

# INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



*This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:*

<https://www.issmge.org/publications/online-library>

*This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.*

# Challenging Problems of Gypseous Soils in Iraq

## Des problèmes difficiles des sols gypseux en Irak

Al- Saoudi N.K.S.

*University of Technology-Baghdad-Iraq*

Al- Khafaji A.N., Al- Mosawi M.J.

*University of Baghdad – Baghdad- Iraq*

**ABSTRACT:** Gypseous soils are classified as one of the problematic soils due to their complex and unpredictable behaviour. They exist in many parts of the world, concentrated mainly in arid and semi-arid regions. In Iraq gypseous soils cover about 20 to 30 % of its total area concentrated primarily on the west desert and extended to the southern parts and directed towards south west. Gypsum soils experience sudden collapse upon exposure to water, losses of serviceability of many structures were observed in different parts of Iraq. Extensive research was made in Iraq to investigate and understand the behavior of Gypsum soils and to set safety limits for the collapse and suggest practical precautions during construction. The enormous amount of data collected from different research sources revealed wide spectrum of information covering the overall performance of Gypsum soils under different environmental and climate conditions. The present paper focuses on the main geotechnical properties of gypseous soils and their effect on the collapsible mode of failure, some practical solutions are also proposed that provide safety precautions.

**RÉSUMÉ :** Les sols gypseux sont classés comme des sols problématiques à cause de leurs comportements complexes et imprévisibles. Ils existent dans plusieurs régions du monde, principalement dans des régions aride et semi-aride. En Irak, les sols gypseux couvrent entre 20 et 30 % du pays et sont principalement concentrés dans le dessert de l'ouest et s'étendent vers les régions du sud et orientées vers le sud-ouest. Les sols gypseux s'effondrent soudainement lorsqu'ils sont soumis à l'eau et beaucoup de structures inutilisables ont été observées dans différentes zones en Irak. Des recherches approfondies ont été menées en Irak pour étudier et comprendre le comportement des sols gypseux afin de déterminer les limites avant l'effondrement et de suggérer des précautions concrètes lors de la construction. L'énorme quantité de données recueillies auprès de différentes sources a révélé un large spectre d'informations couvrant l'ensemble des performances des sols gypseux sous différentes conditions environnementales et climatiques. Le présent document se concentre sur les principales propriétés géotechniques des sols gypseux et sur leurs effets sur les écroulements de structure, enfin quelques solutions pratiques sont aussi développées pour proposer des mesures de sécurité.

**KEYWORDS:** Gypsum, collapsibility, Gypseous Soils, Problematic Soils

### 1. INTRODUCTION

Gypseous soils are one of the most complex materials that challenge the geotechnical engineers. Structures or dams founded on gypseous soil may experience unpredictable deformations that ultimately may cause catastrophic failure. In Iraq it has been reported that several structures have experienced different patterns of cracks and uneven deformations generated primarily from the exposure of the supporting gypseous soils to water. It is a well known fact that gypseous soils demonstrate high bearing capacity and very low compressibility when they are in the dry state. On the contrary a sudden collapsible behaviour was reported when the gypseous soils are exposed to water. The collapsibility of gypseous soils results from the direct contact of water. The dissolution of different types of salts contained inside the mass of gypseous soil will generate new pores inside the soil skeleton and loosen the cementing bonds between the particles. This process creates a meta stable structure that facilitates the sliding of particles into a more dense state. The rate of dissolution of gypsum depends primarily on environmental changes in moisture content generating from fluctuation of ground water table and /or surface water, climate changes typically temperature, permeability and state of flow conditions in addition to the type and content of gypsum.

During the last three decades many attempts were made in Iraq through intensive research programs set in many institution to investigate and understand the behaviour of gypseous soils under various environmental and loading conditions. The first ob-

jective of these research programs was to determine the physical properties of the gypseous soils and to check whether standard tests can be used and if not what modifications are required. Following that several attempts were made to determine the geotechnical properties such as compressibility, collapsibility and shear strength parameters under various flow and environmental conditions and loading conditions. The tests were performed using triaxial and Rowe cells allowing soaking and leaching of the soil samples. Plate load tests were also performed under different soaking periods to monitor the generated deformation with time. Numerical techniques were also used to simulate the dissolution process of gypsum under soaking and leaching conditions.

The abundant amount of data obtained from the lengthy research programs revealed in many cases contradicting results due to the complexity of the gypseous soils. So no rigid conclusions are yet been drawn.

The paper sheds the light on the distribution of gypsum in Iraq. A summary of main physical and geotechnical properties with emphases on the collapsibility is presented and a some remedied are proposed.

## 2. DISTRIBUTION OF GYPSEOUS SOILS IN IRAQ

Gypseous soils exist mainly in arid and semi arid regions, concentrates in continents like Africa, central and southern Asia. Iraq is among the countries of South Asia where gypsum covers about 12 % of its total area. (FAO 1990), although more recent study (Ismail 1994) reported that gypseous soils cover 31.7 % of the total area of Iraq. The first map demonstrating the distribution of gypsum in Iraq was presented by (Buringh 1960) indicating five zones as shown in figure 1. The primary gypsum is located in the extreme north area between the Tigris and Euphrates rivers. The second zone where primary gypsum mixed with limestone located below and parallel to the Euphrates river extending from the west desert to the south. The secondary gypsum is identified in two areas, one in the north below the first zone and one in the south – west. The fourth zone is gypsiferous alluvium extends from the north in a narrow band and gradually widens towards the south. The fifth zone representing the non gypsiferous soil, mainly limestone is identified in two areas one in the north east and the other in the west desert.

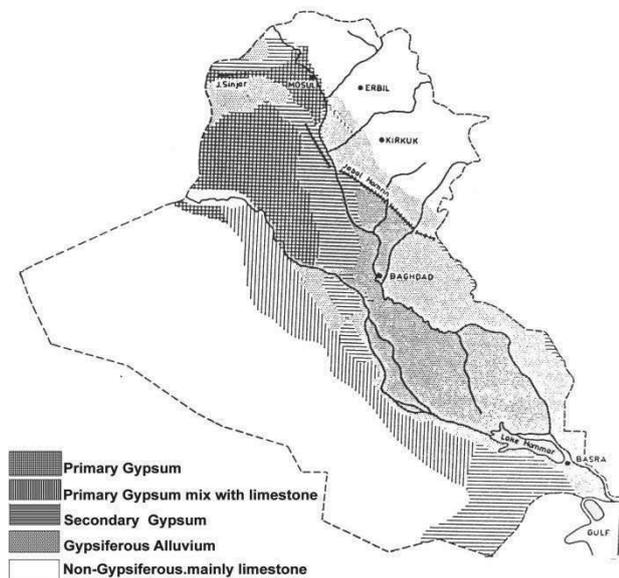


Figure 1 first map of distribution of gypsum in Iraq

A more refined map exhibiting the distribution of gypsum in Iraq was presented by (Al-Barazanji 1973). He investigated thoroughly the type and gypsum content in different parts of Iraq and proposed the map shown in figure 2. Six zones are distinguished according to their origin and gypsum content. Zone one of slightly gypseous over gypsum bedrock denoted by narrow parallel lines taking the shape of a triangle in the upper north of Iraq. The second zone is of moderately to highly gypseous soils over gypsum and anhydrite rock denoted by wider parallel lines, located in the north part between the Tigris and Euphrates rivers. Zone three is gypsum desert denoted by a mesh of small squares, located between zones one and two in the north. Zone four contains highly gypsiferous soils on Pleistocene terraces covering two narrow strips on the left and right of Tigris River denoted by moderately dense dots. The fifth zone is non to slightly gypseous soils denoted by parallel hashes, extends from the upper mid third of Iraq up to the Kuwaiti borders in the south. The sixth zone is moderately to highly gypsiferous soil associated with lime denoted by heavily condensed dots, covering the west Jazira. The two maps comply with each other in most of their subdivisions with slight divergence in others, although different terminologies have been used. Based on figure two, if the soil in zone four is considered as non gypseous soil that does not possess any hazardous impact then most likely 50 to 60 % of the total area of Iraq is covered with active gypsum.

This indicates how serious the challenges are for geotechnical engineers when dealing with such unpredictable material.

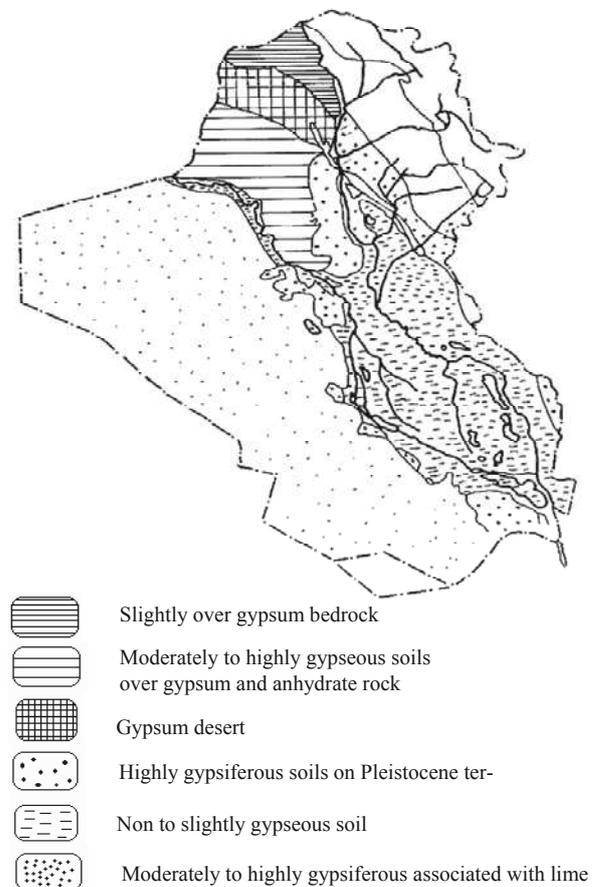


Figure 2 Distribution of gypsum in Iraq (Al Barazanji 1973)

## 3. PROPERTIES OF GYPSEOUS SOILS

The Physical, chemical and geotechnical properties of gypseous soils collected from different parts of Iraq are summarized and discussed below.

### 3.1. Physical properties

The physical properties of natural gypseous soils varies considerably with the amount and type of gypsum soil in addition to the texture and constituents of the soil

#### 3.1.1. Specific gravity

(Schultz and Cleaves 1955) reported that the specific gravity of gypsum ranges between 2.31 to 2.33, increased to 2.95 for anhydrite type. Thus any increase in gypsum content of specific gravity less than 2.33 will lead to a decrease in specific gravity of the soil. (Saleem 1988, Nashat 1990 and Al-Mufti 1997) reached to the same finding unless the gypsum of the unhydrated type.

#### 3.1.2. Maximum dry unit weight

The results of maximum dry unit weight showed contradicting relationship with gypsum content. (Khattab 1988 and Al-Dulaimy 1989) found that the dry unit weight increases with increasing gypsum content up to a certain limit followed by a gradual drop. On the other hand (Subhi 1987 and others) reported a decrease in

dry unit weight with increasing gypsum content. Furthermore, (Al Heeti 1990) showed an increase in dry unit weight with increasing gypsum content. This discrepancy may be due to the type of gypsum (hydrate or anhydrate), type of soil and range of gypsum content considered in the investigation.

### 3.1.3. Soil constituents and texture

The samples of gypseous soils collected from different parts of Iraq showed that gypsum exists primarily in Sandy soil and silty sand and less in silty clay or clayey silt. The presence of appreciable amount of gypsum creates problems in determining the constituents of the soil. During sedimentation test dissolution of gypsum will occur causing the flocculation of silt and clay particles. Pretreatment with water was suggested by (Al-Khashab 1981 and Mohammed 1993). EDTA was suggested by (AL-Khuzai 1985 and others). Most of the treated agents used cause destruction of bonds and most likely revealed an unreliable amount of constituents.

## 3.2. Chemical properties

### 3.2.1 Chemical composition of gypsum

Pure chemical proportions of gypsum as reported by (Nashat 1990) are

20.9 % combined with water

46.6 % sulphur trioxide  $SO_3$

32.5 % calcium oxide  $CaO$

(Majeed 2000) observed that the alkalinity increases with increasing gypsum content. On the other hand the electrical conductivity, cation exchange capacity and exchangeable sodium percentage decrease with increasing gypsum content.

### 3.2.2. Solubility of gypsum

The most effective parameter in the general behaviour of gypseous soils is the solubility. Gypsum is classified as a moderate soluble salt. The solubility of the hydrated type in pure water is 2g/l (Hesse 1971). Some higher values, 2.41g/l and 2.6g/l, were reported for Iraqi gypseous soils (Sirwan et al 1989, Selem et al 1988)

### 3.2.3 Rate of dissolution of gypsum

The rate of dissolution of gypsum is responsible for the development of cavities and sinkholes. It is very complex to be evaluated as it is affected by many environmental conditions such as temperature, source of water, time, concentration of sodium chloride and calcium sulphate etc.

## 3.3. Geotechnical properties

The geotechnical properties of gypseous soils cover, compressibility, collapsibility, permeability and shear strength parameters ( $c$  and  $\phi$ )

### 3.3.1. Compressibility

More than ten researchers have investigated the influence of gypsum on the compressibility characteristics. (Al-Khashab 1981 and many others) reported a decrease in the compression index with increasing gypsum content. It is hard to judge about the contradicting results as many parameters such as the placement conditions, degree of disturbance, and testing methodology. Similar contradicting results were reported for the recompression index. Most of the researchers demonstrated an increase in the secondary compression index with increasing gypsum content. This phenomenon is attributed to the continuous dissolution process of gypsum with time as reported by (Saleem 1988 and Nashat 1990).

The same researchers and many others showed that the coefficient of consolidation remains unchanged with increasing gypsum content.

### 3.3.2. Collapsibility

Gypseous soils are distinguished by their collapsible behaviour upon wetting. The term collapse potential is used to classify the hazardous state of collapsibility. (Jennings and Knight 1957) proposed a double oedometer collapse test to predict the collapsibility of the foundation soil. Two identical samples are tested, one at natural water content and the other after submerging in water for one day. The collapse potential C.P. is defined as

$$C.P. = \Delta e / 1 + e_0 \quad (1)$$

Where

$\Delta e$  is the difference in void ratio of the two samples at a specific stress

$e_0$  is the natural void ratio

The severity according to the collapse potential is shown in table 1.

Table 1. Collapse identification (Jennings and Knight 1975)

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

(Saleem 1988, Nashat 1990 and many others), found that the collapse potential under a constant stress of 200kN/m<sup>2</sup> increases with increasing gypsum content. The gypsum content of the tested samples ranged between 20 - 80% revealed a moderate type of 4 % maximum collapse potential.

### 3.3.3. Modulus of deformation

Al Khafaji et al 2009 investigated the deformability of gypseous soils through plate load tests performed on natural and soaked soils. The tests were performed on two sites GP-GM soil and SM soil and soaking period extended to 7 - 11 days under 300 mm head of water. All types of stiffness moduli were calculated, the initial tangent modulus, the permissible secant modulus at half the yield, the yield secant modulus at the yield and the yield tangent modulus after the yield. The outcomes revealed that soaking decreased the stiffness moduli in the range of 2 to 5 folds for GP-GM soil and from 2 to 3.5 for SM soil. The field tests highlight on the hazardous degree of constructing structures on gypseous soils without awareness of the expected generated settlements that may result from the contamination of water.

### 3.3.4. Hydraulic conductivity

Hydraulic conductivity or coefficient of permeability of gypseous soils is very hard to predict. Standard constant head test on sandy gypseous soils does not reveal reliable results as the gypsum dissolves during flow creating more free space for the soil particles to reorient themselves to a closer state of packing, causing a sudden fluctuation of rate of flow during test. This phenomenon is very difficult to evaluate as the dissolution process is influenced by many factors like type and amount of gypsum, hydraulic gradient, initial placement of soil sample. Attempts were made to perform leaching permeability tests under different stress levels using Rowe cell (Al-Kaisi 1997 and many others). (Al-Qaissi 2001 and many others) using triaxial permeability leaching apparatus cited that the variation in hydraulic gradient combined with diffusion of gypsum encountered serious difficulties in predicted reliable values of the coefficient of permeability.

#### 4. PROPOSED REMEDIES FOR GYPSEOUS SOILS

The inevitable geotechnical problems associated with the abundance of gypseous soils in Iraq create real challenging issues. Based on that proposals were made for treatment of soils focusing on controlling the settlement and reducing the coefficient of permeability or preventing any contact of water between the foundation soil and any source of water. All the proposed treatments are based on elem tests and not verified by field applications

##### 4.1. Chemical treatment

The treatment materials proposed are basically cement, lime and petroleum products

##### 4.1.1. Treatment with cement

(Khatab1986) reported that sulphate resisting cement improved the unconfined compression strength of granular gypsified soil, but a substantial amount of reduction in strength and stiffness upon immersion in water.

##### 4.1.2. Treatment with lime

Al-Obaidy 1992 and Al-Zory 1993 showed that mixing 5 -7 % lime with gypsous soil of 43 % gypsum content exhibited an increase in strength and high resistance to leaching. It is reported that the soil became practically impermeable after 28 days curing.

##### 4.1.3. Treatment with petroleum products

Various types of petroleum products such as kerosene, automobile oil ,fuel oil and bitumenous materials such as S-125 and R-250 were proposed as improvement agents for gypseous soils. (Saleam 1988) found that treating soil of gypsum content between 40-50 % with kerosene caused a decrease in compressibility and permeability by delaying the removal of gypsum.(Al-Aqaby 2001) observed a reduction in cohesion of soil of gypsum content between 30 -67 % upon immersion in water or kerosene. The angle of internal friction was reduced by 6 degrees upon soaking in kerosene.

(Al-Kaisi 1997) found that 4 % automobile oil caused a reduction in the coefficient of permeability by not less than ten folds.

(Al-Hassany 2001)performed consolidation tests on two samples of gypsum content 26 % and 51% treated with fuel oil. The fuel oil tends to fill the pores of soil and prevent water percolation and hence reduce the permeability. The presence of fuel oil also reduced the compressibility and collapsibility.

Bitumenous materials S-125 and R-250,emulsified asphalt, Cut-Back MC-30 were used by (Al-Morshedy 2001 and many others). Gypseous soils treated with one of the above materials showed reduction in coefficient of permability as well as compressibility and collapsibility.

##### 4.2. Physical treatment

(Al-Khafaji 1997) developed simple and quick equations for estimating the optimum water content and maximum dry unit weight to control field compaction of soils with gupsum content ranging between 0.5 -50 %.

#### 5. CONCLUSIONS

Inspite of the abundant data collected concerning the geotechnical properties of gypsefeous soils and the attempts to investigate and understand the behaviour of gypseous soils under different stresses and environmental conditions.The challenges still exist due to the scarceyt and complexity of such natural material. No real firm solution or a general improvement technique can be proposed. It is advised that geotechnical engineers must investigate each case seperatly depending on the type of structure, characteristics of site, environmental conditions coupled with the engineering judgement of the consultant.

#### 6. REFERENCES

- FAO. 1990 . Management of gypsiferous soils. Food and Agricultural Organization of United Nations Rome. Internet <http://fao.org/docrep/to323e/ro323e03.htm>
- Ismail H.N. 1994. The use of gypseous soils. Symposium on Gypsiferous soils and their effect on structures. NCCL *Baghdad. Iraq*
- Buringh P. 1960. Soils and soil conditions in Iraq. Ministry of Agriculture . *Baghdad. Iraq*
- Al-Barazanji A.F. 1973. Gypsiferous soils in Iraq. PhD. Dissertation. *Ghent University. Belgium.*
- Shultz J.R. and Cleaves A.B. Geology in engineering. John Wiley and sons . *New York*
- Saleam S.N.1988. Geotechnical characteristics of gypseois sandy soil including the effect of contamination with some oil products. MSc. Thesis . University of Technology. *Baghdad.Iraq.*
- Nashat I.H. 1990. Engineering characteristics of some gypseous soils in Iraq. PhD. Thesis . University of Baghdad. *Iraq*
- Al- Mufty A.A. 1997. Effect of gypsum dissolution on the mechanical behaviour of gypseous soils. PhD. Thesis . University of Baghdad. *Iraq*
- Khatab S.A. 1986. Effect of gypsum on strength of cement treated granular soil and untreated soil. MSc. Thesis . university of Mosul. *Iraq*
- Al-Dilaimy F.H. 1989. Effect of gypsum content on strength and deformation of remolded clayey soil. MSc.Thesis University of Salahddin. *Iraq*
- Subhi H.M. 1978 The properties of salt contaminated soils and their influence on the performance of rocks in Iraq. PhD. Thesis Queen Mart College. University of London
- Al-Heeti 1990. The engineering properties of compacted gypsified soil. MSc. Thesis. University of Baghdad. *Iraq*
- Al- Khashab M.N. 1981 Investigation of foundation soil behaviour of Qadisiah site –Mosul. MSc. Thesis. University of Mosul.
- Mohammed R.K. 1993 Effect of wetting and drying of engineering characteristics of gypseous soils. MSc. Thesis University of technology. *Baghdad. Iraq.*
- Al-Khuzai H.M.A.1985 The effect of leaching on the engineering properties of Al-Jezirah soil.. MSc. Thesis . university of Mosul. *Iraq*
- Majeed A.H. 2000. Data base for gypseous soils. PhD. Thesis University of Baghdad. *Iraq.*
- HesseP.R. 1971. A textbook of soil chemical analysis. *Chemical publishing co.,Inc.New York pp520*
- Jennings J.E. and Knight K.1957. The additional settlement of foundationsandy subsoil on wetting. Proceeding 4th Int. Conf. Soil mechanics and foundation engineering . vol.1. pp316-319
- Al- Khafaji A.N, Al-Mosawi M.J., Khorshid N.S. and Al-Obaid B.M. 2007 Proceeding of the 17th ICSMGE Alexandria .Eygept pp 727-729.
- Al- Khafaji A.N. Densification of gypseous soil by compaction. Symposium on ground improvement geosystems. London
- Al-Morshedy A.D. 2001 The use of cutback MC-30 for controlling the collapsibility of gypseous soils.MSc.thesis. University of Technology. *Baghdad.Iraq.*