Challenging Problems of Gypseous Soils in Iraq

Des problèmes difficiles des sols gypseux en Irak

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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 challange the geotechnical engineers. Structures or dams founded on gypseous soil may experience unpredictible deformations that ultimatley may cause catostrophic failure. In iraq it has been reported that several structures have experienced different patterns of cracks and uneven deformations generated primearly from the exposion 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 collapsibile 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 decads many attempts were made in Iraq through intensive research programs set in many institution to investigate and underestand the behaviour of gypseous soils under various enviromental and loading conditions. The first objective of these research programs was to determine the physical proerties of the gypseous soils and to check whether staandard 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 moniter the generated deformation with time. Numerical techniques were also used to simulate the disolution 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 regid 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 emphises on the collapsibility is presented and a some remidied are proposed.

2. DISTRIBUTION OF GYPSEOUS SOILS IN IRAQ

Gypseous soils exist mainly in arid and semi arid regions, concentrates in contenents like africa,central and souther asia. Iraq is among the contries 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 tigres and euphraties rivers. The second zone where primary gypsum mixed with limstone located below and parrallel to the euphraties 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 extens from the north in a narrow band and gradually widened towards the south. The fifth zone representing the non gypsiferous soil, mainly limestone is identified in two ares one in the north east and the other in the west desert.

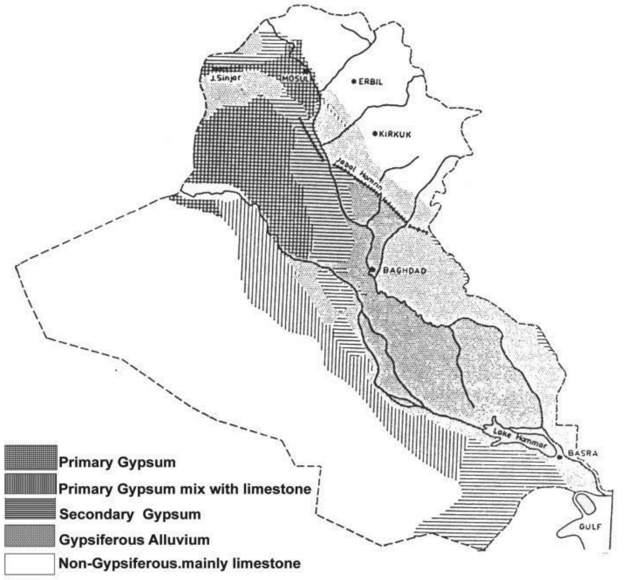

Figure 1 first map of distribution of gypsum in iraq

A more refined map exhibiting the distribution of gypsum in iraq was presented by (Al-Barrazanji 1973). He investigated thoroughyl the type and gypsum content in different parts of iraqand proposed the map shown in figure 2.Six zones are distiguished 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 anhydrate rock denoted by wider parallel lines, located in the north part between the Tigress 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 Tigress 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 but heavily condensed dots, covering the west jazeria. The two maps comply 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 totalarea of Iraq is covered with active gupsum. This indicates how serious the challanges are for geotechnical engineers when dealing with such unpredictible material.

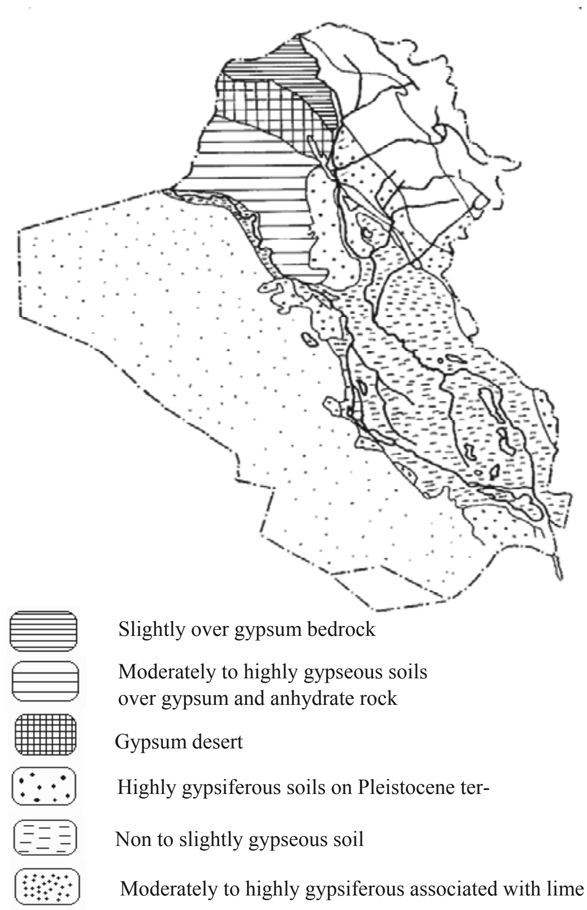

Figure 2 Distribution of gypsum in Iraq (Al Barazanji 1973)

3. PROPERTIES OF GYPSEOUS SOILS

The Physical, chemical and geotecnical 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 thr soil. (Saleam 1988,Nashat 1990 and Al- Mufty 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 AlDulaimy 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. Further more,(Al Heeti 1990) showed an increase in dry unit weight with increasing gypsum content. This descrepency may be due to the type of gypsum (hydriate or anhydriate), type of soil and range of gypsum content considered in the investigation.

3.1.3. *Soil constiuents and texture*

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

3.2. *Chemical properties*

3.2.1 *Chemical compsition 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 oxid CaO

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

3.2.2. *Solubility of gypsum*

The most effective parameter in the general behaviour of gypsous soils is the solubility. Gypsum is classified as a moderate soluable 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 etal 1989, Seleam etal 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 chlorid and calicum sulphate etc.

3.3. *Geotechnical properties*

The geotechnical prperties of gypseous soils cover, compressibility, collapsibility, permeability and shear strength parameters (c and Ø)

3.3.1. *Compressibility*

More than ten researchers have investigated the influence of gypsum on the copressibility characterstics.(Al-Khashab 1981 and many others) reported a decrease in the copression index with increasing gypsum content. It is hard to judje 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 contieous dissoltion process of gypsum with timeas reprted by (Saleam 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 hazarduse 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 submergeing in water for one day.The collapse potential C.P. is defined as

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

Where
Δe is the difference in void raio of the two samples at a specific stress
e_o 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^2 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. *Moduluse of deformation*

Al Khafaji etal 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 socking period extended to 7 -11 days under 300 mm head of water. All types of stiffness moduli were calculated, the initial tangent moduluse, the permissible secant modulus at half the yeild, the yeild secant modulus at the yeild and the yeild tangent modulus after the yeild. The outcomes revealed that soaking decresed 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 highlights on the hazardius degree of constructing structures on gypsious soils without awarness 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 disolves during flow creating more free space for the soil particles to reorient themselves to a closer state of packing, causing a suddent fluctuation of rate of flow during test This phenomenon is very difficult to evaluate as the dissolution process is influenced by many factores like type and amout of gypsum, hydralic 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 gypson encountered serious difficulties in predicted reliable values of the coefficient of permeability.

4. PROPOSED REMEDIES FOR GYPSEOUS SOILS

The invenitable geotechnical problems associated with the abandance of gypseous soils in Iraq create real challanging issues. Based on that proposals were made for treatment of soils focussing 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 elemt tests and not verified by field applications

4.1. *Chemical treatment*

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

4.1.1. *Treatment with cement*

(Khattab1986) reported that sulphate resisting cement improved the unconfined compression strength of granular gypsified soil, but a substaintial 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 impermeabile 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)perfromed consolidation tests on two samples of gypsum content 26 % and 51% treated with fuel oil. The fuel oil tends to to fill the pores of soil and prevent water perculation and hence reduce the permeability. The presence of fuel oil also reduced the copmressibility 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 abandant data collected concerning the
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 challanges 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.

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