0.5 meters from the three sites. The results of sieve analysis placed G1, G2 and G3 samples in Poorly graded sand (SP). We carried Proctor compaction tests in order to determine the maximum dry density and the optimum moisture content of each type of soil.

Ovoido e deformavel foi utilizado na realizacao do ensaio no oedometro. Soils were mixed in a prescribed manner and were placed within an oedometer of specific dimensions. Test ledgers were used, and the height and diameter of the visual soil samples were corrected for modeling purposes. The tests were done in accordance to the requirements of cr2006 standards. To carry out this project, sophiscated clean room designs were adopted that allowed smooth surrounding and uniform temperature conditions to be developed. There was a very slight increase in soil weight after mixing and adhering gypsum and agate, indicating effective binding between the two components and the gypsum mortar base.

## 4. Experimental Results and Discussion

### *4.1. Impact of Various Saturation Levels (Matric Suction, Ψ) on the Load-Settlement Response of Gypsum Soil Under Diverse Stress Conditions.*

As depicted in the imaging below (Figure 1), saturating the soil with gypsum causes far greater levels of settling to occur more rapidly. In soaking wet earth that has not been treated in any way, the earth, especially if subjected to heavier loadings, settles more frequently. When the saturation level is high, volumetric failure is more likely to occur, especially in easily collapseable soils like gypsum.

Soil underwent less and less settlement electronically gauged with an increase in matric pressure from Ψ = 0 to 100 kPa. As the matric suction increases, so does the soil suction, which in turn elevates effective stress within the soil. Because of this, the movement of the soil or its compaction is lessened.

GSM systems have confirmed the influence of soil water content on the load settlement curve due to the impact of unsaturated conditions (high matric suction) on the performance of gypsum soils under load.

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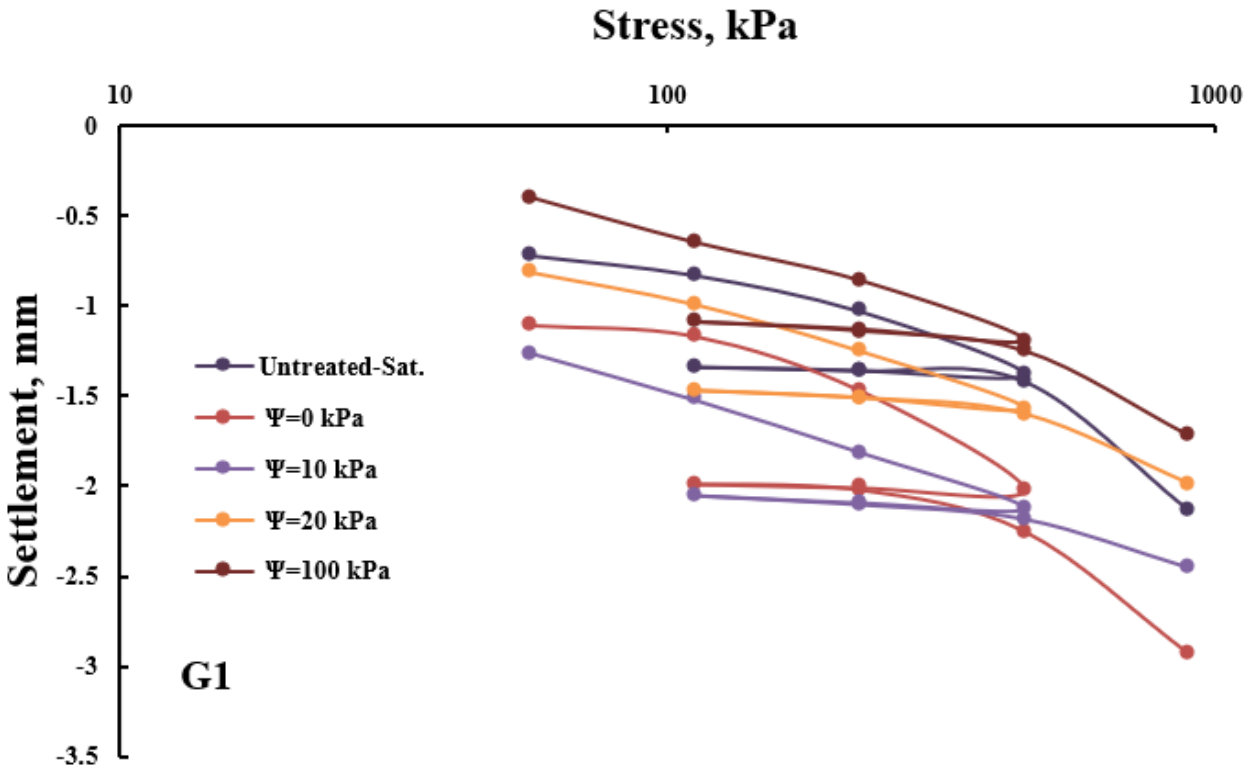
It has also been determined that Gypsum soils with higher levels of matric suction translate to less settlement which means that as water content decrease, more strength is embedded in the soil. For dry or semi-arid regions, the amount of pressure control necessary to prevent soil deformation from an overload is particularly critical for the stabilisation of soil or the and building constructions.

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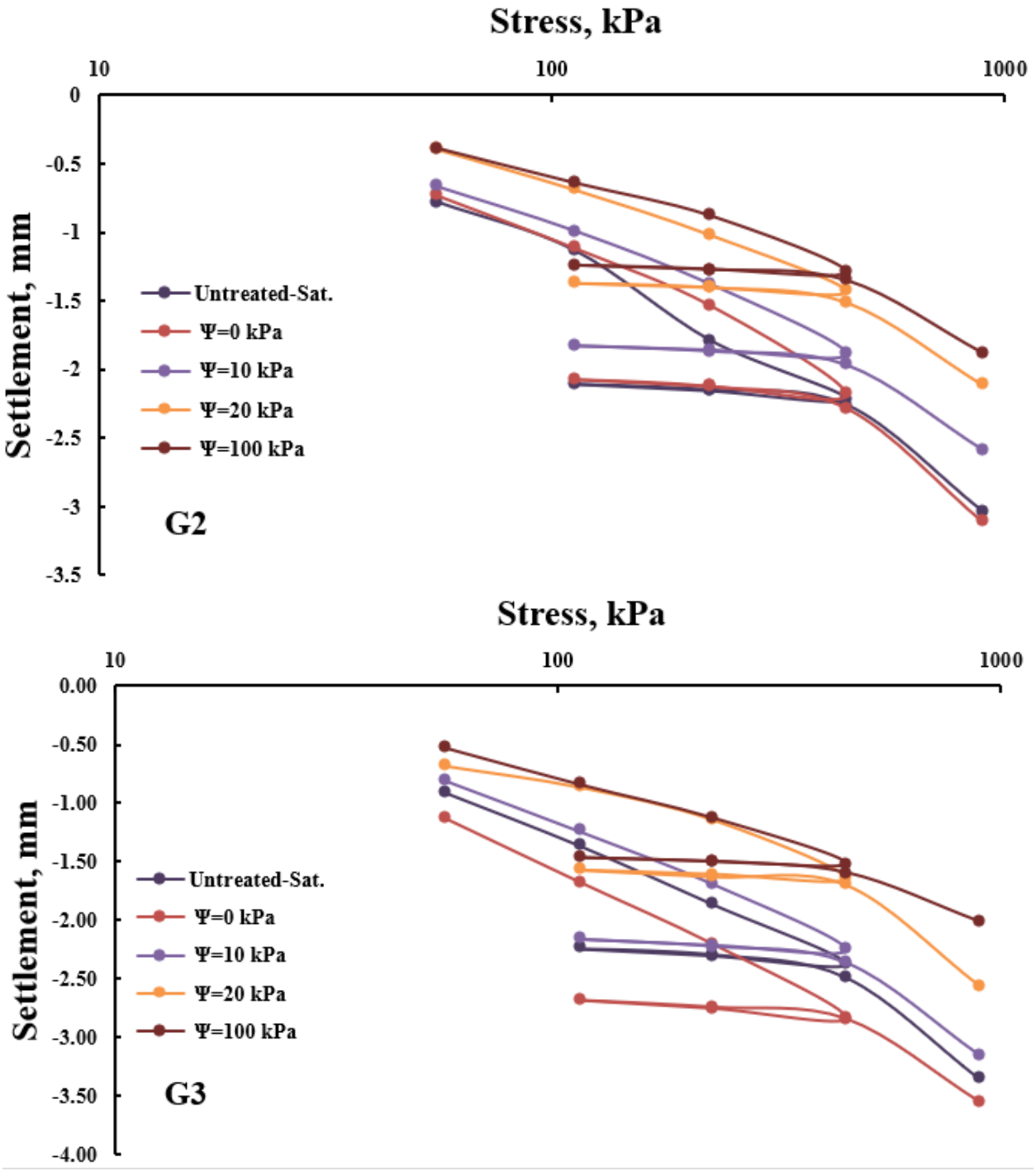


**Figure 1.**
Load-settlement curves of 8.8%, 12.66%, and 30% of gypsum content for different stress conditions.

*4.2. Effect of Saturation Ratio on the Load-Settlement Behavior of Cement-Treated Soil.*

The graphic 4.21 shows the load-settlement response of cement-treated soil at different saturation ratios, indicated by various matric suction values (Ψ = 0 kPa, Ψ = 10 kPa, Ψ = 20 kPa, and Ψ = 100 kPa), in addition to a completely saturated state.

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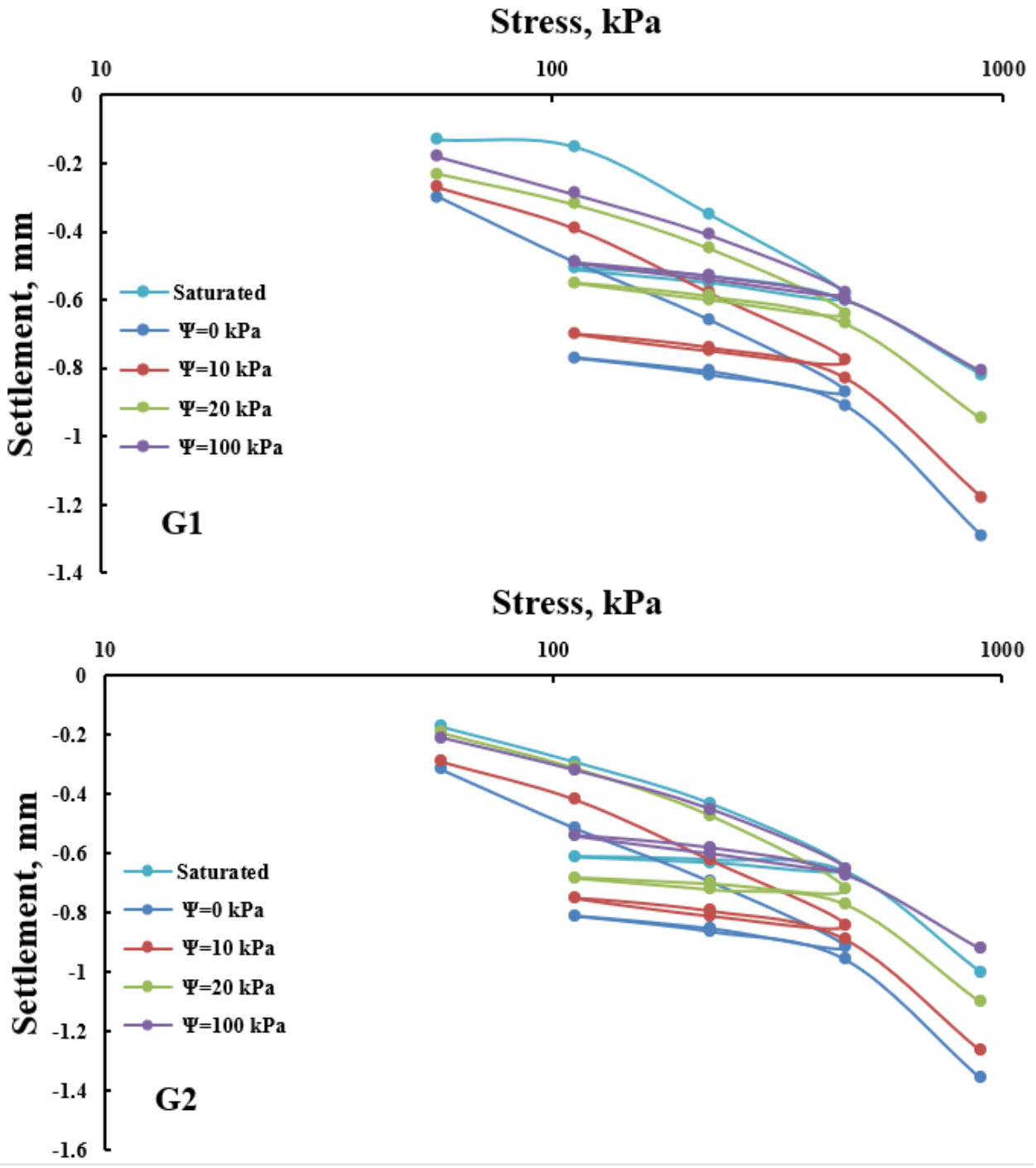
Results show that the cement-treated soil exhibits superior performance in partly saturated situations. Design situations characterized by unsaturated circumstances must consider increased matric suction, which offers enhanced resistance to settlement.

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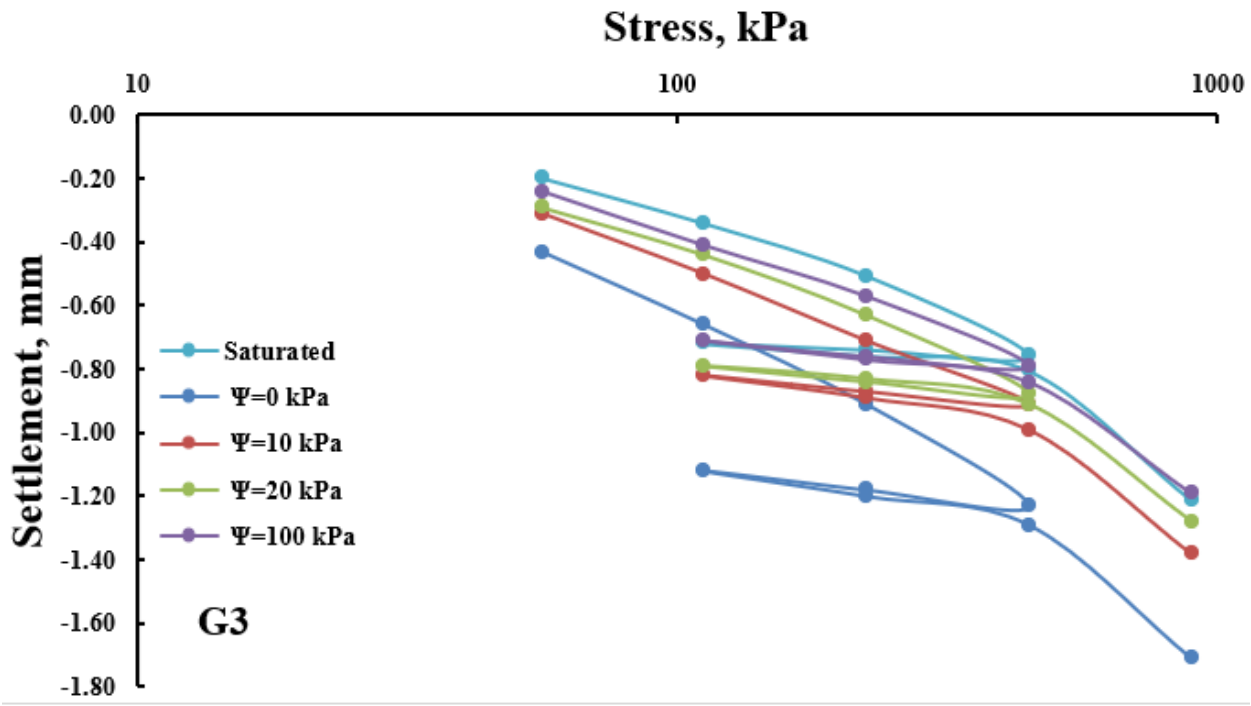


**Figure 2.**
Load-settlement curves of 8.8%, 12.66%, and 30% of gypsum content for on the load-settlement behavior of Cement-treated soil

*4.3. Effect of Saturation Ratio on the Load-Settlement Behavior of CKD-Treated Soil*

The Figure 3 illustrates the load-settlement response of CKD-treated soil containing 8.8% gypsum throughout multiple matric suction situations, including saturated conditions and four different matric suction levels (Ψ = 0 kPa, Ψ = 10 kPa, Ψ = 20 kPa, and Ψ = 100 kPa).

The graphs indicate that when the saturation level rises (from Ψ=0 kPa to Saturated), the soil settlement escalates for a certain stress. This tendency suggests that CKD-treated soil exhibits increased susceptibility to settlement under elevated saturation conditions, irrespective of gypsum level.

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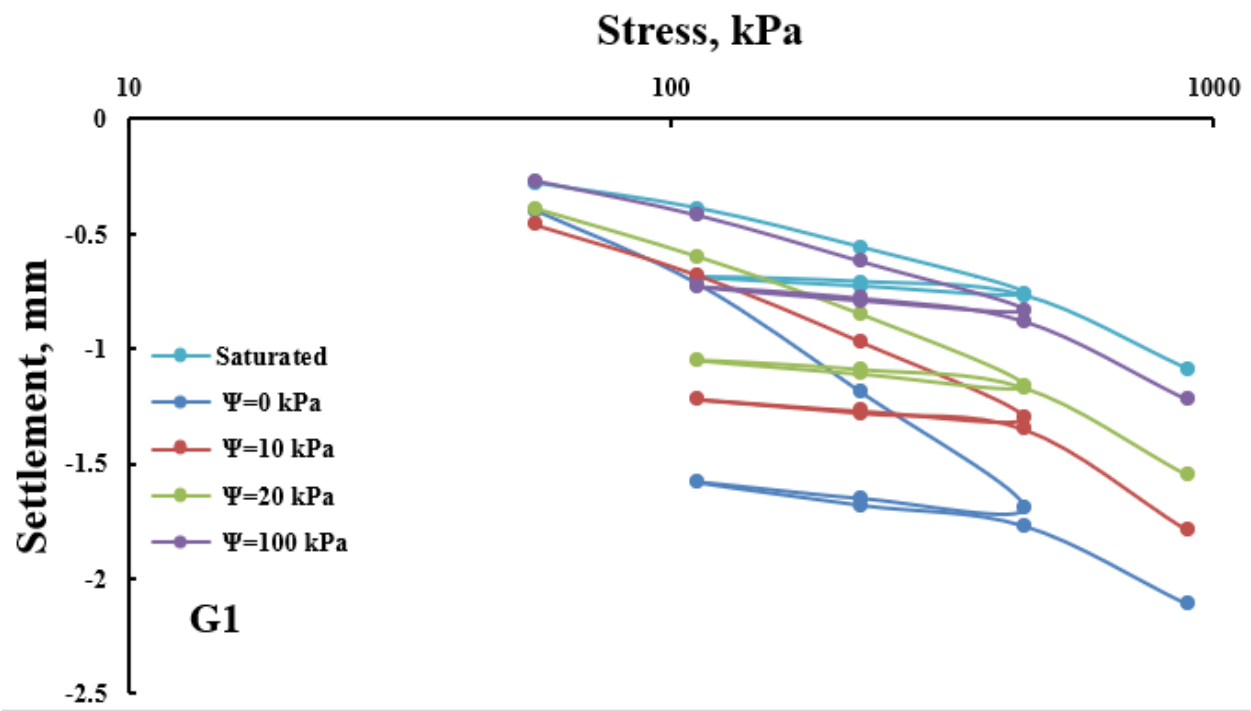


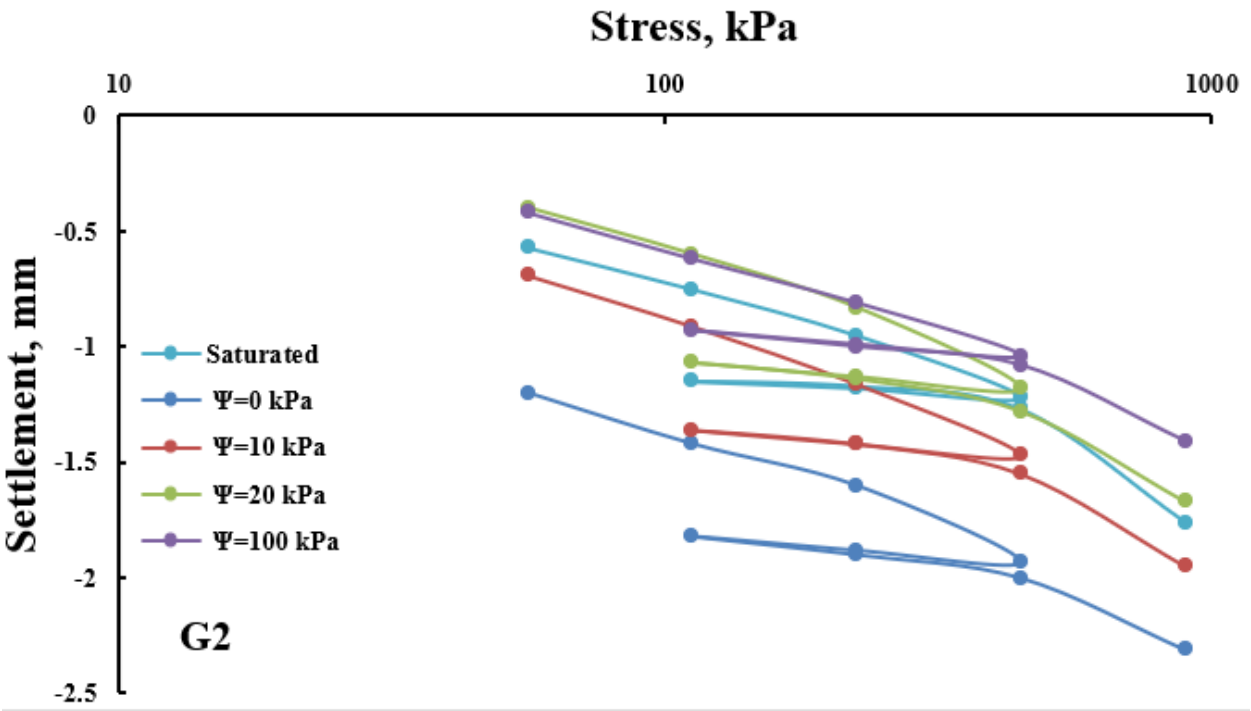


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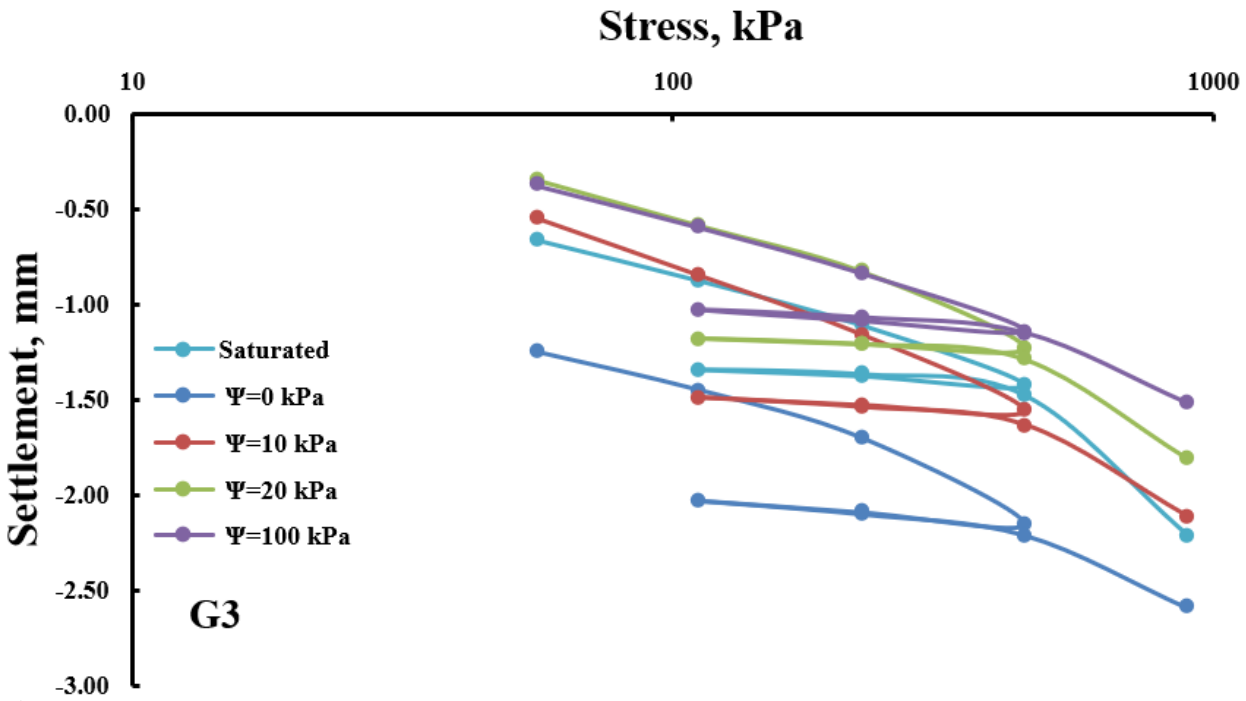


**Figure 3.**
Load-settlement curves of 8.8%, 12.66%, and 30% of gypsum content for on the load-settlement behavior of CKD-treated soil.

## 5. Conclusions

This research investigate the complex behavior of gypseous soils and the significant influence of saturation levels and stabilization techniques on their engineering properties, focusing on soils from Al-Najaf, Iraq. Although the presence of gypsum does not alter the fundamental soil classification (remaining as poorly graded sand), it significantly impacts its response to varying saturation and loading conditions.

1. The presence of gypsum in the soil significantly reduces the maximum dry density achievable during compaction. This effect is more pronounced with increasing gypsum content. The lower density is attributed to the soluble nature of gypsum, which creates voids upon contact with water, compromising the soil structure's integrity12.

2. The degree of saturation plays a crucial role in the settlement behavior of gypseous soils34. Fully saturated soils (matric suction $\Psi$ = 0 kPa) exhibit the highest susceptibility to settlement, particularly under high loads5. As matric suction increases, indicating a decrease in saturation, the soil's resistance to settlement improves significantly. Higher matric suction values enhance the effective stress within the soil, providing greater resistance to deformation and compaction56.

3. The study demonstrates that both cement and CKD treatments enhance the strength and stability of gypseous soils, resulting in reduced settlement under load78. This effect is particularly pronounced in partially saturated conditions (higher matric suction)910. This highlights the importance of considering matric suction in conjunction with stabilization techniques when designing for gypseous soils.



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