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EFFECT OF ACIDIC ON THE PHYSICOCHEMICAL PROPERTIES AND COLLAPSE POTENTIAL OF GYPSEOUS SOILS: EXPERIMENTAL INVESTIGATIONS

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ABSTRACT: The gypseous soils present a challenge when utilizing them as a foundation for structures, making them a problematic soil type. However, when gypseous soils are saturated by anticipated sources such as acidic results from sewerage of industry, the minerals are soluble, resulting in the subsidence of the structures. The study aims to provide valuable insights into the behavior of gypseous soils, which are known for their tendency to collapse and settle. It considered the impact of acidity on the potential for the collapse of gypseous soils, a crucial area of research that can benefit multiple fields. To comprehend the mechanisms governing the behavior of acidic gypseous soils, an investigation in the lab is carried out to determine how the presence of acidity in varying concentrations affects the possibility of the collapse of gypsum soils. To examine the impact of acidity on the chemical composition of gypseous soils, a Scanning Electron Microscope (SEM) analysis was conducted. The results of the analysis were used to create a map of this effect. In addition, the effect of different parameters such as unit weight and initial water content of gypseous soils and their effect on the collapse potential is studied. The results indicate that gypsum dissolves due to a change in the chemical composition of the soil, resulting in an increase in the collapse potential of gypseous soils. Consequently, the concepts of gypsum soil treatment must take into consideration the nature of the facilities constructed on this type of soil, such as industrial structures.

Keywords: Gypseous soils, Collapse Potential, Experimental work, Acidic

1. INTRODUCTION

The behavior of gypsum soil is an interesting study due to the dissolution of gypsum particles when exposed to moisture. Therefore, understanding the behavior and morphology of soil is both fascinating and difficult [1]. Gypsum soils are usually found in semi-arid regions and arid areas in some countries. Gypseous soils cover as much as one-third of the total land area [2]. In an unsaturated state, gypseous soils can withstand a high amount of load, but when water penetrates the soil, a large settlement occurs, which frequently results in costly reconstructions [3].

When gypseous soils come into direct contact with water, the soil becomes more susceptible to collapse. The breakdown of the various types of salts that are included within the mass of gypseous soil will cause the formation of new pores inside the skeleton of the soil and will remove the cementing connections that are holding the particles together. This process results in the formation of a metastable structure, which makes it easier for particles to slide into a state that is denser. The rate of gypsum dissolution is primarily determined by environmental changes in the moisture content of the surrounding environment, which can be caused by shifts in the level of the groundwater table and/or surface water. In addition to the type and quantity of gypsum present, temperature, permeability, and the state of flow conditions can also affect the rate of gypsum dissolution.

For a reliable design of gypsum soil based it is essential to have a better understanding of their physicomechanical properties and the changes in these properties. Several factors can impact the dissolution of gypsum soils, including temperature, pressure, water velocity, grain size, and the amount of water in contact with the gypseous soils [4].

Numerous studies in the literature have considered the impact of substances other than water on the behavior of gypsum soil. Al-Farouk et al. [5] found that gypsum dissolves more slowly in brine than in distilled water. According to James and Lupton [6], increasing the temperature from 5 to 23 °C led to a 3.25 times increase in the rate of gypsum dissolution. However, soluble compounds dissolve when soil is partially or completely saturated, resulting in a significant loss of resistance. In this concept, acidity resulting from the industrial waste due to a leakage in the network that transfer these wastes has a multiplicative effect on this issue since it causes a loss of gypsum and other mass-forming components in the soil.

The investigations conducted by Akili and Torrance [7] stated the significant influence of the chemical composition of water on the rate of gypsum dissolution. Similarly, Subhi [8] demonstrated that the pH level plays a crucial role in the dissolution of gypseous soils when treated with different concentrations of nitric acid (HNO3) and hydrochloric acid (HCl). This is because acids increase the solubility of most compounds. In addition, Shlash and Al-Rawi [9] showed that the proportion of various compounds, such as CaSO4, decreased in gypseous soil when treated with different quantities of nitric acid (HNO3) and hydrochloric acid (HCl). Overall, these studies highlight the importance of understanding the effects of water composition, pH, and acid concentration on the dissolution of gypsum in gypseous soils.

The solubility of gypsum is 2.60 gm/l. They revealed that a soil-to-water ratio of 1:1 would dissolve approximately 0.25 percent of gypsum in a soil sample [10]. In contrast, the presence of this ratio of acids in gypsum soil may have a greater effect on the behavior of this type of soil. Despite the fact that numerous researchers have studied the behavior of gypseous soils, no study has evaluated the influence of sulfuric acid (H_2SO_4) produced from industrial waste on gypseous soils. This information is crucial for adopting specialized construction techniques to prevent potential catastrophes. The present study investigated the effect of acidification on the chemical composition of gypseous soils Using Scanning Electron Microscope (SEM) analysis. In addition, the collapse potential of gypseous soils under acidic conditions is determined.

2. EXPERIMENTAL WORK

The creation of cavities is directly correlated to the rate of gypsum dissolving. It is challenging to assess since it is influenced by a diverse range of environmental factors, such as the temperature, the source of the water, the amount of time, and the acidity concentrations. In the current study, the impact that sulfuric acid (H2SO4) on the behavior of gypseous soils was investigated.

2.1 Material and Sample Preparation

The used soil is sandy gypseous soil with a gypsum content of 44.2%, as shown in Fig.1a. The soil is extracted from 1 to 1.5 m beneath the natural ground surface. The physical tests included the particle size distribution test, the specific gravity test, and the compaction test, which are detailed in Table 1. The particle size distribution of the soil is depicted in Fig.1b. Based on the standards of the Unified Soil Classification System (USCS), the soil is classified as S.P.

A series of one-dimensional single oedometer experiments are carried out to investigate the effect of acidity on the collapse potential of gypseous soils. Each series utilized a pulverized, homogenous, air-dried gypsum soil. In the first series, the test specimens were obtained using a reconstitution procedure. The gypseous soil mass that is required to occupy a given volume of the samples is prepared by placing gypsum soil directly into a ring of an oedometer test with a dry unit weight of 13.5 kN/m^3 and natural moisture content of 5%. The samples were placed in a 75.0 mm in diameter and 19.0 mm in-depth consolidation ring. In order to create the specimen, the soil was tamped into a stiff confining ring using a method that involved dividing the soil into three equal layers to ensure that the soil sample remains stable and does not horizontally move during the compaction or loading process. The use of a confining ring is particularly important in this case, as it prevents any lateral movement of the soil sample, which could potentially distort the results of the test. This allowed for the specimen to be accurately represented. The samples were then subjected to an inundation liquid consisting of distilled water with varying acidic concentrations (0.25%, 0.5%, 1.0%, 2.0% and 3.0%) by weight of the inundation water. For the second and third series, experiments were conducted on samples with varying unit weight density and initial moisture content, respectively, which were immersed in a liquid containing 1% acidic.

2.2 Collapse Tests

The gypseous soils are renowned for their propensity to exhibit collapsible behavior, which can significantly impact their engineering properties. In order to better understand the effect of acidity on the behavior of gypseous soil, a series of tests were conducted in accordance with ASTM D5333-03 [11] Specifications.

Fig.1a Gypseous soil.

Table 1 Properties of soil

Properties	Value	Specifications
Specific Gravity, Gs	2.48	ASTM D854-2014 [12]
Gravel, (%)	0	ASTM D6913-2017 [13]
Sand (%)	96.3	
Fines (%)	3.7	
Coefficient of uniformly, Cu	4.3	
Coefficient of curvature, Cc	1.4	
Dry unit weight, γdry max. (kN/m^3)	15.2	ASTM D 698 - 2021 [14]
Optimum Moisture, OMC Content (%)	18.8	
Field unit weight, γ (kN/m^3)	13.5	
Natural moisture content, w (%)	5	
Void ratio, e	0.84	

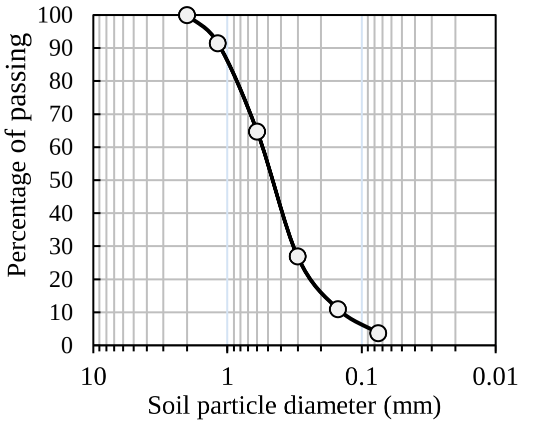

Fig.1b Grain size distribution of soil.

During the consolidation test, the soil was subjected to step pressures up to an inundation stress of 200 kPa, at which point the equilibrium of void ratio was recorded as e_1. Following this, the specimen was immersed in an acidic solution for a period of 24 hours, after which the equilibrium void ratio at the same inundation stress was measured and recorded as e_2. The test was conducted following the recording of one-dimensional volume changes in the samples. The collapse potential (C.P.) is calculated as follows.

$$C_p = \frac{\Delta e}{1+e_0} \times 100\% \quad (1)$$

where Δe is the change in void ratio ($e_1 - e_2$) and e_0 is the initial void ratio.

Table 2 lists the collapse potential values according to ASTM D5333-03 [11] Specifications.

Table 2 This is an example of table formatting

Degree of collapse	collapse potential (C.P.) %
None	0
Slight	0.1 to 2.0
Moderate	2.1 to 6.0
Moderately severe	6.1 to 10.0
Severe	>10

3. SCANNING ELECTRON MICROSCOPY (SEM) TESTS

The present study aimed to investigate the effects of acid attack on gypseous soils using a Hitachi S-3400N scanning electron microscope (SEM). The SEM tests were conducted to reveal the microstructure changes that occurred as a result of the acid attack. The samples were initially coated with a layer of gold for a period of two minutes using the BAL-TEC SCD 005 Sputter Coater machine in order to prepare them for SEM analysis. This step was crucial in enhancing the electrical conductivity of the fragments, which allowed for improved quality of the SEM pictures. Overall, the SEM analysis provided valuable insights into the microstructural changes that occurred in the gypseous soils following the acid attack.

4. RESULTS AND DISCUSSION

4.1 Behavior of Collapsible

The results of a typical single odometer test (SOT) are presented in this section which illustrates the relationship between void ratio, e and pressure, p. The e-log p curves are concave downward, with the void ratio decreasing gradually as pressure increases. The relationship between void ratio and pressure is nonlinear, with a gradual decrease in void ratio with increasing pressure. This behavior does not occur until the stress increment exceeds a critical pressure of (10 kN/m^2), after which the sliding between particles begins. Strain results from the elastic deformations of individual particles for smaller increments [15]. Therefore, in the present study, the initial pressure applied was 25 kN/m^2.

To determine the collapse potential of acidic-gypseous soil as a function of sulfuric acid, water content, and unite weight of soil, statistical analysis was carried out and given in this section as shown in Figures 8, 12, and 16, respectively.

4.1.1 effect of acidity on gypseous soil's vulnerability to collapse

The results of SOT for acid-free gypsum soil are shown in Figures 2 to 7. From these figures, it can be seen that an abrupt change in the void ratio, which appears as a vertical line and indicates that the soil is of the collapsible type. The influence of this behavior of gypsum soil can be explained due to gypsum acting as a cementing agent, which prevents the sliding of the particles. Furthermore, when gypsum is exposed to water, it undergoes a process called dissolution, which causes the particles to reorient themselves and results in a change in volume. Furthermore, the relationship between the collapse potential of gypsum soils and the concentration of acid is depicted in Figure 8. From this figure, it can be stated that the presence of acid in gypseous soil increases the dissolution of gypsum and the fragility of soil structure.

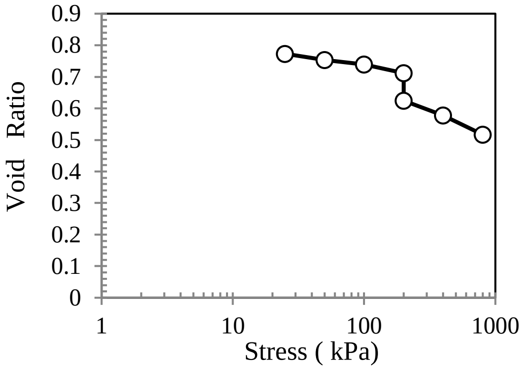

Fig.2. Standard single oedometer test for acid-free gypsum soil.

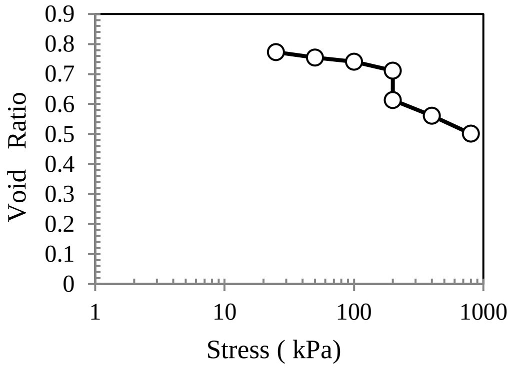

Fig.3. Standard single oedometer test for gypsum soil (0.25 % acid).

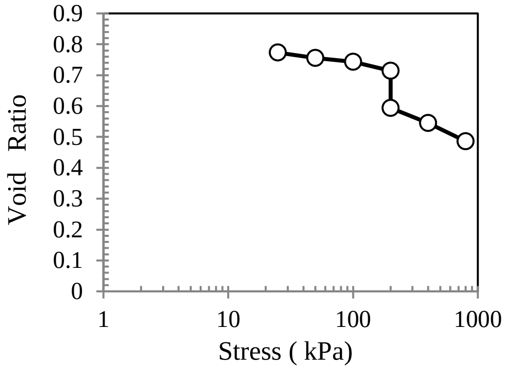

Fig.4. Standard single oedometer test for gypsum soil (0.5 % acid).

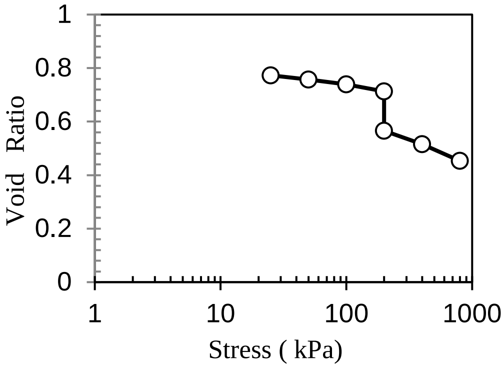

Fig.5. Standard single oedometer test for gypsum soil (1 % acid).

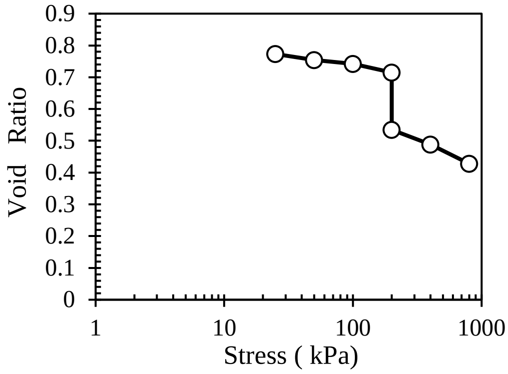

Fig.6. Standard single oedometer test for gypsum soil (2 % acid).

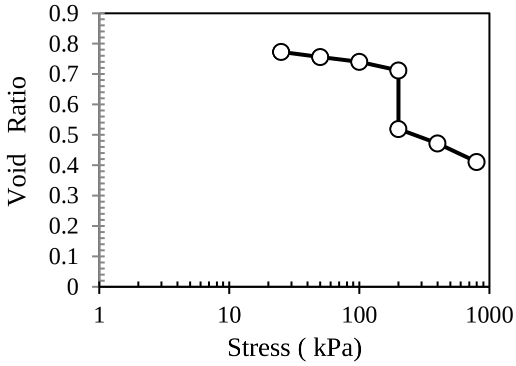

Fig.7. Standard single oedometer test for gypsum soil (3 % acid).

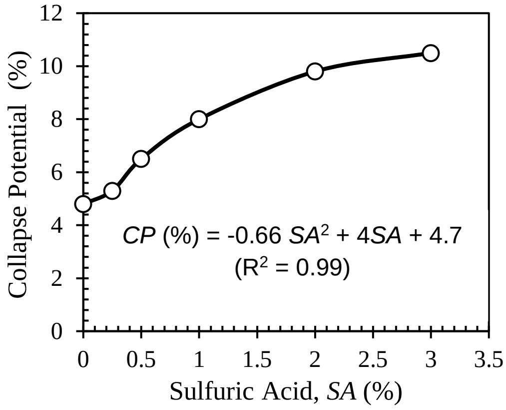

Fig.8. Collapse potential of gypsum soil vs. sulfuric acid.

4.1.2 effect of moisture content on acidic-gypseous soil behavior

Figures 9 to 11 provide a graphical representation of the impact of water content on the collapse potential of gypseous soil when exposed to 1% sulfuric acid. The experiment was conducted using three separate sets of samples, each with varying levels of water content (5%, 10%, and 15%). The present study revealed that the collapse potential of the gypseous soil is significantly affected by its moisture content. Specifically, the collapse potential decreases as the initial water content increases. This can be attributed to the fact that an increase in water content beyond the initial level leads to a higher quantity of dissolved salts. Figure 12 visually represents the relationship between water content and collapse potential, demonstrating that gypseous soil with a higher initial water content is less likely to collapse when exposed to acidity.

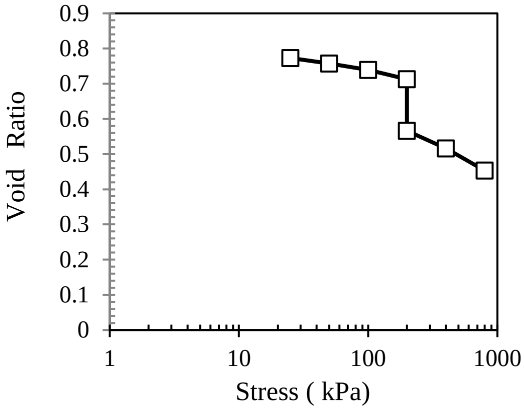

Fig.9. Collapse potential of gypsum soil with 5% moisture.

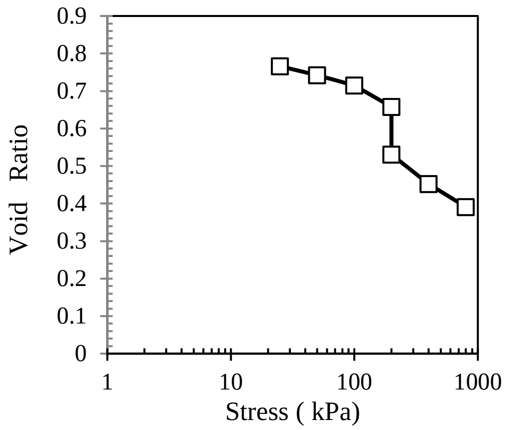

Fig.10. Collapse potential of gypsum soil with 10% moisture.

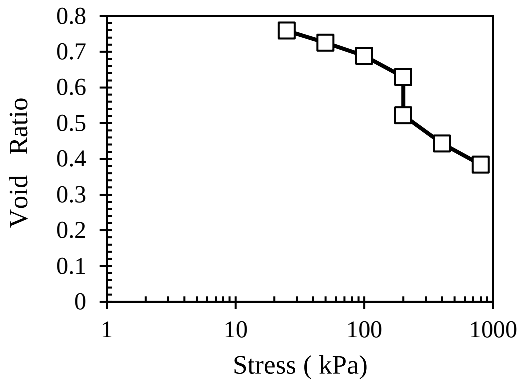

Fig.11 Collapse potential of gypsum soil with 15% moisture.

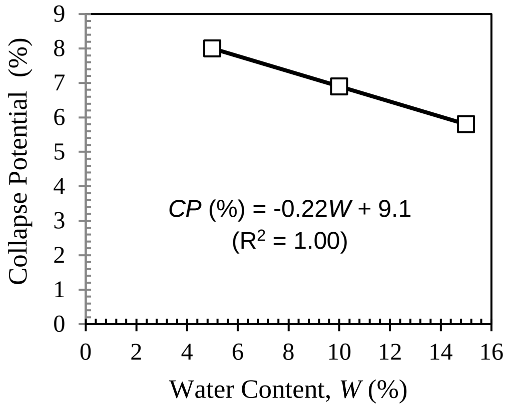

Fig.12 Variation of collapse potential of gypsum soil with moisture content (1% sulfuric acid).

4.1.3 Effect of unit weight on acidic-gypseous soil behavior

To study the effect of unit weight of the soil on the collapse potential, three samples were prepared at different unit weights (13.5, 15.0, and 16.4 kN/m3) at 5 % water content and 1% sulfuric acid. The main results of the effect of unit weight on the collapse potential are presented in two forms; the first form is represented by the relationship between the collapse potential versus the stress, as shown in Figures 13 to 15. The second form relates the collapse potential percent versus unit weight, as shown in Figure 16. From these figures, it can be noticed that the collapse potential decreases with increasing unit weight. The influence of increasing the unit weight of the soil can be explained in that it acts as a cementing agent which prevents the sliding of the particles upon wetting and is resistant to the reorientation of particles. In addition, the process of densifying the soil disrupts the weak cementitious linkages that hold the soil particles together, which causes them to rearrange themselves into a structure that is more robust [16]. According to Vanapalli et al. [17], the influence of weak binding on the collapsibility is reduced when more water infiltrates the voids.

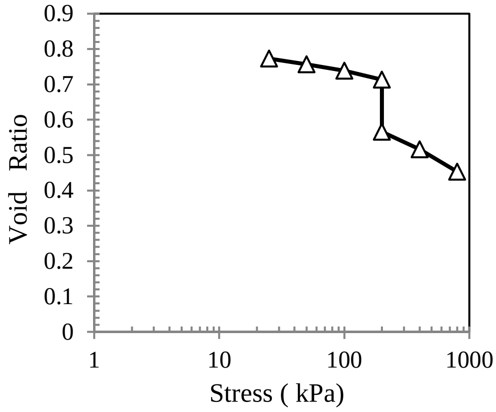

Fig.13 Variation of collapse potential of gypsum soil (γ =13.5 kN/m^3) at 1% acid.

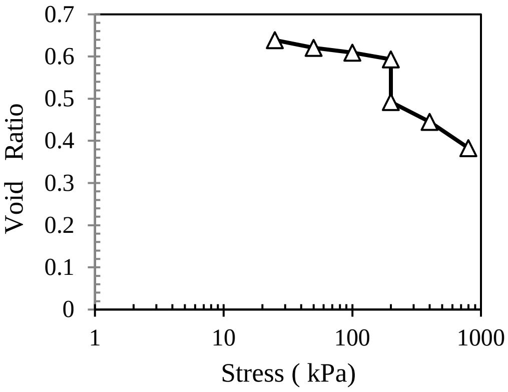

Fig.14 Variation of collapse potential of gypsum soil (γ =15.0 kN/m^3) at 1% acid.

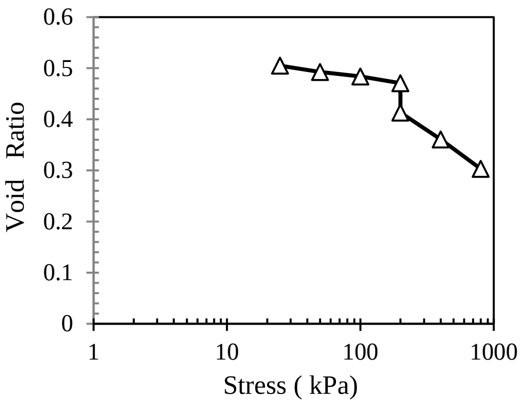

Fig.15 Variation of collapse potential of gypsum soil (γ =16.4 kN/m^3) at 1% acid.

4.2 Analysis of Scanning Electron Microscopy (SEM)

Gypseous soil exists in crystalline or nanocrystalline calcium sulfate ($CaSO_4.2H_2O$) or anhydrate calcium sulfate ($CaSO_4$). Due to the dissolution of calcium sulfate and the formation of cavities in the texture of the soil, and therefore gypseous soil loses its strength.

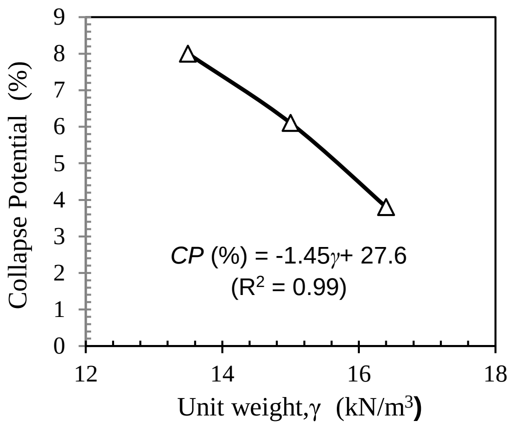

Fig.16 Variation of collapse potential of gypsum soils with unit weight at 1% sulfuric acid.

The rate of dissolution of calcium sulfate is dependent on the moisture content. When gypsum comes into contact with water, dissolution begins and continues until equilibrium is reached or all gypsum is consumed.

The solubility of gypsum is widely recognized as the most influential factor in determining the general behavior of gypseous soils. Gypsum is classified as a salt with moderate solubility, and the water solubility of the hydrated form has been measured at 2g/l [18]. Several studies have been conducted to investigate the solubility of gypsum under different conditions, and the results of these studies have shed light on the behavior of gypseous soils. Freeze and Cherry [19] reported that the solubility of gypsum in purified water at 25°C and a pH of 7 is 2.1 kg/m^3. In another study by James and Kirkpatrick [20], the solubility of gypsum in purified water at a lower temperature of 10°C was found to be slightly higher, at 2.5 kg/m^3. The understanding of the solubility of gypsum is critical for predicting the behavior of gypseous soils and for designing structures that are capable of withstanding the unique properties of these materials. In the present study, Equations (2) to (4) showed the change in thermodynamic values of solubility reactions, which results in the transformation of metastable gypsum to stable anhydrite in the sulfuric acid solution

$$\boldsymbol{CaSO_4\ 2H_2O + H_2O + H_2SO_4 \rightarrow CaO + SO_2 + SO_4 + 4H_2O^{\uparrow}} \quad (2)$$

$$\boldsymbol{CaO + H_2O \rightarrow Ca(OH)_2} \quad (3)$$

$$\boldsymbol{Ca(OH)_2 + + H_2SO_4 \rightarrow CaSO_4\ 2H_2O} \quad (4)$$

The gypsum is stable at low concentrations of H_2SO_4 solution and transforms into anhydrite at

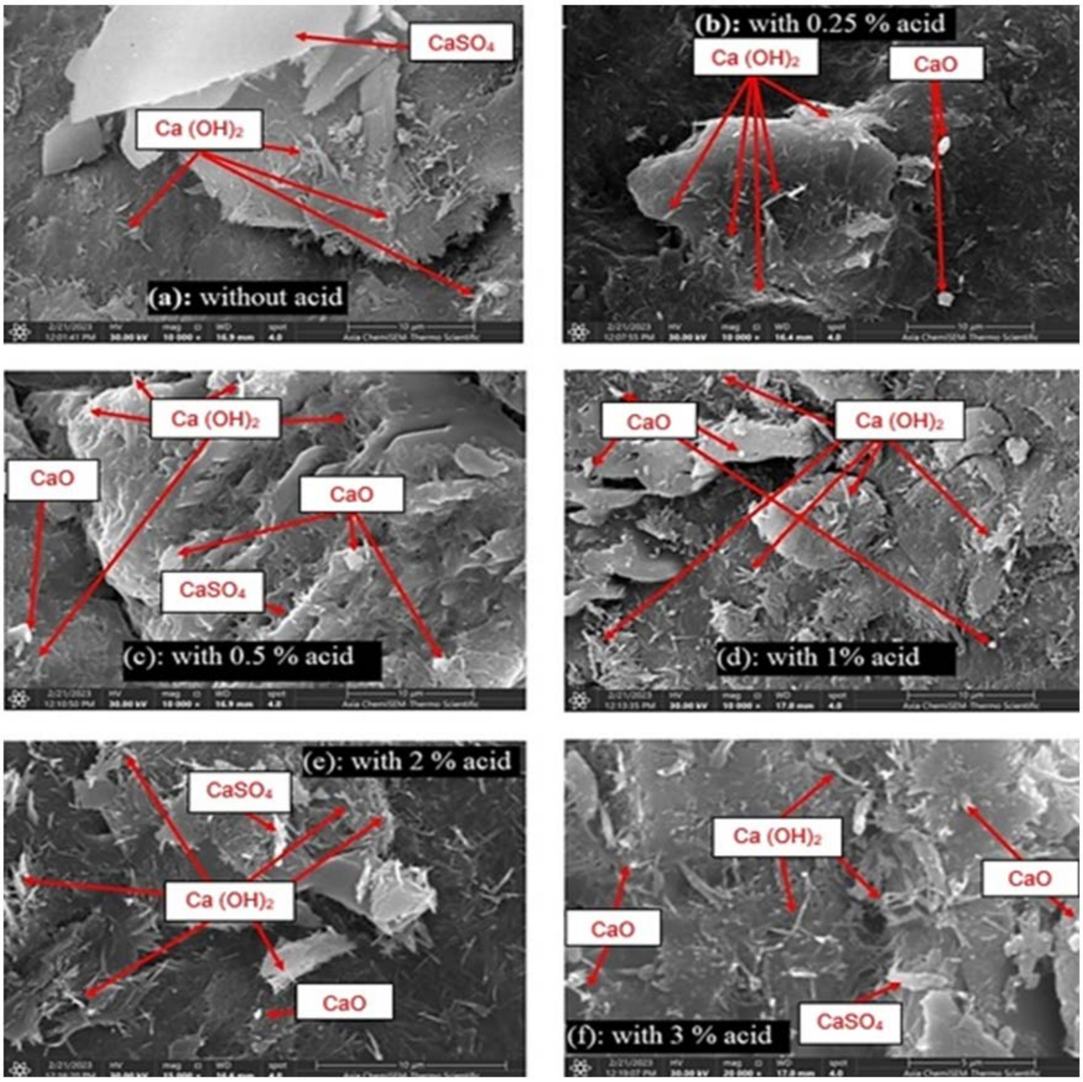

Fig.17 Scanning electron microscope images of (a) gypsums soils without acid (b) 0.25% acid (c) 0.5% acid (d) 1% acid (e) 2% acid (f) 3% acid.

high concentrations of acidic solution. Therefore, gypsum solubility increases with increasing acid concentration. The results of this study agree with the Scanning Electron Microscope (SEM) analysis shown in Figure 17.

5. CONCLUSIONS

Despite the abundance of data collected concerning the geotechnical features of gypseous soils, attempts to explore and comprehend the behavior of gypseous soils when subjected to varying amounts of stress and various environmental circumstances are scarce. Because of the intricacy of such natural materials, the challenges are still present today. This paper has presented a comprehensive study on the effect of acidity on the physicochemical properties of gypseous soils.

The primary effects of acidity on collapsible soils were analyzed via an experimental laboratory campaign and scanning electron microscopy (SEM) analysis. The following conclusions are drawn based on the results acquired.

1. Gypseous soil tested with varying acidic contents reveal that the collapse potential of gypseous soil is most pronounced for soil samples with the highest amount of acidic up to 2%, while an increase in the amount of acidic has a minimal effect on the collapse potential beyond this value.
2. The results of Scanning Electron Microscopy (SEM) analysis revealed that the microstructural changes of gypseous soil caused by acid resulted in an increase in salt dissolution.
3. The initial water content of gypseous soil containing an acidic has an effect on the collapse

potential. According to the results, a reduction in the degree of collapse from moderately severe to moderate can be achieved by increasing the initial water content by 10%.

4. The initial unit weight of gypseous soil containing an acidic has a significant effect on the collapse potential. The increase in the unit weight from 13.5 kN/m^3 to 16.5 kN/m^3 of gypseous soil can reduce the degree of collapse from moderately severe to moderate.

5. It is necessary to treat gypseous soils according to the collapse potential under the effect of acidity in lieu of water in order to either improve construction practices or prevent potential dangers posed by gypseous soils that include acidic.

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