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Controlling collapsibility potential by improving Iraqi gypseous soils subsidence: A Review study

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Abstract. Gypseous soils classified as the most difficult soil due to their complex and unexpected behaviour. Gypseous soils around the world, formed mainly in arid and semi-arid lands. In Iraq, gypsum soil covers 20-30% of total area of Iraq specifically, in western, south and southern west areas. For the soil engineer, it is of great importance to know properties of soil before designing and building any structure. Since the gypseous soil can collapse when the water run through, therefore, many Iraqi researchers have worked out to find the best methods to improve this kind of soil. This paper summarizes most of these studies and present chemical and physical treatment applied to gypsum soils in Iraq to improve bearing capacity of gypsum soils and reduce settlement and collapsibility, improve the Bearing capacity in present study improved AL Fallujah Gypseous soaked soil after using geogrid increase the Bearing capacity about (51)% .

1. Introduction

Gypsum soils consider very hard type of soils to deal with by geotechnical engineer. It has very low compressibility and high bearing capacity at dry state, but the problems starts when the water flow through the soil it can collapse and cause structure failure. The failure is due to dissolution of salts, which forms more pores in the soil. The problems created due to exposure of gypsum soils to water can be catastrophic because it is unpredictable. Therefore, many researchers have worked to improve the gypsum soils to avoid many problems that are actually happening in the time being in Iraq. There is no enough data to show the best method to deal with and improve gypsum soil. This paper is focusing on the research that carried out with different techniques using physical or chemical treatment. Summarized information shown in tables for physical and chemical treatments to control the gypsum soils problems in Iraq.

2. Distribution of gypseous soils in Iraq

Gypseous soils distributed naturally in arid and semi-arid zones in continents of Africa, and Asia. Iraq is among Asian countries where gypsum soils cover about 12% of its total area. There is an old map by [1] which show the five areas of soils distribution in Iraq ‘Figure 1’, and [2] mentioned that it covers 31.7% of regions in Iraq.

IOP Conf. Series: Materials Science and Engineering **745** (2020) 012107 doi:10.1088/1757-899X/745/1/012107

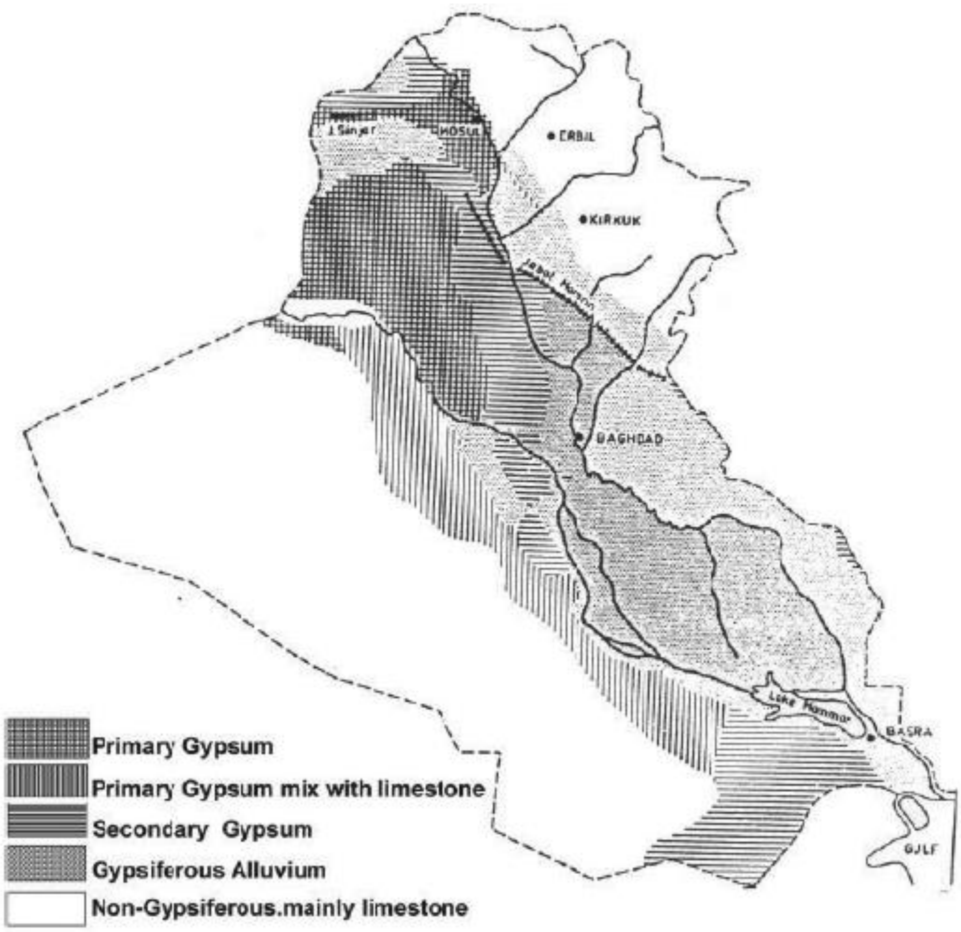

Figure 1. Five areas of soils distribution in Iraq [1]

Gypseous soils in specific areas in Iraq investigated thoroughly by [3] who suggested the proven original map of these soils as shown in 'Figure 2'.

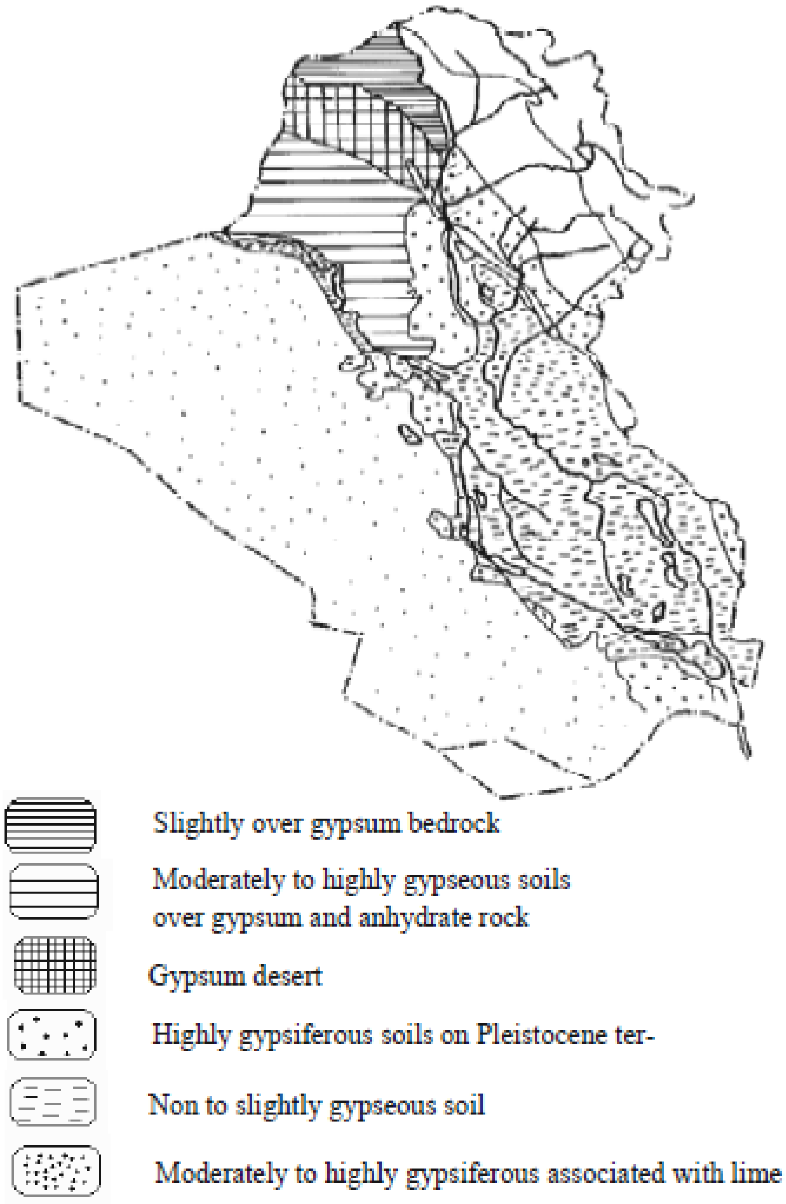

Figure 2. Distribution of gypsum in Iraq [3]

3. Characteristics of gypsum soil

Natural gypseous soil has certain physical properties, which varies significantly according to the gypsum amount, constituents of soil, and texture.

The research work carried out by [4] stated that the unique load related to gypsum grades 2.31-2.33 can reach to 2.95 due to the type of anhydrite. Other research work held by [5-7] reached the same results.

When the gypsum content increase to a certain level will be decreased as the weight of the dry unit increase as stated by [8, and 9]. As the gypsum content increase the dry unit weight decreases as reported by [10], in contrast [11] mentioned that as gypsum content increase, the dry unit weight increase as well. The difference in findings is due to the type of gypsum (Hydrate or anhydrite) and gypsum percentage in soil.

IOP Conf. Series: Materials Science and Engineering **745** (2020) 012107 doi:10.1088/1757-899X/745/1/012107

The most useful parameter for normal behaviour of gypsum soil is solubility. The solubility in the aqueous and luminous water is 2 g/L [12]. Larger values of 2.41 and 2.6 g/L were in Iraqi gypsum soils [5].

Many researchers have investigated the relationship between gypsum content and pressure index. There is a limit of pressure index as the gypsum content increased [13]. It is difficult to judge different effects of specific parameters such as; methodological experience, placement conditions, and disturbance dimensions. A similar contradictory effect was reported due to the re-compression index.

Most researchers emphasized that the secondary suppression index increase as gypsum content increases. This phenomenon is due to the continued gypsum decomposition process, including times, which was reported by [5, and 6].

The researchers confirmed that the main factor that affects the soil properties is gypsum content.

The gypsum soil is highly affected by moisture content, which leads to dangerous effects and can cause structure collapse [14]. Table 1 conclude the severity index for collapse potential percentage.

Table 1. Severity index [14]

Severity	No problem	Moderate	Trouble	Severe	Very severe
C.P.%	0-1	1 to 5	5 to 10	10 to 20	>20

The substantial breakdown predicted under constant force of 200 kN/m^2, and it increases as the gypsum content increase [5, and 6].

4. Gypseous soil remedies

In the process of designing and building structures on gypsum soils, the soil engineer needs to think about whether soil properties improved economically or not. According to these needs, investigators tried few techniques. In many cases, using these technologies on-site can be costly. The following methods are available to improve the engineering properties of gypsum soils.

4.1. Physical treatment

4.1.1. Geogrid

Many researchers worked on this field [15-17], they find that the best results were approached using geogrid. Therefore, the author here will focus more on this method and present other methods for review purpose as presented in ‘Table 2’ and ‘Table 3’.

The gypseous soils from Tikrit (Salah Al-Din) treated with dunes, geogrid, and geotextile under soaking [15]. Homogeneous soils tested and relationship between bearing pressure (KPa) and settlement time (min) as presented in Figure 3. The results showed that by replacing a certain percentage of gypseous soil with geogrid, the endurance capacity increases to (2.5-3.0) times [15].

IOP Conf. Series: Materials Science and Engineering **745** (2020) 012107 doi:10.1088/1757-899X/745/1/012107

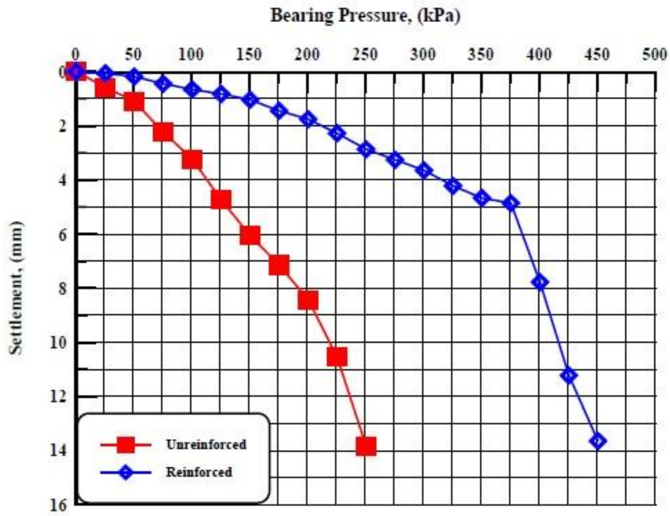

Figure 3. Relationship between settlement and bearing pressure, using geogrid with soaked gypseous soil [15]

The same findings of (in present study) was in agreement with [15] results by using geogrid. Figure 4, shows the optimum bearing loading The results of the experimental model are presented on. Soil improvement techniques such as soil reinforcing systems used to increase the bearing capacity of soil and to reduce the settlement (in present study) [AL-Kifae,AL-Zabady].

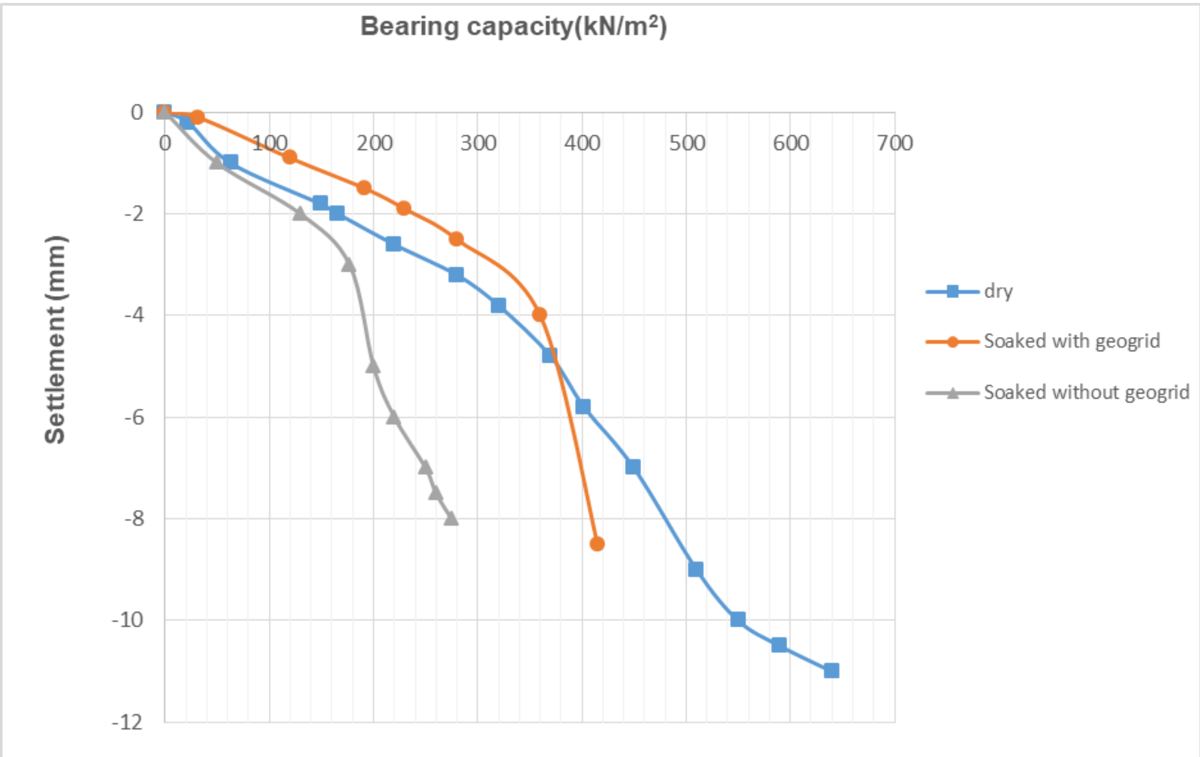

Figure 4. Relationship between settlement and bearing pressure for AL-Fallujah gypseous soil [AL-Kifae,AL-Zabady]

From different research work, results showed that the durability increased as mentioned by [15, 16], bearing capacity increased [17]. In addition, [18, 19] worked on geogrid under soaking. All findings presented in Table 2.

4.1.2. Compaction
Another physical treatment adopted by [20-23], and by high compaction [24].
4.1.3. Leaching
This method approached by [25, 26].
4.1.4. Pre-wetting
[27] carried out this method, which improved compressibility.
4.1.5. Other physical methods
Stone column applied by [28], and adding clinker [29]. Other research carried by [30] to find bored pile model.
'Table 2' summarize studies conducted by Iraqi researchers to improve the gypsum soil over the past two decades to present different types of physical treatment.

Table 2. Physical treatment research work performed in Iraq.

No.	Ref. no.	Gypsum content%	Site/Iraq	Treatment	Findings
1	15	40%	Baiji Salah Aldin	geogrid	Endurance capacity increased 2.5-3.0 times
2	16	32%	Al-Nda'a Al-Najaf	geogrid	High durability
3	17	6%, 26%	Al-Najaf	geogrid	Improvement of collapse reduction factor (CRF)
4	18	27, 76%	Bahr Al-Najaf Al-Najaf	Geogrid under soaking	Increasing CBR for reinforced twice than unreinforced soil, but it decreases when soaking period increases for unreinforced and reinforced soil.
5	19	37.56%	Kirkuk	compaction	The cohesion increases. When moulding water content increase, the angle of internal friction decreases and increases with increasing gypsum contents
6	20	50%	-----------	compaction	Concluded new formula for max dry density & optimum moisture content for less than 50% GC.
7	21	35%	------------	compaction	Traditional stone column was effective.
8	22	60.5, 41.1, &27%	Al-Garma AL-Anbar	Dynamic compaction	Improvement in compressibility as GC increase.

9	23	---------	Baiji Salah Al-Din	Dynamic compaction	Effective angle of internal friction increased, compression index increased.
10	24	28%	Around Baghdad	High compaction	When increasing compaction there is an increase of Resilient Modulus (MR), but when soaking period increases the MR decrease significantly.
11	25	63%	Al-Ramadi Al-Anbar	leaching	As the soil compacted after leaching gypseous soil (dry density) the CBR was increasing.
12	26	44%	North of Baghdad	leaching	The cohesion was reduced significantly, high reduction in leaching strain, permeability, and dissolution of gypsum.
13	27	50%, 70%	Aldor-Al-Anbar & Balad Salah Al-din	Pre-wetting	Improvement in the S/B value, gave 90% compressibility reduction.
14	28	30%	Ain Al-Tamur Karbala	Ordinary & Encased stone columns	Increasing stress ratio & settlement ratio for ordinary column, While slight increase of bearing capacity for encased stone column.
15	29	40%	Al-Axandria region Babylon	Clinker additives	There was >73 % of improvement in collapse potential. As clinker% increases the compressibility decreases, compression index decreased, the cohesion increased, and angle of internal friction decreased.
16	30	42%	Bahr Alnajaf Al-Najaf	Bored Pile model	Soil settlement is more than the pile settlement. Large draw down in bearing capacity.

4.2. Chemical treatment

Table 3, present most of chemical treatment performed by Iraqi researchers to improve gypseous soil. The chemical additives used summarized as follows:

4.2.1. Adding lime

Researchers worked on chemical treatment by adding lime [31-33], while [34] added 5% hydrated lime + 2.5% hydrated Calcium + 6% Kaolin, and [35] used asphalt with lime. The researchers approached different findings according to the gypsum content percentage and type of additives.

4.2.2. Adding Asphalt

Asphalt added to gypseous soil to improve the properties. Asphalt added with lime by [35], different percentage of cut back liquid asphalt by [36-38]. While [39] has adopted emulsified asphalt addition, while [40] used grouting of emulsified asphalt, and liquid asphalt [41, and 42]. New method bas carried out by [43] by adding recycled asphalt and rice husk. [8, and 44] tried to add sulphate resisting cement.

4.2.3. Adding cement

As mentioned at 4.2.2. [8, and 44] added sulphate resisting cement. Other method used cement with ceramic [45]. Cement addition performed by [46], and bentonite added with cement and limestone by [47].

4.2.4. Bentonite and Kaolin

Bentonite added by [47] with limestone and cement as mentioned in section 4.2.3, while [48] used bentonite and kaolinite. [49] Have tried adding bentonite with different percentages and [50] applied kaolin addition.

4.2.5. Calcium chloride

Calcium chloride added with different percentage as hydrated and unhydrated form [51-53] to different gypsum content percentage soils and different finding found. $CaCl_2.2H_2O$ added by [51], the results are shown in Figure 4, that 2.5% addition of hydrated Calcium Chloride was highly improving the properties with time by reducing leaching strain percentage [51].

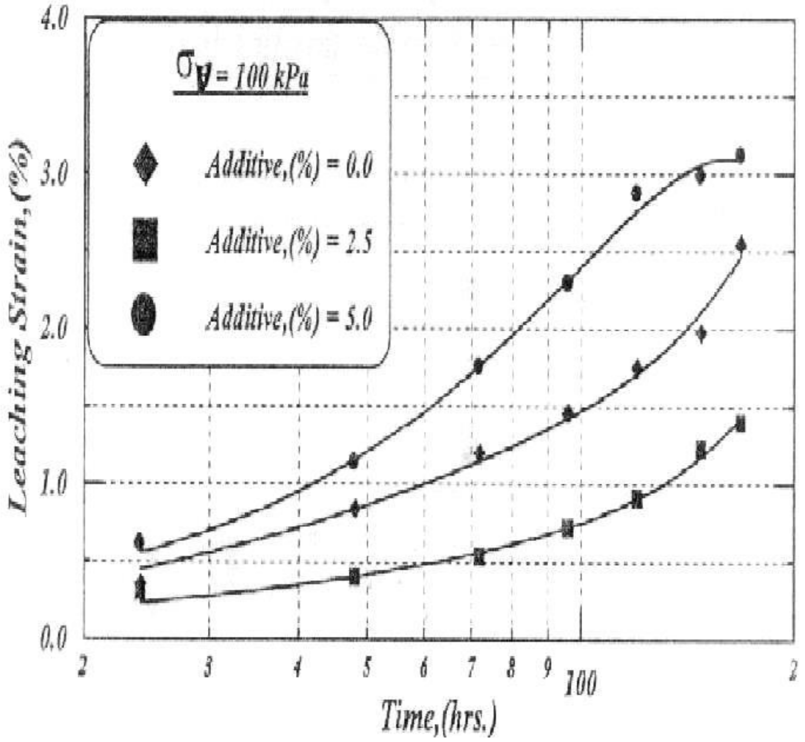

Figure 5. Leaching strain versus log (Time) at 100kPa stress [51]

4.2.6. Sodium silicate

Sodium silicate added by [54] while [55] used different percentage of sodium silicate with lime.

4.2.7. Fuel

Researchers added different types of fuel such as; kerosene with gas oil [5], contaminated gypsum soil with kerosene was tested [56], while [57 and 58] used fuel oil.

4.2.8. Other additives

Some experiments carried out by using bituminous material [59]. Bitumen S-125 and RC-250 added to gypseous soil. Figure 5 shows the coefficient of permeability vs. time of gypseous soil mixed with RC-250.

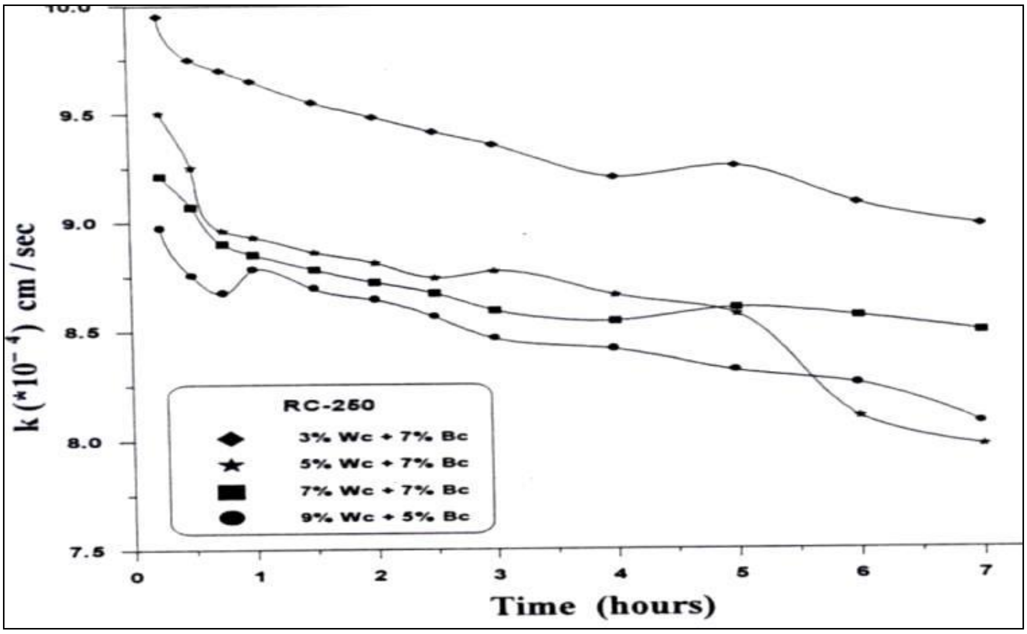

Figure 6. The coefficient of permeability vs time of gypseous soil mixed with RC-250 [60].

Other materials added by different researchers such as; silicon oil [60], nano materials (fly ash and silica fume [61], glass and ceramic [62], [63, and 64] approached good results by grouting with acrylate liquid, and for first time tire waste (rubber) was used by [65]. All findings for chemical treatment tabulated at Table 3.

Table 3. Chemical treatment methods applied in Iraq.

No.	Ref. no.	Gypsum Content %	Site	Treatment	Findings
1	31	20 & 82%	Samarra	Lime	As lime % increases there is significant increase in compression strength.
2	32	7, 23, & 34%	Al-Jazirah Al-Anbar	Lime	The treatment of soil with 5% lime caused a decrease in unrestricted compressive strength.
3	33	0-25%	-----------	Lime	The strength of soil improved due to calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) formation.
4	34	48.30%	Baiji Salah Al-Din	5% hydrated lime + 2.5% hydrated Calcium + 6% Kaolin	By adding 5 % lime, the permeability of gypsum soils was reduced compared to addition of calcium chloride and kaolin only.
5	35	------	Al-Dour Salah Al-Din	Asphalt &Lime	33- 50% reduction in settlement
6	36	35, 70%	Al-Tharthar Al-Anbar	7% cut back liquid asphalt	7% was the best percentage, which showed an increase in both cohesion and internal friction angle.

IOP Conf. Series: Materials Science and Engineering **745** (2020) 012107 doi:10.1088/1757-899X/745/1/012107

7	37	30%	Karbala	3, 6, 9, 12, and 15% cut back asphalt	9% cut back asphalt gave the best improvement ratio of the loader.
8	38	34%	Tikrit Salah Al-Din	2, 4, 6, 8, and 10 % cut back asphalt	Introduced new mathematical model presenting the relationship between CBR and unconfined compression strength.
9	39	72%	Al-Tharthar Al-Anbar	Emulsified asphalt	The effective mixing ratio of the asphalt emulsion was 6%.
10	40	34.66%, 69.50%	Al-Tharthar Al-Anbar	Grouting with emulsified asphalt	The collapse settlement reduced to 50%. Cohesion and internal friction angle was increased with 7% emulsified asphalt.
11	41	40-50%	Tikrit Salah Al-Din	Liquid Asphalt	Unconfined compressive strength increased as the binder content increase to a certain limit. Failure of treated soil is more than that of untreated samples.
12	42	28%	Al-Owja Salah Al-Din	Liquid Asphalt	The addition of liquid asphalt introduced good elastic properties, and reduces the total strain.
13	43	36.40%	Karbala	Recycled asphalt pavement with rice husk ash	The maximum drought density increases with increasing mixing content, while the opposite is exact for optimal water content.
14	8	------	----------	Sulphate resisting cement	As gypsum content increase there was great reduction in soil strength.
15	44	17, 18, & 29%	Basrah, Fallujah, & Karbala	3.5, 7, & 10% high sulphate resisting cement	The improvement of gypsum soil indicated by increasing elastic modulus with the addition of cement due to the increase of soil hardness.
16	45	35%	Al-Tar Al-Najaf	Cement, and ceramic	The maximum dry density increases with the increases in mixing content.
17	46	42.55%	Karbala	2, 3, 5, 8, 10, 13, & 15 % cement	10 % of cement decreases the collapsibility about 86.54%.
18	47	60-70%	Ain Al-Tamor Karbala	Cement, bentonite, and limestone	The susceptibility of the collapse of gypsum soil increased as stress and soaking time increased.
19	48	50%	Al-Qarma	Bentonite & Kaolinite	10% bentonite improved the soil quality compared to kaolinite.

20	49	45%	Al-Ramady Al-Anbar	2.5, 5, 7, and 10% Bentonite	2.5% of bentonite effectively reduced the probability of collapse.
21	50	44.50%	Tikrit Salah Al-Din	Kaolin	The permeability coefficient and the susceptibility of dissolved gypsum reduced by adding 6% Kaolin.
22	51	43.80%	Tikrit Salah Al-Din	2.5, and 5% of $CaCl_2.2H_2O$	The properties of the treated soil were highly improved when 2.5%.calcium chloride added.
23	52	35, 38, & 72%	Heet, Al-Khalidiah, and Al-Ramadi	$CaCl_2.2H_2O$	Compressibility, coefficient of permeability, collapsibility, dissolved gypsum, all decreased.
24	53	53%	Heet Al-Anbar	20% calcium chloride	Compression, breakdown, permeability coefficient, dissolved gypsum ratio decreased
25	54	---------	---------	Sodium silicate	The probability of collapse increased due to the dissolution of gypsum.
26	55	---------	Jurf Al-Sakhar	4, 8, and 12% sodium silicate + 3% lime	Collapse reduced by increasing the sodium silicate percentage.
27	56	37, 58, & 65%	Baiji Salah Al-Din	Contaminated with Kerosene	By increasing kerosene content, the coefficient of cohesion decreases, a slight decrease in the angle of internal friction, and the maximum shear pressure decreases too.
28	5	40, & 50%	Habanya Al-Anbar	Kerosene and gas oil	The additives have reduced soil compression and permeability due to delayed gypsum removal.
29	57	47%	Tikrit Salah Al-Din	Fuel oil	5% of fuel oil was the optimum value that provided good solid material and higher strength in the case of moisture.
30	58	26.55, & 51.60%	Al-Tharthar Al-Anbar	Fuel oil	The fuel oil is an excellent material to modify the gypsum in the soil to improve the permeability and collapsibility.
31	59	---------	-----------	S-125 & RC-250 Bituminous material	Better engineering characteristics obtained by using S-125.
32	60	70%	Artificial soil (30% Silber sand)	Silicon oil	The silicone oil is a suitable material for adjusting the basic properties of gypsum soils from collapsibility and shear quality.
33	61	58%	Salah Al-Din	Fly ash & Silica fume (Nano materials)	Improvement > 83 % decreases the collapsibility sharply.

34	62	60%	----------	5, 7, & 9% of glass & ceramic	-------------
35	63	18, 29, 55, & 72%	Karbala & Al-Najaf	Grouting with acrylate liquid	Compressibility decreased up to 60-70%, and collapsibility 50-60%.
36	64	60 to 70%	Karbala & Al-Najaf	Grouting with acrylate liquid	The treated gypseous samples exhibited a low collapse potential.
37	65	41.24%	2, 4, 6, & 8%	Tires waste	Internal friction significantly increases and dry density minimized.

5. Conclusion

As noticed in this review paper that all previous research work was carried out individually and using different materials with different methods. Therefore, it is very hard to decide which method is the best for gypseous soil to get the optimum improvement because the soil properties and gypsum content is available in Iraq with wide variation.

Despite the variation in the research findings to the active improvement of gypseous soils the main findings can be discussed as follows:

1- Number of techniques used for research purposes during the last two decades by many investigators in Iraq only. These studies include various chemical and physical treatment techniques. Generally, despite of the methods were costly and provided distinctive skill in preparation but the problems created by gypseous soil have to be treated. There are many factors indicate the most effective method of improvement of these soils (the ability to reduce the collapse settlement during soaking and leaching, and the durability of the improving material).

2- Soil stabilization is of great importance to improve its engineering performance with several methods such as mechanical, chemical. The improving materials such as bentonite, lime and cement was used as additives mixed with the gypseous soil to investigate the possibility of improvement of soil behaviour and to study their effect on permeability and collapsibility by using models and shear strength properties for gypseous soil improved with limestone, and study the collapsibility by using models.

3- The improvement of gypseous soil achieved by the use of different types of reinforcement (geogrid) and the other variables (number of layers and length of reinforcing layer). In the present study an increase in bearing capacity from (275 kN/m2) before the use of reinforcement materials to (415 kN / m2), after the use of geogrid AL Fallujah gypsum soaked soil when using reinforcement materials. Soil arming systems have evolved effectively, as many polymer materials have emerged. They are mainly made of synthetic fibres with different properties and uses. These materials have been used in areas such as industrial fabric and industrial mesh The most important of these are the construction of roads on weak lands and rail bridges And underwater installations such as the protection of beaches, docks, slopes and bridges The retaining walls were finally used to strengthen the soil below the foundations

However, further research recommended approaching new cost-effective methods

IOP Conf. Series: Materials Science and Engineering **745** (2020) 012107 doi:10.1088/1757-899X/745/1/012107

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