

Review of Previous Studies on Gypsiferous Soil Behavior and Stabilization

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Abstract

The Gypsous soil especially in Iraq have very high gypsum (calcium sulfate) contents and are highly affected by water. At dry state, a gypsum gives an illusory binder unlike on wetting when they dissolved and the shear strength decrease significantly with compressibility extensively increased and fall of structure. The present paper provides an overview of the geotechnical behaviour of gypsiferous soils, focussing on the mechanisms leading to collapses, environmental impacts and laboratory and field testing techniques commonly used in practice. Several soil stabilization methods are critically analysed including classical chemical methods (lime, cement, cement kiln dust), physical and mechanical techniques (compaction, geogrids) but also sustainable alternatives such as biopolymers, nanomaterials or industrial by-products and recycled waste materials. The review shows that while there are some stabilization methods which show clear short-term benefits, little is known about long-term performance under cyclic wetting–drying and saline conditions. In this regard, special consideration should be provided to the gypsiferous soils in ecologically sensitive regions, such as the Najaf Sea. The paper highlights the required research and demonstrates the necessity for low-environmental-impact, sustainable and locally available stabilization materials to delay loss of bearing capacity and stabilize long term the performance of substrate geotechnical works placed on gypsiferous soil.

Keywords: Gypsum soil, Collapse potential, Gypsum dissolution, Gypsum content.

1.1. General

Gypsiferous soils are common in arid and semi-arid areas, and is known as one of the most complex geomaterials in geotechnical-related fields due to their complicated hydro-mechanical behavior. Iraq contains large deposits, most notably in Najaf, Karbala and Anbar governorates where these are commonly part or all of the underlying strata for roads, housing and water-management structures. Taking into account engineering properties, these soils are primarily controlled by the gypsum (calcium sulphate) content which results in visible cementation when dry yet makes them highly susceptible to moisture absorption.

Upon wetting, gypsum dissolution weakens interparticle bonding with time which results in a significant reduction of shear strength, higher compressibility and in the most extreme cases

collapse. Numerous experimental and field studies have consistently indicated that the collapse potential and degradation of mechanical characteristics grow with gypsum content, which becomes a serious threat to performance and serviceability of geotechnical structures. Unpredictability of this phenomenon has caused numerous construction failures from deleterious settlement and/or loss of bearing capacity

Conventional chemical stabilization using lime and cement has been widely reported to enhance strength and reduce collapse susceptibility by modifying soil fabric and bonding. Mechanical methods, such as dynamic compaction, have also been applied to densify gypsiferous soils and improve their load-bearing capacity. More recently, advanced stabilizing agents, including nanosilica and polymer-based additives, have been introduced, demonstrating promising improvements in strength retention and resistance to moisture-induced

Despite these advances, the long-term performance of stabilized gypsiferous soils remains inadequately understood, particularly under the variable environmental conditions typical of Iraq, such as cyclic wetting-drying, salinity fluctuations, and temperature extremes. The limited availability of long-term field data and durability assessments constitutes a critical knowledge gap. Consequently, a rigorous synthesis of existing research is required to clarify current understanding and identify directions for future investigation. This study aims to contribute to this objective by providing a focused review of gypsiferous soil behavior and stabilization, with particular relevance to environmentally sensitive regions such as the Najaf Sea area.

1.2. Collapsible soil

1.2.1. Definition and Formation

Collapse has been defined as the mechanism of sudden reduction in soil volume of a metastable soil structure (i.e., an open porous structure) under certain conditions of loading and/or saturation. Such soils are typically capable of withstanding high vertical applied stresses in their natural state without significant volume change, but when saturated with water, they undergo rapid and significant volume decrease (Opukumo et al., 2022)

Collapsible soils are a major engineering challenge in arid and semi-arid regions, where potential structural problems arise due to soil collapse when saturated with water. This phenomenon is primarily associated with the open structure of soils (AL-Rawas, 2000).

The structural properties of collapsible soils contribute to multiple structural problems, manifesting as cracks and excessive settlement of structures. Collapsibility is attributed to multiple factors, including decreasing surface tension at saturation, high concentrations of dissolved salts, low clay content, and insufficient compaction during settling. Together, these factors confirm that collapsibility is intrinsically linked to the porous nature of the soil's cumulative texture (Mohsen & Albusoda, 2022).

1.2.2. Geographical Distribution and Geotechnical Characteristics of Collapsible Soils in Iraq

Gypseous soil are extensively spread throughout Iraq and are primarily found in dry and semi-arid areas. It occupies (20-30)% of the nation's land area (Al-Saoudi et al., 2013). particularly in the western, southwestern, and semi-desert regions. These soils typically consist of clay, silt, and sand deposits with an open, unsaturated granular structure. While stable in their dry state, they collapse suddenly upon becoming saturated with water due to seepage or a rise in the groundwater level. These soils are widespread in the governorates of Anbar, Najaf, Karbala, Muthanna, and parts of Salah al-Din, and their formation is associated with recent geological formations such as gypsum and anhydrite, and gypsum deposits .

Based on the distribution maps constructed by (AL-KAABY, 2007) for gypseous soils in Iraq across two different depths:

1. Map of the Surface Layer (Depth: 0 – 25 cm) [Figure (1)]:

- Area: Covers 39% of the total investigated area of Iraq.
- Concentration: The gypsum content is relatively low, with an overall mean of about 6.3% (reaching up to 87% in certain hotspots as a maximum).

2. Map of the Deep Layer (Depth: 25 – 150 cm) [Figure (2)]:

- Area: Expands and spreads to cover more than half of Iraq (53%).
- Concentration: The gypsum concentration clearly increases, with the overall mean reaching 11.33% (and can reach up to 94% at these depths).
- In General:
- The surface layer is generally less hazardous due to its lower gypsum concentration Figure (2). Conversely, the real danger and collapsibility risk significantly increase with depth Figure (2), particularly at a depth of 40 cm where the gypsum concentration reaches its peak.

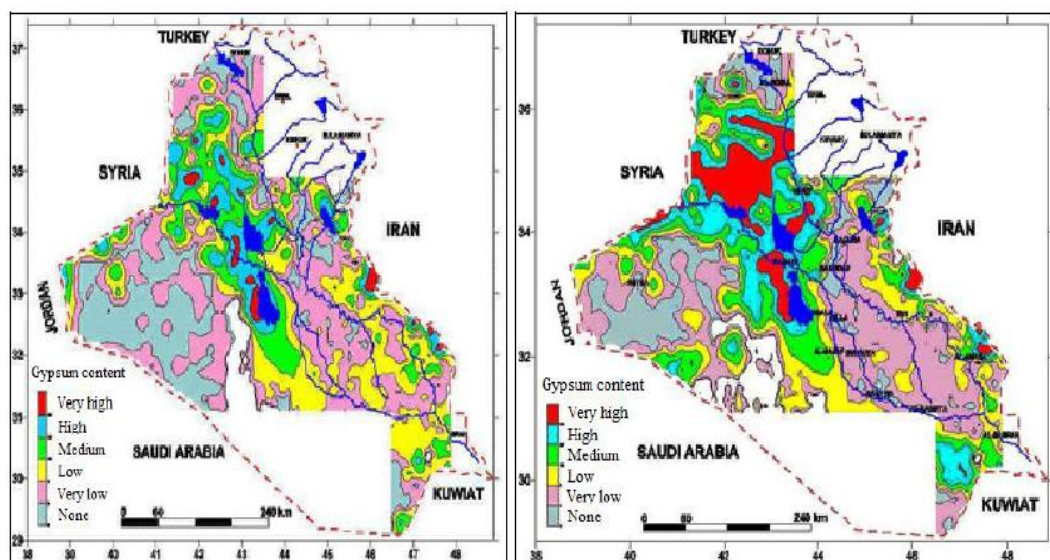


Figure (1): (Gypsiferous soil map of Iraq (depth 25 – 150 cm) (AL-KAABY, 2007) Figure (2): Gypsiferous soil map of Iraq (depth 0 – 25 cm) (Al-Kaabi, 2007)

1.2.3. Physical and Chemical Properties of Collapsible Soils

Collapsible soils are characterized by an open porous structure and low density. Weak stabilizing materials such as calcium carbonate, soluble salts (including gypsum), and dry soil hold this structure in dry conditions. The different bonding arrangements of these soils are shown in Figure(3), which illustrates how the bonds between particles can vary between an open and collapsible structure(AL-Rawas, 2000).

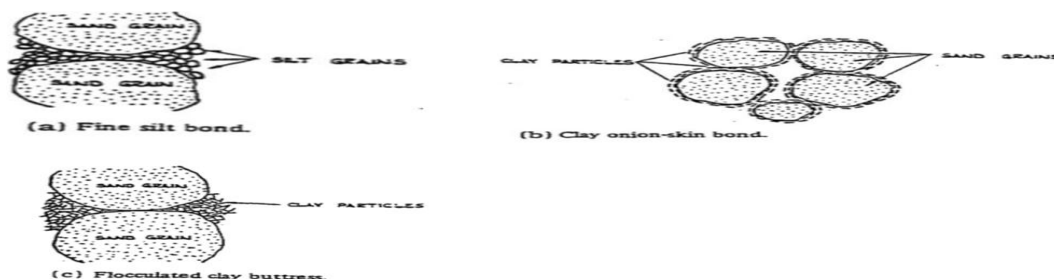


Figure (3): Capillary suction bonding and clay bonding in collapsible soils (suggested by Barden et al; cited in(Opukumo et al., 2022).)

1.2.3.1. Void Ratio and Critical Humidity

The initial porosity index (e_0) and initial dry density are key variables in assessing soil collapse probability. Collapse Potential (C_p) is expressed as the change in the porosity index (Δe) or the change in sample height resulting from the collapse of the sedimentary structure (AL-Rawas, 2000). Figure 4 illustrates how these properties affect collapsibility. Part (A) shows the direct relationship between the initial porosity index and collapse probability, whereby soil collapseability increases with increasing initial porosity. Part (B) shows the inverse relationship between initial dry density and collapse probability.

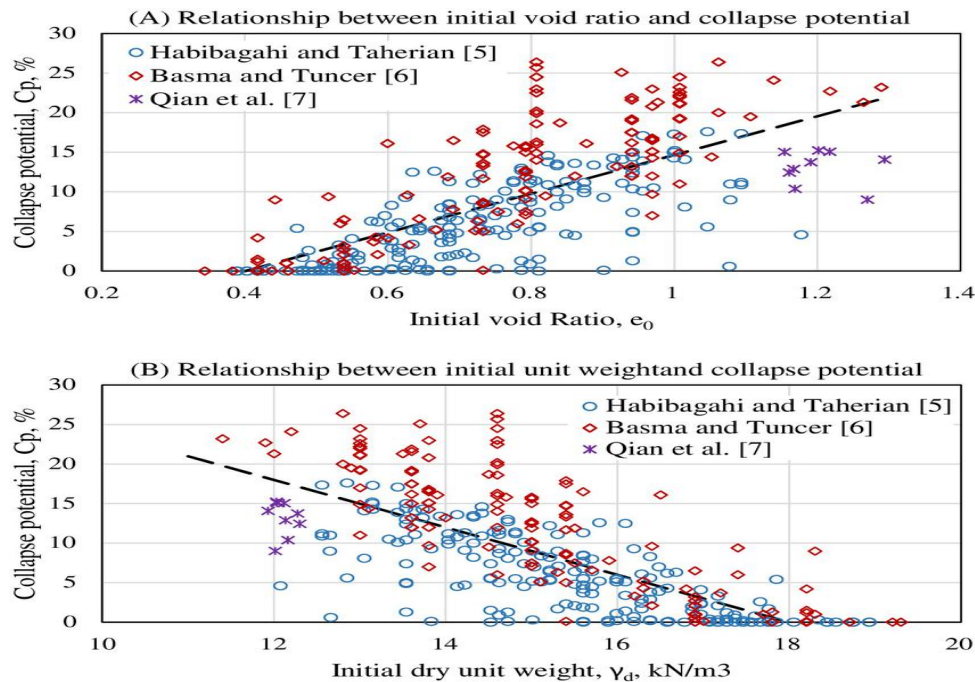


Figure (4): Relationship of the collapse potential vs initial void ratio (A) and dry unit weight (B) (Ashour et al., 2020)

The classification of (Jennings & Knight, 1975) represents an important framework for understanding collapsible soils. They explained that subsidence occurs when the soil is in a semi-stable state with an open structure, allowing it to transform into a denser state upon wetting, as reported by (Brink, 2021). Table (1) shows the classification of collapse potential

Table(1): Guiding values of collapse potential (Jennings & Knight, 1975)

Collapse potential	Severity of problem
0%-1%	No problem
1%-5%	Moderate trouble
5%-10%	Trouble
10%-20%	Severe trouble
>20%	Very severe trouble

1.2.4. Mechanism of Collapse

1.2.4.1. Dissolution Collapse

collapse occurs when wetting - with or without additional loading - leads to the destruction of the bonds between particles, transforming the initial open structure into a denser and more stable one (Opukumo et al., 2022).

1.2.4.2. The Relationship Between Gypsum Content and Collapse Magnitude

The gypsum content in soil critically influences the collapse magnitude, as gypsum crystals act as weak cementing agents that bind soil particles under dry conditions. Studies indicate that sandy soils cemented by soluble salts like gypsum show high collapse susceptibility upon saturation, where the dissolution of these crystals disrupts interparticle bonds, resulting in a sharp reduction in soil volume. The risk escalates when gypsum content exceeds a specific threshold, as the increased quantity of soluble cementing material intensifies the collapse phenomenon (Opukumo et al., 2022)

1.2.4.3. Sudden Collapse upon Wetting

The sudden collapse of gypsum soil is the engineering problem in arid and semi-arid regions. The soil suddenly collapses when it is wetted, due to gypsum bond dissolution between particles, which can cause sudden particle rearrangement and rapid shear strength loss.

(Al-Saoudi et al., 2013) exhibited that gypsum is a binding material, which imparts initial strength to the soil in the dry state, but this strength is rapidly lost when water infiltrates the soil, as the gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) dissolves, resulting in sudden collapse. The extent of this collapse depends on several factors, such as content of gypsum, initial apparent density of the soil, and applied stress level.

Gypsum dissolution is one of the main factors controlling the behavior of sandy gypsum soils under loads. Dissolution leads to the disintegration of the granular structure and a decrease in the soil's compressive strength (Fattah et al., 2017) indicated in their study that the collapse potential increases with increasing gypsum content and degree of saturation, and they demonstrated this through an oedometer test.

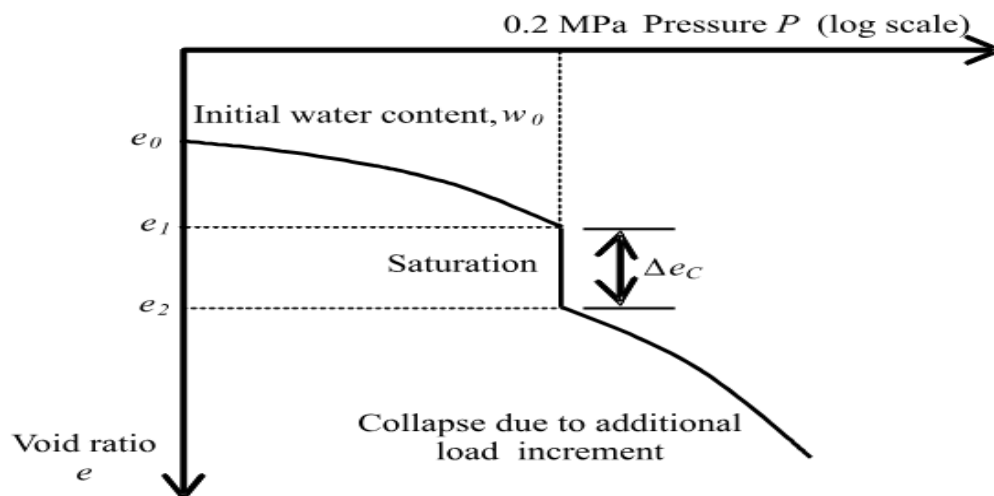


Figure 5 : Typical collapse potential one dimensional consolidation test (Abbeche et al., 2007) .

1.3. Literature Review

The following is a list of recent publications related to deformation measurements in soil for the most common methods:

(Al-Obaidi, 2003), The researcher investigated the geotechnical behavior of highly gypsiferous soil containing 60% gypsum collected from Al-Anbar University, Al-Ramadi, Iraq. A modified Soil Leaching Apparatus was used to test cylindrical soil specimens 15 cm in diameter and 15 cm in height under a constant hydraulic gradient of 16, with both upward and downward water flow, while an oedometer was used to perform permeability-leaching tests. To improve the soil properties, glass sand (quartzite) and crushed ceramic were added at

replacement ratios of 5%, 7%, and 9%. The results showed that the additives filled the voids created by gypsum dissolution, reduced the collapse potential, improved the engineering properties of the soil, and the permeability coefficient gradually decreased during the leaching process.

(Gaaver, 2012) Compaction's impact on the collapsible soils' geotechnical characteristics was being examined in this ongoing investigation. Test trenches at four locations in the Borg El-Arab neighborhood, which is roughly 20 kilometers west of Alexandria, Egypt, yielded undisturbed block samples. Both soaked and unsoaked conditions were used to examine the samples. It was shown how water inundation affected the geotechnical characteristics of collapsible soils. A comparison of compacted and natural, undisturbed samples of collapsible soils was carried out. A relationship between the collapse potential and the initial moisture content was attempted. The compacted collapsible soils' California Bearing Ratio and the liquid limit were empirically correlated. Geotechnical engineers should be able to reasonably estimate the complicated parameters of collapsible soils using simple laboratory tests thanks to the relatively simple correlations that have been shown.

(Karim et al., 2013): The present study investigated the possibility of improving the gypsum-rich, erodible soil at the Al-Karma site (which has a relatively high gypsum content of approximately 50%)-located in Anbar Governorate-using kaolinite and bentonite as additives. The basic concept involves mixing these additives with the natural soil at different weight percentages (5%, 10%, 15%, and 20% of the dry soil weight). The results showed that the soil's shear strength coefficients sometimes increased and then decreased with increasing additive content. It was concluded that bentonite was much more effective in increasing c and reducing ϕ than kaolinite. Meanwhile, kaolinite was more effective than bentonite in reducing c . The study also concluded that the shear strength of gypsum soil was improved by using such additives (5% kaolinite alone or 20% bentonite alone), as they increased bond strength in addition to acting as a binder.

(Fattah et al., 2014) The researcher evaluated the geotechnical properties of four types of gypseous soils with varying gypsum contents treated by grouting with acrylate liquid. Experimental results on undisturbed samples showed that the treatment successfully decreased the soil's compressibility by 60–70% and reduced its collapse potential by 50–60% due to the formation of a thin, protective acrylate film around the gypsum particles that prevents water interaction and dissolution. Furthermore, the chemical grouting significantly altered the shear strength parameters; in unsoaked specimens, it enhanced cohesion due to its bonding effect while comparatively decreasing the angle of internal friction by preventing direct particle-to-particle contact. Lastly, while the strength of the treated sandy specimens increased with overall stress under saturated conditions, this rate of strength gain slowed down as the soil became unsaturated, eventually leading to a loss in strength once the suction exceeded a specific threshold.

(Al-Busoda & Al-Rubaye, 2015) The gypseous soil used in the study was transported from the central Iraqi city of Bahr Al-Najaf, which is part of the Al-Najaf Governorate. The model pile was installed in gypseous soil that contained 42% gypsum. Tests of compression axial model pile load have been conducted for model piles embedded in gypseous soil at an initial saturation level of 7% both prior to and during soil saturation. Based on the outcomes of the pile load tests, a number of criteria have been applied to determine the model bored pile's bearing capacity. It was discovered that for every model pile load test, Shen's approach produced results that were nearly suitable. Because moisture reduces the gypsum's cementing action, a

significant reduction in bearing capacity was seen when the model pile was loaded after soaking for 24 hours.

(Ali & Fakhraldin, 2016) With the objective offer baseline data for future construction design, this study examines the characteristics of the soil. Analysis and investigation were done on the chemical and physical characteristics of the soil. According to the findings, the majority of the soil is categorized as sandy with few fines, with cohesion ranging between 0 and 13.2 kPa and an internal friction angle between 26.3 and 41.2 degrees. The liquid and plastic limits (LL and PL) vary between 21 and 29% and 11 and 15%, respectively. For the soil in western areas, the low values of LL and PL rise as one moves eastward. The ideal moisture content and maximum dry density range from 8.6 to 13.2% and 17.5 to 19 kN/m³, respectively. While the gypsum concentration ranges from 13.6 to 28.3%, the investigations also reveal that the organic and sulphate contents have modest ranges of 1.9% to 2.9% and 2.2 to 2.7%, respectively.

(Al-Obaidi & Al-Mafragei, 2016) The researcher investigated the settlement and collapse behavior of gypseous soils collected from various locations in the Salah Aldeen Governorate. The methodology relied on conducting field plate load tests (under both dry and wet conditions) and Standard Penetration Tests (SPT) at depths ranging from 1 to 5 meters.

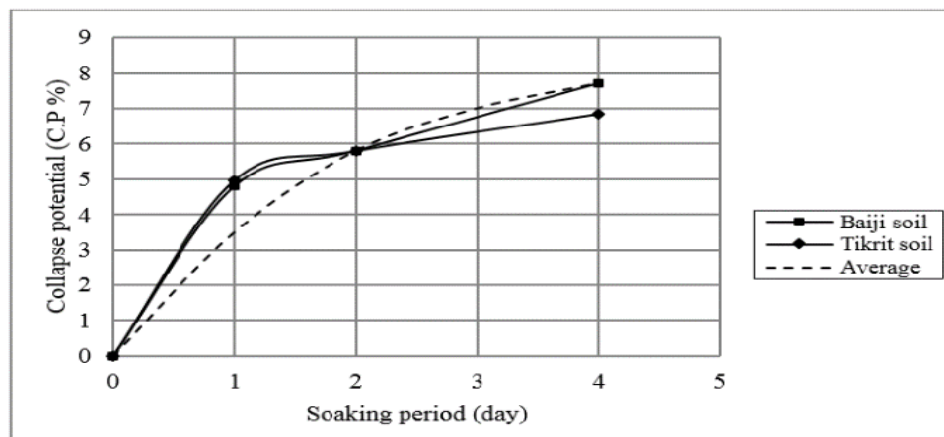
The researcher concluded that dry gypseous soils settle less than weakly gypseous soils, adding that the settlement of the latter can be calculated using fundamental equations based on SPT data. Additionally, the results showed that gypseous soils serve as a reliable foundation base during short-term wetting; however, they undergo severe settlement during long-term flooding due to the dissolution of salts and gypsum a process controlled by the initial gypsum content, acting loads, and soil mineralogy. Ultimately, the study established that the standard SPT is not applicable for determining the settlement of gypseous soils under soaking conditions.

(Fattah et al., 2017) This researcher compared the collapse index estimated from the plate loading test with the collapse potential predicted from the laboratory standard collapse test. The Basrah Governorate's Rumaila served as the soil site for the study. The soil is regarded as having a moderate degree of collapse, according to the results of a collapse test conducted on two samples, which revealed that the collapse potential, I_c , of the two samples is 5.091% and 3.502%. Based on a field plate load test, the average resolving slump coefficient for salty ground was shown to be between 0.94% and 1.2%. The study of collapse potential revealed a clear difference between the two method's boundary conditions.

(Ayeldeen et al., 2017) The researcher employed several concentrations of biopolymer were employed, and the experimental program was carried out at two curing times (shortly after the soil was mixed with the biopolymer and after a week of curing). A collapsible potential test was conducted using various mixing circumstances (wet mix and dry mix), and shear parameters were evaluated for the treated specimens in both soaked and unsoaked situations. To forecast how the treated collapsible soil would behave both before and after being submerged in water, a computer model was developed. According to the findings, guar gum and xanthan gum can both be utilized as enhancement materials for collapsible soil treatment. when the soil was blended with 2% biopolymer concentration in the wet instance, the collapsible potential reduced from 9% to 1%. increased the cohesiveness of the soil from 8.5 kPa to 105 kPa by increasing the concentration of xanthan gum from 0% to 2% after a week curing, thereby boosting the total shear strength of the soil. The shear strength of the soil can be increased by around 30%; however, the collapsible potential of the soil material will be reduced by nearly 20%.

(Schanz & Karim, 2018): Numerous qualities, including scanning electron microscopy (SEM), XRD, chemical, physical, compressibility, collapsibility, shear strength, and suction, are tested in the experimental study. The test findings showed that Tikrit soil had a higher collapse potential (CP) at low stress levels. Higher CP is obtained for Baiji soil at low stress levels,

suggesting that CP increases as gypsum content decreases. Additionally, the CP dramatically rises when the stress level and soaking time increase for a given stress level. Baiji soil is rated as moderate trouble to minor according to the collapse potential severity classification, but Tikrit soil is rated as trouble to moderate. Both soils become problematic after soaking. Additionally, after soaking for 6 and 24 hours, the Tikrit soil shear parameters (and) decreased by 12.2 to 9.2% in the internal friction angle and 91.5 to 94.2% in cohesiveness, respectively, compared to dry conditions. For low consistency soils (liquid limit < 30%), such as Tikrit soil, the maximum total suction is measured. Figure 6 shows Collapse potential versus time at 200 kPa stress level .potential



Figure(6) : Collapse potential versus time at 200 kPa stress level for Baiji and Tikrit gypseous soils Schanz and Karim (2018)(Schanz & Karim, 2018)

(Muhauwiss, 2018); The researcher investigated how gypsum removal affects classification of granular soil. At varying depths from the natural ground surface, four gypsum soil specimens were collected from Tikrit's Al-Qadisiyah district. The depths of 0.75, 1.10, 2.00, and 3.30 meters were chosen. Accordingly, the equivalent gypsum contents were 42.23%, 32.50%, 8.75%, and 19.82%. By washing with distilled water, the gypsum particles were dissolved and eliminated using the Ethylenediaminetetraacetic Acid (EDTA) solution. The findings demonstrated that gypsum may be successfully removed from granular soils using Ethylenediaminetetraacetic Acid (EDTA) solution and distilled water washing.

In every studied specimen, the gypsum ratio was lowered to less than 2%. The specimens' specific gravity rose between 2% and 12%, while the proportion of organic matter remained same. The process of removing the gypsum had an impact on the soil specimens' granular distribution curves and decreased the pace at which soil grain diameters increased. In general, there was no difference in the categorization process of the soil before and after the gypsum was washed off.

(Snodi & Hussein, 2019): The researcher investigated the potential use of rubber tire waste as an additive to strengthen gypseous soils. The prescribed soil was combined with varying amounts of the waste material (2, 4, 6, and 8%).

In contrast to cohesiveness, which was hardly impacted, the obtained data demonstrate that the angle of internal friction increases dramatically with the addition of a variable percentage of tire residues.

Furthermore, the rubber from used tires reduces the ideal moisture level and maximum dry density for this kind of soil. When the waste fraction is included, the difference between the ideal moisture content and maximum dry weight is linear.

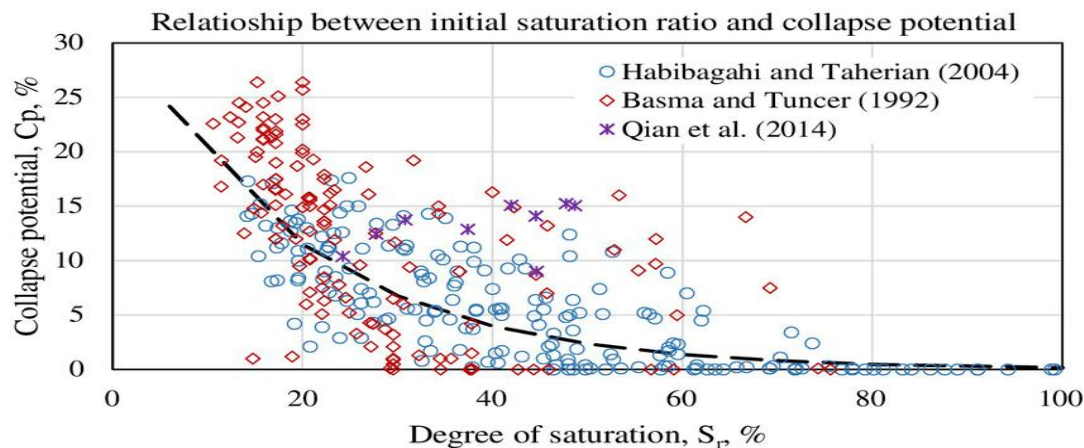
(Ibrahim, 2019): By the mixture of soil and three kinds of stabilizer material silicone oil, sodium silicate and bentonite, this work was conducted to improve the permeability property of

gypseous soil. Four kinds of soil were prepared. One was untreated soil, the other was a mixture of 70% gypseous soil and 30% silicone oil, the third was a mixture of 70% gypseous soil and 30% sodium silicate, the other was a mixture of 70% gypseous soil and 30% bentonite. The oedometer-permeability drainage instrument was used to evaluate the leaching of all prepared soil. The results show that the coefficient of permeability decreased with increasing time, dissolving of gypsum and the leaching strain. The reduction may be explained by the filling of the pores created by the dissolving of gypsum with stabilizer materials after leaching, which reduces the Seepage. However, the stabilizer elements act as an impermeable layer to prevent the water and the gypsum particles from coming in direct contact with each other. The leaching strain increases and the amount of dissolved gypsum increases with the progress of the leaching. This tendency could be explained by the gypsum's ongoing disintegration, which results in an ongoing settlement. Additionally, as the leaching process progresses, the void ratio rises due to the presence of pores caused by the continual dissolution of gypsum. Due to a decrease in gypsum dissolution, treated gypseous soil has a lower void ratio than untreated soil, which in turn lowers leaching strain. When it comes to lowering the coefficient of permeability, sodium silicate outperforms silicone oil and bentonite.

(Ziani et al., 2019) One of the primary problems in soil mechanics is the study of collapsible soils caused by flooding. The majority of studies on this kind of soil have focused on identifying it, understanding how it collapses, and treating it with glass fibers, salts, and hydraulic binders. However, not much study has been published on how they might improve their processes by using natural resources like pozzolan or industrial waste like slag to address socioeconomic and environmental issues. In this study, a number of experiments were carried out to investigate the impact of varying the amounts of granulated slag and natural pozzolan on the suction and collapse potential (C_p) of a laboratory-reconstituted soil that behaved similarly to undisturbed and natural soils.

It was shown in the results that treating collapsible soils with granulated slag and natural pozzolan significantly reduced the collapse potential (C_p), which was followed by a decrease in suction. The same samples were also subjected to SEM/EDAX analysis, which showed that these two material particles were present in the soil pores and that the soil's mechanical and physical properties were significantly improved.

(Ashour et al., 2020): The researcher indicated how S_r has a major impact on the C_p of flooded soil, which significantly drops as S_r levels rise.. Figure (2-7) Relationship between the collapse potential and the initial degree of saturation based on the principles of the traditional triaxial test, the post-inundation stress-strain curve (i.e., mobilized shear strength) of the soil is constructed using the determined parameters of flooded collapsed soil, such as e and ϕ . For validation, the anticipated and actual stress-strain curves of flooded collapsible soils are compared.



Figure(7): Relationship between the collapse potential and the initial degree of saturation(Ashour et al., 2020)

(Hayala et al., 2020) Using laboratory studies, the impact of using nanomaterials to stabilize and improve gypseous soil was investigated. The gypseous soils were gathered from an intake location in Bahar Al-Najaf and combined with two different kinds of nanomaterials (Nano-silica and Nano-clay), which were applied in trace amounts as a percentage of the soil sample's dry weight. Tests were performed to determine the collapse potential, specific gravity, and sieve analysis. The results from the experiment demonstrated a notable alteration in the soil sample's geotechnical characteristics. As soon as the percentage of used nanomaterials is increased, the collapse potential falls until it reaches a certain point, at which point it will rise. Therefore, even a little amount of nanomaterials added to gypseous soil could improve its qualities. When adding nano-silica to soil, the collapse potential (C_p) decreases as the amount of nano-silica increases until 1% of the added nanomaterials is reached. Then, when the amount of stabilizer is increased, the C_p decreases by approximately 91%, and the effect of the additive (nano-silica) shifts the collapse severity classification from "moderate trouble" to "no problem."

(Al-Zabedy & Al-Kifae, 2020); In order to increase the bearing capacity of gypsum soils and decrease settlement and collapsibility, this paper reviews the majority of these investigations and the current chemical and physical treatments performed to gypsum soils in Iraq. In this study, the bearing capacity improved AL Fallujah After applying geogrid, gypseous-soaked soil increases bearing capacity by roughly 51%.

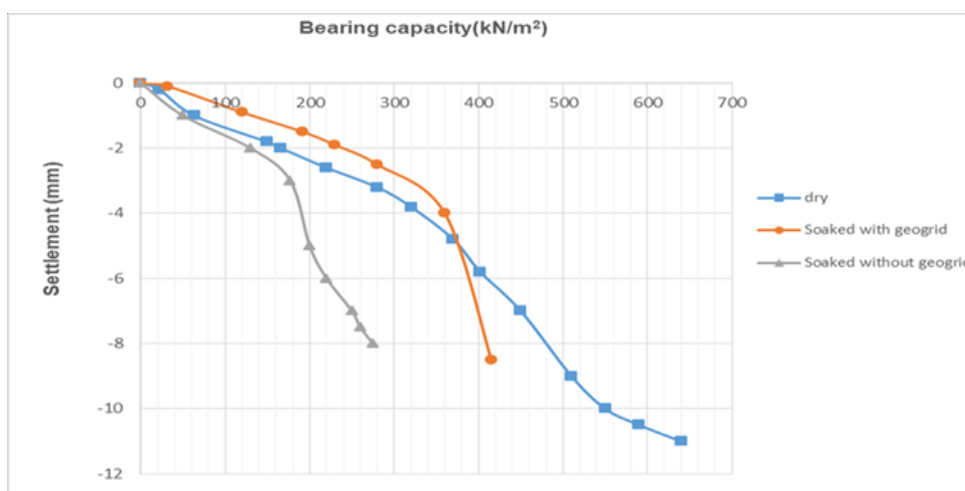


Figure (8): Relationship between settlement and bearing pressure for AL-Fallujah gypseous soil (Al-Zabedy & Al-Kifae, 2020)

(Karkush et al., 2020) Two gypseous soils from two distinct locations in Iraq Al-Najaf city (42% gypsum content) and Al-Samawa city (54% gypsum content) were subjected to laboratory testing for this study. The chemical and geotechnical characteristics of the soils under study were enhanced by adding nano-clay (N_C) in three different percentages: 1%, 2%, and 4%. The treated soil samples underwent physical and chemical categorization tests. Additionally, testing of the soil samples' collapsibility and shear strength were performed under both soaking and dry circumstances. Regardless of the proportion of nano-clay, the test findings showed that combining it with gypseous soils had an impact on the soils' hydraulic conductivity and consolidation behavior. When 4% nano-clay was added to soil samples, the collapse potential dropped by 77%. Generally speaking, 4% nano-clay improves the chemical and geotechnical characteristics of gypseous soils the best.

(SujitM. et al., 2020) The researcher examined the whole analysis of employing gypsum and crumb rubber powder (CRP) to stabilize and improve soil characteristics. Gypsum is taken at a constant proportion of 2%, whereas the percentage of crumb rubber powder is 5%, 10%, 15%, etc. Various tests are conducted, such as the CBR test, the standard Proctor test, the liquid limit, and the plastic limit. It has been discovered that adding gypsum and crumb rubber powder enhances the characteristics of soil.

(Abraham & Mahmood, 2021) The researcher examined the impact of reducing matric suction, or moisture, on soil deformation at a particular stress level. The tests are carried out using a modified Oedometer setup, which also applies water and air pressures to reach the desired matric suctions. Three matrix suctions of 50, 20, and 0 kPa are included in the study, and each is subjected to three net normal stresses of 221 kPa, 442 kPa, and 885 kPa, respectively. 95% of the maximum dry density determined by the Proctor test is achieved by remolding the soil specimens. The findings showed that the stress of 221 kPa has the highest collapse potential (C_P) value. The majority of the C_P is attained prior to the soil becoming saturated. This problem needs to be taken into account as an improvement while analyzing and designing the foundation in unsaturated gypseous sandy soils.

(Abdulrasool & Al-Wakel, 2021) The researcher aimed to enhance the behavior of gypseous soil so that shallow foundations can be supported by it. A laboratory study is conducted to assess how varying volumes of polyurethane foam affect the volumetric strain, collapse potential, and mechanical behavior of gypseous soil in order to better understand the stabilization mechanisms. To identify the efficient treatment zone, physical models of a footing on polyurethane foam-treated gypseous soil are analyzed. Because of its ability to effectively reduce changes in volumetric strain and collapse potential, 3% polyurethane foam will be suggested as a way to modify the behavior of gypseous soil based on the results obtained. Using the current conventional theories, the current study develops a theoretical approach that predicts the ultimate bearing capacity for a footing on the surface of treated gypseous soil based on a non-dimensional characteristic.

(Al-Teameemi & Al-Rubaiee, 2022): The researcher examined the impact of adding lime on the engineering characteristics of gypseous soil extracted from a portion of the Najaf-Karbla plateau (52, 48, 72% gypsum). Additionally, this study demonstrates a rise in the amount of gypsum in the soil in the study area's northwest direction. For the three samples, the maximum dry density and ideal moisture content (2.065, 2.025, and 2.003) were at 15%, 14%, and 15%, respectively. As the ratio of hydrate lime increases, the maximum dry density decreases and the ideal moisture content rises. The findings demonstrate that when gypscous soil is treated with more than 3% hydrated lime, it becomes non-plastic. Cohesion Force diminishes when the percentage of lime added increases from 3% to 6%, reaching zero when the addition reaches 9%. This is because when 6% of lime is added, the cohesion strength between molecules is increased; but, when 9% of lime is added, the cohesion strength drops to zero. When the soil is

treated with hydrated lime, the findings of a liquid limit are altered, and the soil's liquidity limit becomes more apparent. The lime induces flocculation and agglomeration of clay particles. Additionally, it is observed that when the percentage of lime increases, the internal friction angle reduces.

(Jassam et al., 2023): The researcher examined experimentally how the initial water content affects the collapsibility characteristics of both natural and treated gypseous soils with 5% cement. The initial moisture content of the soils was examined at 5%, 10%, 15%, and 20%. Soil 1 and Soil 2, which had varying gypsum contents of 28.43% and 43.62%, respectively, were utilized. The soils came from Tikrit City in the Iraqi Saladin Governorate. The findings demonstrate that the collapse potential is significantly impacted by the initial water content. When the initial water content is 20%, The moisture content reduces the collapse potential by up to 70%. Additionally, compared to treated soils with varying beginning water contents, the decrease in collapse for natural soils was higher. Increasing the initial water content can lessen the abrupt collapse, which is a significant issue.

(Niyomukiza et al., 2023) The researcher examined the effectiveness of using leftover crushed glass to modify the soil's engineering characteristics. Experiments on non-stabilized soil and waste glass powder (WGP) stabilized soil in percentages of 3, 5, 7, and 9% of the dry weight of the soil were used to accomplish the study's goals. The results demonstrated that subgrade soil is strengthened and less susceptible to volume change when glass powder is added. After adding 7% waste glass powder to the soil, the maximal compressive strength was achieved; after that, the strength decreased. According to the study, adding 7% waste glass powder content is appropriate for stabilizing soil with characteristics similar to those found in the study area.

(Al-Gharbawi et al., 2023) developed a modified technique to evaluate the collapse behavior of gypseous soil using a larger specimen than that adopted in the conventional collapse test to achieve more representative saturation conditions. The study investigated natural collapsible gypseous soil prepared at relative densities of 35% and 75%. The soil was treated with magnesium oxide (MgO) at 0%, 5%, 10%, and 15%, while carbonated magnesium oxide was examined after carbonation periods of 0, 1, 3, and 24 hour. A modified Rowe cell equipped with moisture sensors was used to evaluate collapse behavior. The results showed that the modified test provided higher collapse potential than the conventional test for untreated soil. Moreover, treatment with 10% MgO followed by 3 hour carbonation reduced the collapse potential by approximately 93%, demonstrating the effectiveness of magnesium oxide in improving the collapsible behavior of gypseous soil.

(Khodabandeh et al., 2023) The viability and effectiveness of treating collapsible soils with a wide range of stabilizing materials, such as fibers, polymers, nanomaterials, industrial waste materials, and biological approaches, have been thoroughly examined in this study.

Investigations were conducted into the treated collapsible soils' collapse potential, shear strength parameters, The process by which each substance improves the soil's strength is covered in this essay. Previous studies have shown that adding a tiny quantity of fibers, polymers, and nanomaterials (less than 4% of dry mass soil) significantly altered and improved soil properties. However, higher quantities (about 30%) might be advantageous for industrial waste products like marble dust and textile sludge, Unconfined compressive strength (UCS), permeability decrease, swelling, and durability enhancement.

(Khodabandeh et al., 2024) Investigated the effect of metakaolin and perlite on improving the physicochemical properties of collapsible loess soil. The treated and untreated soils were evaluated using Zeta potential measurements, and the microstructural changes were verified by Scanning Electron Microscopy (SEM). The results showed that both metakaolin and perlite enhanced the soil properties by increasing the absolute Zeta potential. SEM observations

revealed that the treated soil exhibited a denser and more homogeneous structure with fewer pores and better particle aggregation than the untreated soil. Furthermore, the formation of calcium aluminosilicate hydrate (CASH) due to the addition of metakaolin improved the cementation between soil particles, resulting in enhanced mechanical properties. X-ray diffractogram (XRD) of soils is presented in Figure (9).

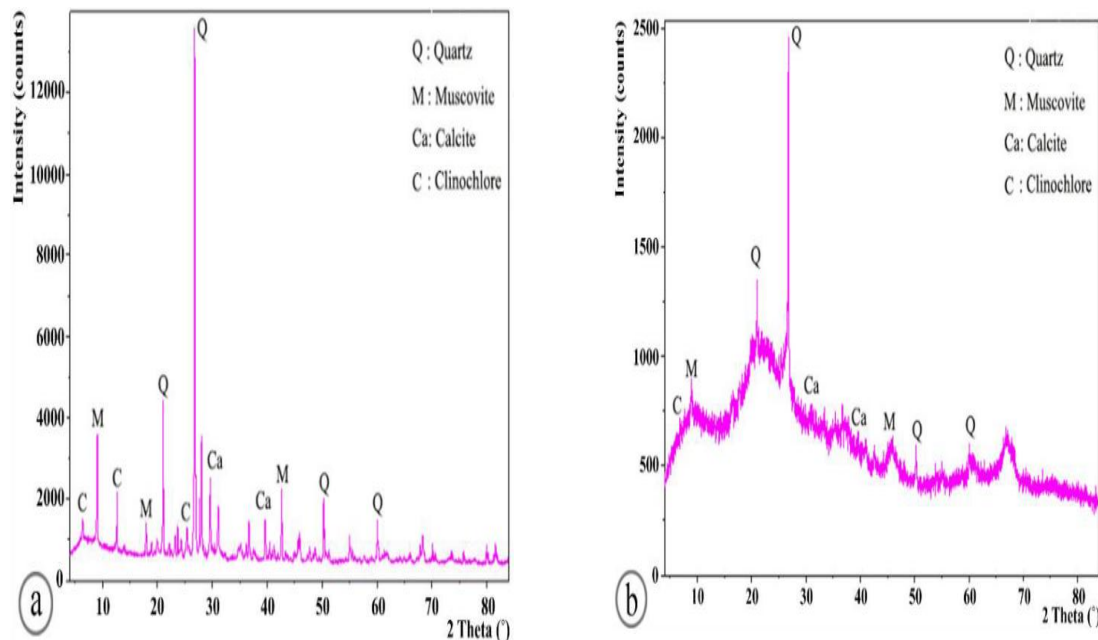


Figure (9): XRD patterns of a) soil b) stabilizing agent metakaolin(Khodabandeh et al., 2024)

(Gücek et al., 2024) The researcher investigated simultaneously improving soil using two different kinds of waste products. The conventional Proctor test, the unconfined compressive strength test, the California Bearing Ratio (CBR) test, and cyclic triaxial tests were among the laboratory experiments used to assess the improvement of soil properties by hybrid waste materials. The aim of this study is to identify critical parameters for road pavement design and construction and to demonstrate how the use of hybrid waste materials to stabilize subgrade can significantly improve the sustainability of road construction. The mechanical and physical properties were examined in detail to find the best mixes. Results based on the dry weight of soil suggest that a mixture of 20% glass powder and 3% rubber tires is the best combination of waste glass powder and tires.

Results based on the dry weight of soil suggest the best combination of waste glass powder and lignin is 15% glass powder and 15% lignin. These results provide insight into the sustainable use of waste products for road construction projects.

(Abdalhussein et al., 2025) The paper proposes optimal percentages of cement kiln dust (CKD) to apply for the purpose to mitigate the compressibility problem for use for soil stabilizing. For the gypsum sand soils that dominate the projects use 1%, 2%, 3%, 4%, and 5%. The results may lead to the use of engineering techniques in these areas that are more productive and sustainable. 22% of the soil studied was from Al-Najaf City, Iraq. Six tests were administered to each of the four groups in this study: the first group worked in a saturated state without using a High Air Entry (HAE) ceramic disc, and the second group employed HAE to show how the two groups differed from one another. The initial matric suction of 100 kPa was carried out by the fourth group, while the third group used a matric suction (ψ) of 20 kPa. The results demonstrated that when the CKD additive was increased, the settlements decreased with increasing matric suction and improved with the optimal value of CKD. The optimal values for

the saturation state, unsaturation states with zero matric suction, unsaturation tests with $\psi = 20$ kPa, and unsaturation tests with $\psi = 100$ kPa were 2.8%, 2.9%, 3%, and 2%, respectively.

(Al Watar & Al-Kifae, 2024) The suitability of clayey soils for enhancing gypseous soil is examined in this study. Two soil samples were taken from Al Najaf City, Iraq, and tested in a lab. They were named as Soil I (gypsum concentration: 35.4%) and Soil II (gypsum content: 12.3%). To improve the engineering characteristics of gypseous soils and reduce the negative effects of soaking, this paper studies inexpensive clayey soil available locally. Electrical conductivity (EC), total dissolved solids (TDS) concentration and permeability of soil were tested. The permeability properties were tested on treated and untreated samples to assess the effect of soil treatment with different clayey soil contents. The samples were leached using the leaching method for five days to analyze the parameter variations. The first test results showed the differences in the data that were collected from the tested soils. However, the differences decreased progressively and it was found that the clayey soil was a useful material for modifying the gypseous soils' natural permeability. As testing progressed, the values converged to constant values.

(Aldarraji & Ganjian, 2024) This paper studies the effect of pre-test curing and soaking time on the collapse potential of a soil due to application of variable concentration nanoclay. The investigated soil was obtained from the city of Najaf in Iraq. Sand was the predominant component in the soil sample. The non-hazardous nanoclay, Montmorillonite K10, is used.

The testing is performed using a computer-controlled Oedometer. A single Oedometer test (SOT) for dry and wet samples at 200 kPa stress is used to estimate the collapse potential. The data pertaining to four concentrations of nanoclay, 0, 3, 6 and 12%, are used. Each data set consists of three groups of pre-tests for various soaking and curing times.

Every experiment starts with the same initial dry density of 1.64 g/cm³, water moisture of 3%, and gypsum content of 29%. The results of this investigation demonstrate that as the pre-test curing time increases, the collapse potential (CP) of natural soil specimens decreases. Adding nanoclay generally results in a fall in CP, with 6% of the nanoclay showing the greatest reduction in CP. Additionally, the pre-test curing for the soil specimens treated with nanoclay increases, which raises the CP associated with the no-curing state.

(Ahmed et al., 2024) aimed to determine how the initial saturation ratio affects the collapsibility of polymer-treated compacted gypseous soils at field dry unit weight. For each scenario, multiple starting saturation levels ranging from 20 to 90% were specified by compacting soils with varying initial water contents. Three percent (3, 6, and 9%) of polymer was applied to the soils.

Prior to adding water to the soil mixture, the stabilizer concentration of the polymer was diluted. The amount of stabilizer utilized and the dilution ratio to reach a specific saturation degree were determined by the moisture content. The findings demonstrate that when the initial saturation ratio rose, the collapse index drastically decreased. the collapse index drastically decreased .

The lowest collapse index was obtained at an initial saturation of 50% for both natural and polymer-treated soil. At an initial saturation level of 50% and a polymer content of 3%, the collapse index of soil with gypsum contents of 18 and 58% was decreased by 92 and 89%, respectively. A theoretical equation considering all the coefficients studied in the present investigation ($R^2 = 0.925$) was used to predict the potential collapse index of natural and polymer-treated gypseous soils.

(Al-Riahi et al., 2025) The researcher investigated the behavior of gypsum soils and the effect of gypsum content and various soil properties on their collapseability. Physical tests were

conducted on an artificial soil composed of clay loam with different gypsum contents (20%, 40%, and 60%). The results showed that increasing gypsum content is associated with a significant increase in collapseability. The void content, total unit weight, and saturation level were also found to significantly influence the soil's mechanical behavior.

The researchers developed predictive statistical models to elucidate these relationships and facilitate the engineering evaluation of gypsum soils. The results also showed that the collapse potential at 200 kPa was 27% and 44% higher, respectively, in the Single & Double Oedometer Tests. This is attributed to the gypsum dissolution and softening of the soil in the double-gauge test before full compression was reached.

(Hayder et al., 2025): The researchers investigated the effect of metakaolin (MK) on improving the engineering properties of sandy subgrade soil. The soil was treated with 5%, 10%, and 15% MK, using sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) as alkaline activators, and cured for 1, 3, and 7 days. The experimental program included unconfined compressive strength (UCS), direct shear, California Bearing Ratio (CBR), failure strain, Young's modulus, and plate load tests to determine the subgrade reaction modulus (K_s). In addition, SEM was used to investigate the microstructural changes in the stabilized soil. The results showed that the mixture containing 10% MK activated with NaOH achieved the highest compressive strength and produced a denser, less porous soil structure than the Na_2SiO_3 -activated mixture. Furthermore, the stabilized soil exhibited a more homogeneous microstructure, and the authors proposed a modified collapse test using a larger specimen and upward saturation, which provided higher accuracy and reliability than the conventional collapse test.

This study, therefore, improves our understanding of the mechanical nature of gypsum soils and provides useful methods to evaluate and manage its collapse potential for geotechnical and engineering purposes.

The research articles in the literature concerned with measuring and measuring and observing soil deformation may be tabulated as in Table(2).

Table(2): Summary of measurement methods used by articles

No.	Author (Year)	Material / Focus	Main Findings
1	Al-Obaidi (2003)	Leaching behavior of gypseous soil	Permeability decreased with time, while leaching strain increased.
2	Gaaver et al., (2012)	Effect of compaction on collapsible soils	Compaction significantly reduced collapse and improved CBR.
3	Fattah et al., (2014)	Acrylate grouting	Reduced compressibility and collapse by 50–70%.
4	Al-Busoda et al. (2015)	Pile behavior in gypseous soil	Bearing capacity decreased after soaking.
5	Ali & Fakhraldin (2016)	Physical and chemical properties	Reported gypsum content, LL, PL, compaction ranges.
6	Fattah et al. (2017)	Field vs laboratory collapse tests	Clear difference between field and lab collapse measurements.
7	Ayeldeen. et al., (2017)	Biopolymers	Collapse reduced from 9% to 1%; shear strength improved.
8	Schanz & Karim (2018)	Collapse and suction behavior	Collapse increased with soaking time and stress level.
9	Muhauwiss (2018)	Removal of gypsum using EDTA	Changed gradation and specific gravity.

No.	Author (Year)	Material / Focus	Main Findings
10	Snodi & Hussein (2019)	Waste rubber tire	Friction angle increased; OMC decreased.
11	Ibrahim (2019)	Sodium silicate / bentonite	Sodium silicate best in reducing permeability.
12	Ziani et al. (2019)	Slag + pozzolan	Significant reduction in collapse potential.
13	Ashour et al., (2020)	Saturation effect on collapse	Collapse decreased with higher saturation.
14	Hayala et al., (2020)	Nano-silica + nano-clay	Collapse reduced sharply.
15	Zabedy & Al-Kifae (2020)	Iraqi treatments review	Geogrid improved bearing capacity.
16	Karkush et al., (2020)	Nano-clay	4% nano-clay reduced collapse by 77%.
17	Sujit M. et al. (2020)	Gypsum + crumb rubber	Improved CBR and compaction.
18	Abraham & Mahmood (2021)	Matric suction effect	Highest collapse at low stress.
19	Abdulrasool et al., (2021)	Polyurethane foam	3% foam reduced collapse.
20	Al-Tameemi & Al-Rubaiee (2022)	Lime stabilization	Soil became non-plastic above 3% lime.
21	Jassam et al. (2023)	Water content + cement	Collapse reduced up to 70%.
22	Niyomukiza et al. (2023)	Waste glass powder	Optimum at 7% glass powder.
23	Al-Gharbawi et al., (2023)	Modified collapse test + MgO	10% MgO reduced collapse by 93%.
24	Khodabandeh et al. (2023)	Review of stabilization methods	Fibers and nanomaterials improved soil behavior.
25	Khodabandeh et al. (2024)	Metakaolin + perlite	Improved soil fabric and cementation.
26	Gücek et al. (2024)	Glass + rubber hybrid waste	20% glass + 3% rubber optimum mix.
27	Abdalhusein et al. (2025)	CKD stabilization	Optimum CKD 2–3%.
28	Al Watar et al. (2024)	Clayey soil mixing	Improved permeability behavior.
29	Al-darraji& Ganjian (2024)	Nanoclay + curing	6% nanoclay best result.
30	Ahmed et al., (2024)	Polymer saturation +	3% polymer reduced collapse ~92%.
31	AL-Riahi. et al. (2025)	Statistical model	Higher gypsum increased collapseability.
32	Hayder et al. (2025)	Metakaolin activation	10% MK gave highest strength.

Conclusions

A comprehensive review of previous studies ." Investigation and Modify the Geotechnical properties of Bahar Al-Najaf Collapsible Soil" reveals that most research has focused on the use of conventional chemical or synthetic materials to improve soil properties, such as cement kiln dust, magnesium oxide, synthetic foam, polymers, nanoclay, and fly ash. These materials have demonstrated good effectiveness in reducing collapsibility and increasing shear strength,

but they sometimes require specialized equipment or high costs and may have adverse environmental effects.

Previous studies on improving gypsum soils can be categorized into three main groups:

1. Traditional chemical methods: using cement, lime, cement kiln dust (CKD), and metal oxides (MgO and CaO).
2. Physical and mechanical methods: such as compaction, geogrids, or clay soil mixing to reduce permeability and collapse.
3. Sustainable and modern methods: relying on natural and renewable materials such as biopolymers (guar gum and xanthan gum) or industrial waste such as fly ash, nano-clay, pozzolans, and slag.

Studies have shown that collapse is affected by gypsum content, voids, and saturation levels. Chemical stabilizing agents reduce collapse but are expensive and may have environmental impacts. Most research has focused on synthetic materials, with a lack of studies on environmentally friendly local alternatives, highlighting the need for sustainable solutions that promote recycling and reduce emissions.

Based on this, this research aims to utilize sustainable, locally sourced materials such as crushed glass and recycled rubber to improve gypsum soil in the Najaf Sea, due to their advantages:

1. Low environmental impact.
2. Low cost and local availability.
3. Improvement of geotechnical properties (collapse resistance, density, shear strength) through a safe physical mechanism.

Thus, this work attempts to bridge the research gap between traditional chemical methods and modern approaches to soil improvement using sustainable and environmentally friendly materials, making the proposed research methodology more reliable and applicable to gypsum fields such as the Najaf Sea.

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