Migration Letters

Volume: 20, No: S8(2023), pp. 144-154

ISSN: 1741-8984 (Print) ISSN: 1741-8992 (Online)
www.migrationletters.com

Electrical Resistivity Method to Characterize Collapsibility of Gypseous Soil

Arwa F. Dheyab[1], Farouk M. Muhauwiss[2]

Abstract

Arid and semi-arid regions have had many gypseous soils. Due of its unpredictable moisture response, it is one of the most difficult soils. Gypsum, a moderately soluble salt, can affect soil engineering qualities, and changes in water content can cause fast soil fabric collapse, harming adjacent structures. These deposits are metastable. Geotechnical qualities are critical to civil engineering design and construction. Traditional site research methods included drilling and excavation to assess geotechnical parameters. The methods were limited by cost, time, and data coverage. Continuous soil subsurface resistivity profiles can be obtained quickly and non-destructively using electric resistivity. The objective of this study is to investigate an electrical resistivity approach for characterizing collapsibility features in gypseous soils. To achieve this, disturbed gypseous soil samples were taken from Salah-Aldeen Governorate, Iraq. The laboratory measured the electrical resistance of gypseous soils with 4-16% water content and 75-95% compaction ratios using a Miller 400 D resistivity meter. Results showed that electrical resistivity vs. pressure curves followed similar trends as e vs. logp curves in dry conditions but not in soaked conditions.

Keywords: *Gypseous Soil, geotechnical parameters, Electrical Resistivity.*

1. Introduction

Gypseous soils are widespread in Australia, Argentina, Russia, and Spain. Gypseous soil covers over 20% of Iraq. Iraq has almost 9% of the world's gypseous soils (FAO 1990). They live mostly in dry and semiarid regions with less than 400 mm of yearly rainfall. Iraq has around 20% gypseous soils (Nashat 1990), which make up 3.7–10% of the global total. Engineering and agriculture view gypseous soils as a serious challenge due to several project issues. Gypsum dissolves continuously as water seeps through the soil mass (Fattah, al-Shakarchi, and al-Numani 2008). Wetting modified the engineering qualities of such soils, putting the structure at risk. Due to rising gypsum levels in soil, several Iraqi infrastructure disasters occurred in recent years (Karim, Schanz, and Ibrahim 2015).

The single oedometer test is a widely accepted and efficient technique for evaluating compressibility qualities in a very short period of time. Furthermore, it has been observed that doing single oedometer tests can yield continuous data instead of discrete data that is dependent on the size of load increments. This continuous data can significantly enhance the accuracy of determining the compressibility mechanical parameters for collapsible soils (Rahardjo et al., 1995; Blatz et al.,2002; Tarantino and De Col,2008; Delage et al., 2007; Kochmanová and Tanaka, 2011; Qin et al., 2015).

[1] Department of Civil Engineering, Tikrit University, Iraq, civil.arwa@st.tu.edu.iq
[2] Department of Civil Engineering, Tikrit University, Iraq, dr.faroukmajeed@tu.edu.iq

Several attempts and investigations have been carried out, both in field and in the laboratory, to examine the behaviour of these soils and ascertain their features in response to issues encountered throughout the construction process (Mansour et al., 2008; Abid Awn, 2010). Laboratory tests offer a means of quantifying engineering qualities within a regulated experimental framework, encompassing various boundary conditions and environmental factors. According to Liu (2007), the drilling and sampling operation typically causes disturbance to soil samples, resulting in potential deviations between the measured engineering properties and their true values.

According to Clayton et al. (1995), the investigation of subsurface profiles often involves the utilization of various methods such as boring, drilling, probing, as well as in-situ examination. The efficacy of the traditional approach is contingent upon various elements, including as the site's topography and accessibility, the overall size of the site, the duration of the process, and the associated expenses. Linear or curved interpolation is commonly used in conventional practices to calculate the subsurface profile. The process of interpolating soil parameters between boreholes might lead to inaccuracies and result in higher project expenses (Leung et al., 2018).

Electrical resistivity surveys are a great way to describe subsurface profiles without disturbing soil structure. This strategy is less expensive and more rapid than traditional methods for investigating a big area (Amato et al., 2012). Electrical resistivity imaging quickly images a vast survey area's subsurface. It's inexpensive and easy to analyse survey data. Electrical resistivity is an effective geotechnical and geoenvironmental site investigation method. Bioreactor landfill bottom liners, covers, and leachate recirculation have been examined using resistivity imaging (Manzur, 2013; Hossain, 2017; Alam, 2017). Due to these benefits, electrical resistivity is widely used for preliminary subsurface investigations, geohazard evaluations, and geoenvironmental studies. Numerous studies examined electrical resistivity and the physical and mechanical properties of soil. Electrical resistivity is related to soil hydraulic properties such as degree of saturation, water content, density, pore water salinity, and pore structure (Muñoz et al., 2012; Seladji et al., 2010; Kibria and Hossain, 2012), Liu et al. (2013) and Rinaldi and Cuesta (2002) used electrical resistivity to measure the level of soil compaction. Long et al. (2012) revealed that electrical resistivity of clay is inversely related to shear strength, plasticity index, and clay content.

The current study aims to investigate an electrical resistivity approach for characterizing collapsibility features in gypseous soils and to establish a correlation between electrical and geotechnical properties.

2. Materials and Methods

2.1 Soil samples

Two sites in Salah-Aldeen Governorate, Iraq, provided gypseous soil. The first is from Baiji with 10–30% gypsum. The second is from Tikrit University with 40%–80% gypsum. Disturbed samples were obtained 0.5-2.5 m below ground level using a machine power shovel. This study measured geotechnical and electrical parameters of five disturbed gypseous samples. The essential characteristics of the soil being tested, including distribution of grain sizes, plasticity index, and modified proctor test, are presented in Table 1.

Table 1: Basic properties of soils

Properties	G1	G2	G3	G4	G5
Gypsum content %	12	29	48	65	77
Unified soil class	SP	SP	SP	SP	SP

LL (%)	38.1	37.3	32.1	30.2	28.5
PL (%)	32.5	31.2	28.3	N.P	N.P
Max. dry unit weight (kN/m^3)	18.25	18	17.92	17.57	17.42
Optimum moisture content (%)	12.5	12.2	11.2	11.6	11.7
Cu	10.82	9.81	10.61	14.53	15.51
Cc	0.96	0.98	0.92	0.97	0.81
D_{10}	0.16	0.16	0.17	0.12	0.10
D_{30}	0.50	0.49	0.52	0.46	0.36
D_{60}	1.68	1.56	1.77	1.79	0.10

2.2 Description of the cell

The oedometer cell used in this study was designed to conduct compressibility experiments on samples of compacted gypsum. It is composed primarily of a chamber, sample ring, loading piston, stainless steel ball, electrodes, and two porous discs. The sample's initial height was 20 millimetres. The inner diameter of the 50 mm sample ring was manufactured of a high-strength and rigid insulating material. A pair of circular stainless-steel foil electrodes measuring 30 mm in diameter and 0.1 mm in thickness were attached to the top and bottom surfaces of the sample. Two electric cables were used to connect the electrodes to the current and potential leads of a Miller 400D resistance meter. Between the upper and lower porous stones affixed to the electrodes were sandwiched samples and two pieces of filter paper.

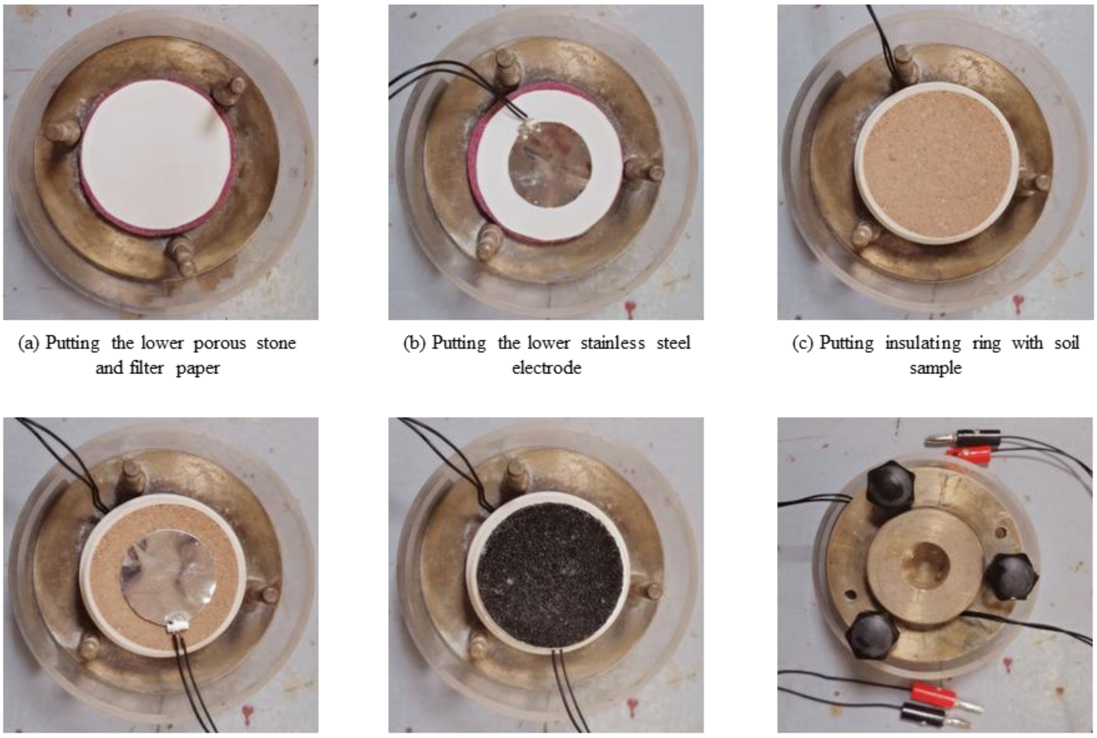
Due to the fact that measurements were taken on both extremities of the sample, a two-electrode measurement was utilised. The following equation can be used to measure soil resistivity:

$$\rho = \frac{RA}{L} \qquad (1)$$

Where, ρ: is the soil resistivity (Ω·m), R: is the resistance (Ω) measured, A: is the electrode area (m^2), and L: is the distance between the two electrodes (m). The measured resistivity was adjusted to the standard temperature of 15.5 °C.

2.3 Procedure for performing a single odometer test (SOT).

The sample was placed in the oedometer cell chamber with the sample ring following compaction (sample preparation). Before placing the sample in the chamber, the lower horizontal electrodes, filter paper, and porous stone were installed (Figure 1a-b). After the sample was positioned in the chamber, the upper horizontal electrodes, filter paper, porous stone, and loading piston were mounted over the sample (Figure 1d-f). Then, fine electric filaments were used to connect the electrodes to the resistance meter.



(a) Putting the lower porous stone and filter paper

(b) Putting the lower stainless steel electrode

(c) Putting insulating ring with soil sample

(d) Putting the upper stainless steel electrode

(e) Putting the upper porous stone and filter paper

(f) Putting loading piston

Figure 1: Preparation sample for resistivity- oedometer tests

An experiment was done to assess soil resistivity under different dry unit weights and moisture contents. Distilled water with a conductivity of 12.94 micro Siemens was employed for the purpose of conducting resistivity tests. An insulating ring was employed to compress soil samples to a specific moisture content and dry unit weight following the process of screening with a 4.75 mm sieve. After sample installation, an initial vertical pressure of 1 kPa was applied to the sample to improve contact between the loading piston and the sample. The testing procedures are conducted in accordance with ASTM D5333-03. The experiments were conducted at 25, 50, 100, 200, 400, and 800 kPa loads. During these experiments, soil samples were covered with plastic wrap to prevent excessive evaporation, which could lead to erroneous results. Before imparting additional load, readings from dial gauges and electrical resistance are recorded. To determine the collapse potential, the specimen is submerged at an applied stress of 200 KPa. The test is then continued with additional loading, as in a standard consolidation test. The collapse potential (Cp) is defined numerically as follows:

$$\mathrm{CP}\ (\%) = \Delta\varepsilon = \frac{\Delta \mathrm{H_e}}{\mathrm{H_0}} = \frac{\Delta \mathrm{e}}{1+\mathrm{e_0}} \times 100 \qquad (2)$$

where:

$\Delta\varepsilon$ is the vertical strain,

ΔH_e is the change in height of soil resulting from wetting,

H_o is the initial height of the soil,

Δe is the change within the void ratio of the sample resulting from wetting, and

e_o is the natural void ratio.

3. Results and Discussions

The correlation between load-deformation and electrical properties may provide useful information to utilize electrical resistivity. The relationship between water content, dry density, void ratio, collapse potential, and resistivity was explored according to soil specimens with different compaction levels (R.C): (0.75, 0.85, 0.95) and different water contents (M.C): (7%, 10%, 13%).

3.1 Effects of Pressures on Electrical resistivity of the Soils

The variations of electrical resistivity of soil samples with applied stresses at dry and soaked conditions are illustrated in Figures 2 to 6 For dry conditions, the experimental results showed that the trends of variation in electrical resistivities with pressures were similar to e vs. logP curves. The electrical resistivity of soil samples exhibited a trend of decreasing abruptly with each new first load applied.

This indicates that compression causes the redistribution of water, air, and soil particles in the soil. When the load is small, compression has a significant effect on the soil structure, which results in a rapid decrease in the electrical resistivity of soil specimens. As the applied load increases, air is squeezed out of the soil, and saturation increases. The electrical resistivity gradually tends to become less sensitive to changes in stress and strain.

Under soaking conditions, it was observed that electrical resistivity increased as the applied pressure increased. Nonetheless, the increase was mild compared to the dry sample. As the interstitial water dissipates under the application of loads, the moisture contents of saturated specimens decrease with the increase in stress. Therefore, an increase in electrical resistivity occurs with the increase of stress.

3.2 Effects of Void Ratio on Electrical resistivity

Compression curves of stress—void ratio data points were obtained from oedometer tests. For both dry and soaked samples, similar compression curves (e-logP). In addition, the void ratio decreased with the increase of vertical stress. In the case of the same water content, the higher the dry density, the smaller the void ratio. The void ratio decreases with increasing water content. For soil whose initial water content is fewer than 13%, the change in water content has a significant influence on the compression and deformation of soil. This is especially important for soils with a compaction ratio of less than 0.85.

As the variations of electrical resistivity and void ratio showed similar trends with the increase in stresses, the relationship between void ratio and electrical resistivity was investigated. In dry conditions (pre-wetted) the general trend of the void ratio was observed as the void ratio decreased, the resistivity value decreased, but it had a different trend for soaked conditions. However, the rate of decrease depends on moisture content, dry density, and gypsum content. while in soaked conditions, it had a different trend.

3.3 Effects of gypsum content on the soil electrical resistivity

Soil sample resistivity increases with increasing gypsum content. A maximum value of resistivity was reached by soil (G4) with gypsum content (64.7%), and then the value steadily decreased.

The rate of change in the resistivity of the soil was not similar in all water content. Increasing water content leads to a declining impact of gypsum content on resistivity values as a function of gypsum content. For moisture content less than 13% the change in resistivity is higher for higher gypsum levels and lower for lower gypsum contents. However, at 13% moisture content this change is not enhanced. From presented figures, it is seen that the rate of change in resistivity with unit weight increases with the increase in gypsum content.

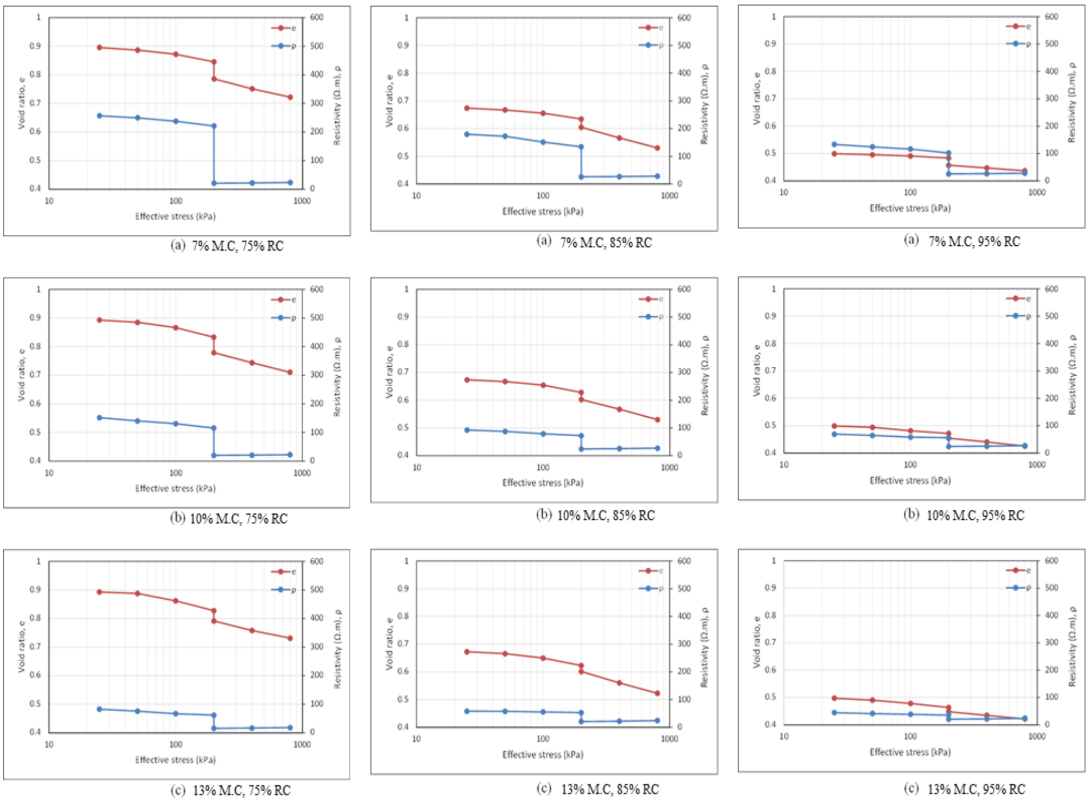


Figure 2. Void ratio-effective stress-resistivity curve of G1 soil

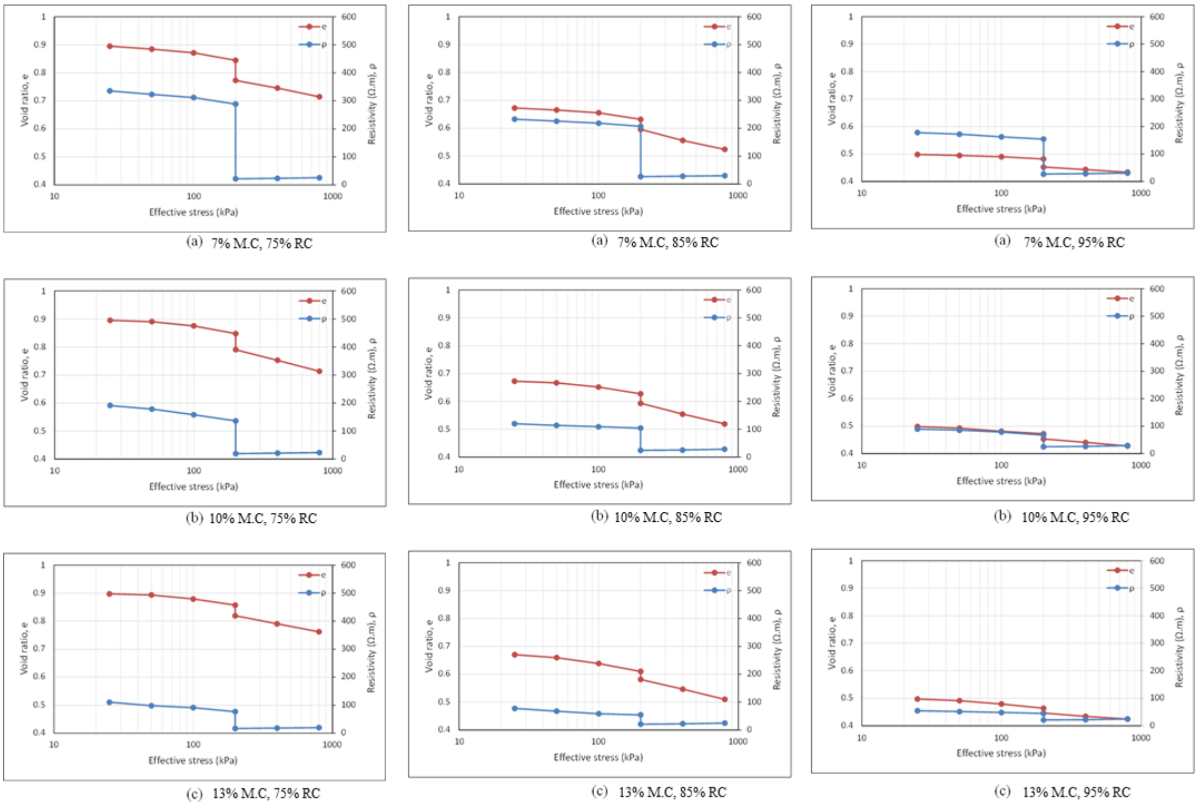


Figure 3. Void ratio-effective stress-resistivity curve of G2 soil

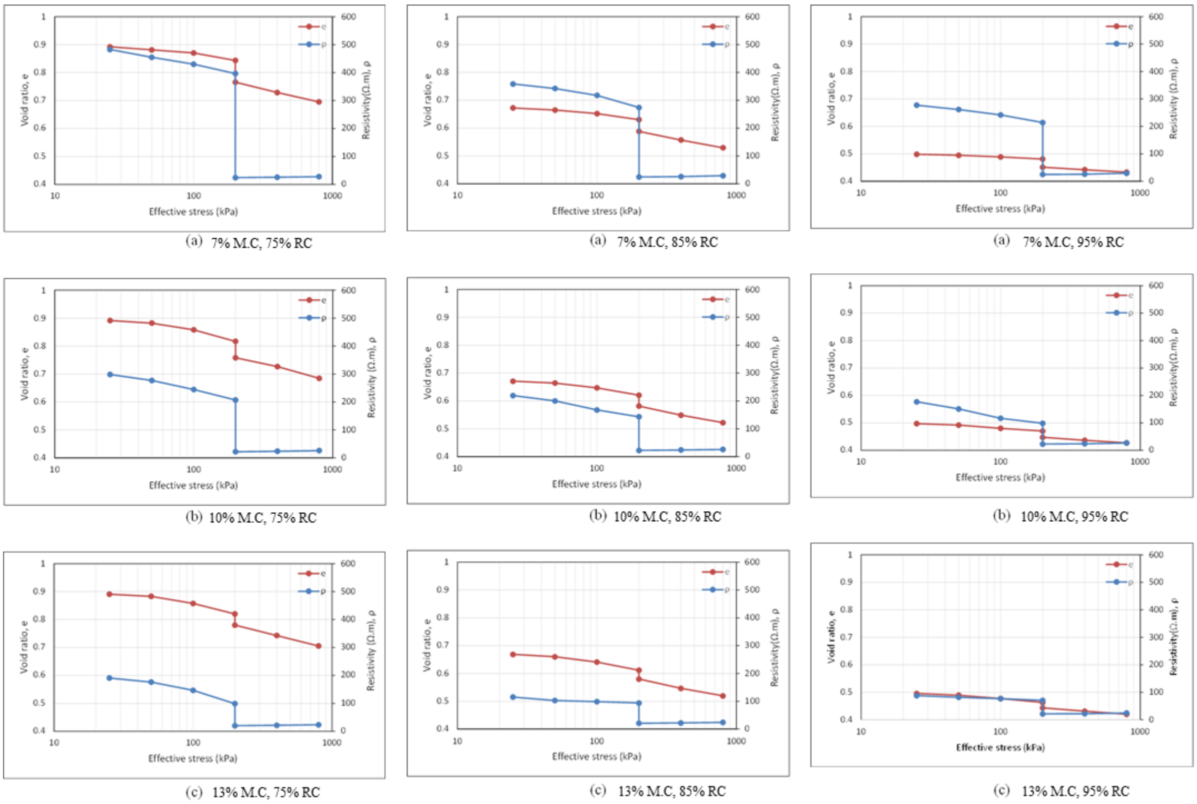


Figure 4. Void ratio-effective stress-resistivity curve of G3 soil

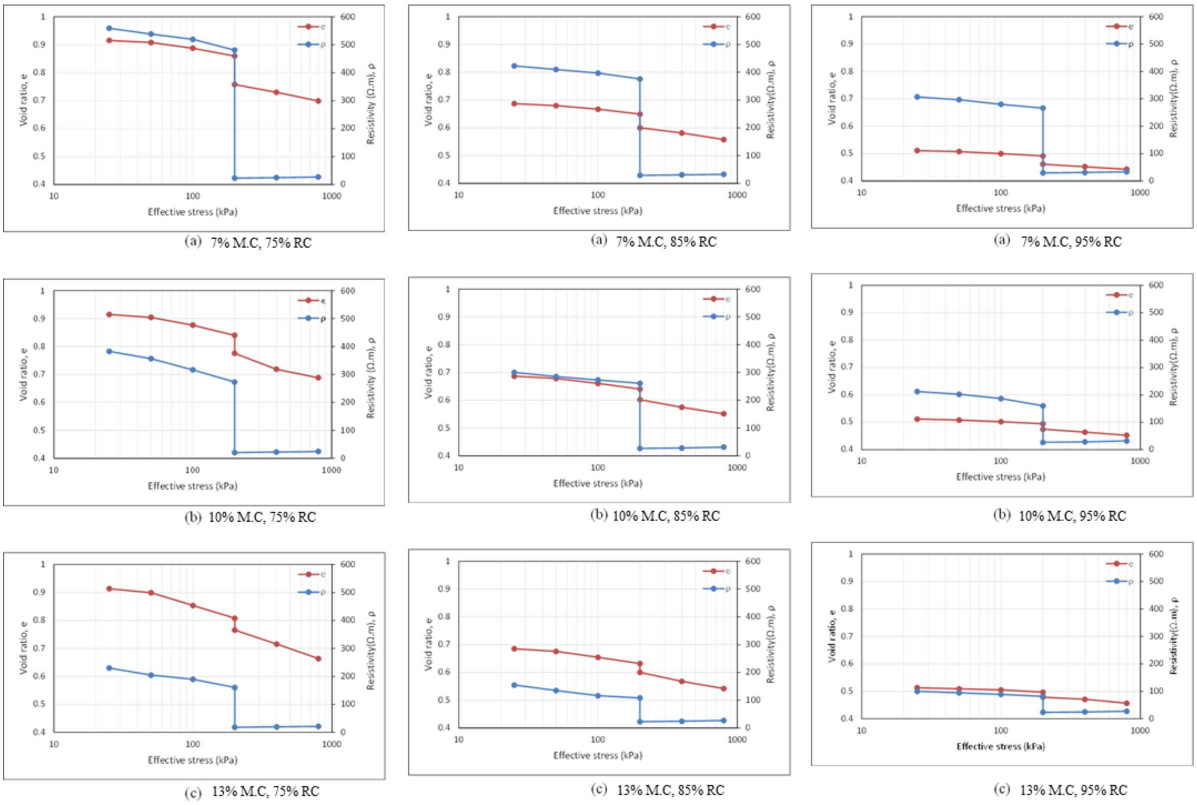


Figure 5. Void ratio-effective stress-resistivity curve of G4 soil

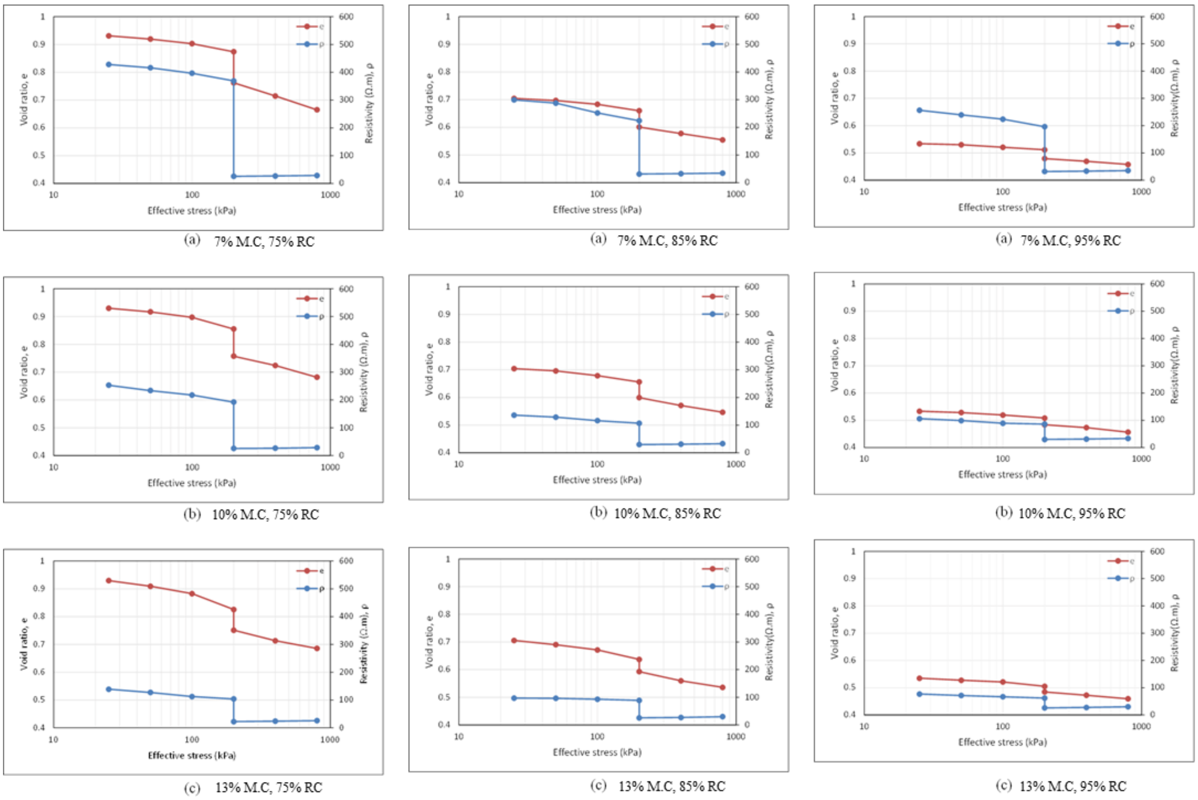


Figure 6. Void ratio-effective stress-resistivity curve of G5 soil

3.4 Collapsibility of gypseous soils

The results of collapse potential measurements in single oedometer tests are summarized in Table 2. The table also presents the classification of collapse severity according to ASTM D5333. The calculated collapse potential (CP) under 200 kPa stress levels.

The initial void ratio is important when determining specific collapse characteristics; the higher the void ratio, the greater the collapse potential. The collapse potential of soils decreases with a reduction in void ratios and an increase in water content. As expected, increasing the degree of compaction greatly decreases the soil's collapse potential and total compression. For a low compaction ratio (75% RC), the collapse potential is ‘moderate’ essentially irrespective of the water content in all gypsum contents. However, the magnitude of collapse increases as the gypsum content in the soil increases. For 85% RC and water content less than 13%, the collapse potential is ‘moderate’ in most gypsum contents except the soil with the lowest gypsum content (the collapse potential is ‘slight’). Comparatively, increasing water content to 13% leads to reduced collapse to ‘slight’ except for the soil with the highest gypsum content (the collapse potential is ‘moderate’). For a high compaction ratio (95% RC), the collapse potential is ‘slight’ for most water content values.

Table 2: The collapsibility of soils

Soil	Compaction ratio	M.C %	C.P %	Classification
G1	0.75	7	3.22	Moderate
G2			3.89	Moderate
G3			4.23	Moderate
G4			5.48	Moderate
G5			5.96	Moderate

G1	0.75	10	2.94	Moderate
G2			3.09	Moderate
G3			3.23	Moderate
G4			3.50	Moderate
G5			5.27	Moderate
G1	0.75	13	1.98	Slight
G2			2.05	Moderate
G3			2.19	Moderate
G4			2.33	Moderate
G5			4.07	Moderate
G1	0.85	7	1.81	Slight
G2			2.21	Moderate
G3			2.58	Moderate
G4			2.98	Moderate
G5			3.56	Moderate
G1	0.85	10	1.58	Slight
G2			2.08	Moderate
G3			2.41	Moderate
G4			2.32	Moderate
G5			3.41	Moderate
G1	0.85	13	1.33	Slight
G2			1.80	Slight
G3			1.97	Slight
G4			1.96	Slight
G5			2.69	Moderate
G1	0.95	7	1.77	Slight
G2			1.98	Slight
G3			2.03	Moderate
G4			2.01	Moderate
G5			2.14	Moderate
G1	0.95	10	1.18	Slight
G2			1.29	Slight
G3			1.54	Slight
G4			1.32	Slight
G5			1.64	Slight
G1	0.95	13	1.06	Slight
G2			1.19	Slight

G3			1.34	Slight
G4			1.21	Slight
G5			1.38	Slight

4. Conclusions

Based on the experimental results, it can be drawn the following conclusions:

1. Collapsibility of soils was correlated with electrical resistivity. Based on the investigation, it was determined that the electrical resistivity vs. pressure curves followed similar trends as e vs. logp curves in the dry conditions, but it had a different trend for soaked conditions.

2. Collapse potential was found to increase with decreasing values of relative compaction and water content. Moreover, the magnitude of collapse increases as the gypsum content in the soil increases.

References

Abid Awn, S.H. (2010), "A Modified Collapse Test for Gypseous Soils." Proc., 1st Engineering Sciences Conference, Diyala University, Iraq, Diyala Journal of Engineering Sciences, Special Issue, pp. 299-309.

Alam, M. J. Bin. (2017). Evaluation of Plant Root on The Performance Of Evapotranspiration (Et) Cover System (Issue October). The university of Texas at Arlington.

Amato, M., Lapenna, V., Rossi, R., & Bitella, G. (2012). Multi-electrode Resistivity Imaging. In S. Mancuso (Ed.), Measuring Roots: An Updated Approach (pp. 189–211). Springer Berlin Heidelberg.

Blatz, J.A.; Graham, J.; Chandler, N.A. Influence of suction on the strength and sti ness of compacted and-bentonite. Can. Geotech. J. 2002, 39, 1005–1015.

Clayton, C.R., Matthews, M.C., & Simons, N.E. (1995). Site Investigation: A Handbook for Engineers. 2nd Edition.

Delage, P.; Le, T.T.; Tang, A.M.; Cui, Y.J.; Li, X.L. Suction e ects in deep Boom Clay block samples. Géotechnique 2007, 57, 239–244.

FAO. 1990. Managements of Gypsiferous Soils. Report, Food and Agricultural Organization of the United Nations, Bulletin No.62. Rome.

Fattah, M. Y., Y. J. al-Shakarchi, and H. N. al-Numani. 2008. "Long-term Deformation of Some Gypseous Soils." Engineering and Technology 26 (12): 1461–1483.

Hossain, M. I. (2017). Non-Destructive Evaluation of Soil Moisture Evapotraspiration Cover System (Issue December).

Karim, H. H., T. Schanz, and A. N. Ibrahim, (2015), "Microstructural Characterization of Iraqi Gypseous Soils", Proceedings of the 2nd International Conference of Buildings, Construction and Environmental Engineering, American University of Beirut(BCEE2), 17-18 Oct.

Kibria, G. and Hossain, S., "Investigation of geotechnical parameters affecting electrical resistivity of compacted clays," Journal of Geotechnical and Geoenvironmental Engineering, vol. 138, no. 12, pp. 1520–1529, 2012.

Kochmanová, N.; Tanaka, H. Influence of the soil fabric on the mechanical behaviour of unsaturated and saturated clay. Soils Found. 2011, 51, 275–286.

Leung, Y. F., Liu, W., Lei, Y., & Hsu, S. C. (2018). Quantifying cost effectiveness of subsurface strata exploration in excavation projects through geostatistics and spatial tessellation. Automation in Construction, 90(February), 243–252.

Liu, W. (2007) Thermal Analysis of Landfills. PhD Dissertation, Wayne State University, Michigan.

Liu, Z., Zhang Y., Fang W., “Experimental research on relationship between electrical resistivity and compactibility of loess,” Journal of Xi’an University of Science and Technology, vol. 33, no. 1, pp. 84–90, 2013.

Long, M., Limacher, R., Donohue, S., L’Heureux, J. S., Solberg, I. L., Ronning, J. S., O’Connor, P., Sauvin, G., Romoen, M., & Lecomte, I. (2012). Relationship between electrical resistivity and basic geotechnical parameters for marine clays. Canadian Geotechnical Journal, 49(10), 1158–1168.

Mansour, Z., Z. Chik and M.R. Taha, (2008), “On Soil Collapse Potential Evaluation” Int. Conf. on Construction and Building Technology. E, (03): 21-32.

Manzur, S. R. (2013). Hydraulic Performance Evaluation of Different Recirculation. May, 1–222.

Muñoz-Castelblanco J. A., Pereira J. M., Delage P. et al., “The influence of changes in water content on the electrical resistivity of a natural unsaturated loess,” Geotechnical Testing Journal, vol. 35, no. 1, pp. 11–17, 2012.

Nashat, I. H., (1990), “Engineering Characteristics of Some Gypseous Soils in Iraq”, Ph.D. thesis, Civil Engineering Department, University of Baghdad, Baghdad, Iraq.

Qin, P.J.; Ye, W.M.; Chen, Y.G.; Chen, B.; Cui, Y.J. Influence of strain-rate on hydromechnical behavior of highly compacted GMZ01 bentonite. Eng. Geol. 2015, 195, 85–92.

Rahardjo, H.; Lim, T.T.; Chang, M.F.; Fredlund, D.G. Shear-strength characteristics of a residual soil. Can. Geotech. J. 1995, 32, 60–77.

Rinaldi, V. A., & Cuestas, G. A. (2002). Ohmic conductivity of a compacted silty clay. Journal of Geotechnical and Geoenvironmental Engineering, 128(10), 824–835.

Seladji, S., Cosenza, P., Tabbagh, A., Ranger, J., Richard, G., 2010. The effect of compaction on soil electrical resistivity: a laboratory investigation. European Journal of Soil Science, 61, 1043-1055.

Tarantino, A.; De Col, E. Compaction behaviour of clay. Géotechnique 2008, 58, 199–213.