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Effect of Leaching and Gypsum Content on Properties of Gypseous Soil

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Abstract- Gypseous soil is one of problematic soils to be used as foundation of road, building and other structures. It is considerably strong and has good properties when it is dry. The problem appears when constructing heavy buildings or hydraulic structures on these soils after wetted by water from rainfall or from the raising of water table level from any source and leaching the salts from the soil.

The primary objective of this paper is to presents the current state of the gypseous soil subject to leaching. A review is provided aiming to discuss the effect of gypsum content and leaching on gypseous soil.

Index Terms- Gypseous soil, Gypsum content, Leaching

I. Introduction

The gypseous soil is a soil which has enough gypsum content to change or affect its engineering properties. Gypseous soils are usually stiff in their dry state due to the cementing action provided by gypsum, but great loss of strength and pronounced increase in compressibility occur when gypsum is dissolved by partial or full saturation. This problem becomes more severe when the water flows through such soils causing loss of mass due to the leaching of gypsum.

Leaching is the process of removal of salts and soluble materials from soil by flowing water. Soils which contain soluble materials exhibit continuous variations in their engineering properties upon leaching. These changes create serious problems to the structure constructed on or within these soils.

1.1. Definitions

1.1.1. Gypseous soil

Gypseous soils are soils that contain gypsum. Gypsum is a mineral salt represented by Hydrated Calcium Sulphate ($CaSO_4.2H_2O$) formed from 20.9% combined with water H_2O, 46.6%, Sulphur Trioxide (SO_3) and 32.5% Calcium Oxide (CaO). It has low specific gravity 2.32, which generated large influence on the physical and mechanical properties of soil containing large amount of these materials, ***Nashat (1990)***.

1.1.2. Leaching

Leaching is the process by which liquids percolate whether naturally or artificially through a porous material resulting in the dissolving and washing of soluble constituents out of the percolated material, ***Al-Zgry (1993).*** In practice of soil mechanics, Leaching can be defined as a process, which removes materials in solution (e.g. salts) and cementation agent from a section in the soil profile ***Brenner et.al. (1981)***.

1.2. Distribution of Gypseous Soils

(Alphen and Romero, 1971), estimates these soils would cover roughly 850.000 km^2. According to the United Nations, Food and Agriculture Organization, ***(FAO, 1990)*** increase the extent of gypseous soils to (1.0-1.5) million km^2, with major areas in the Middle East and the southern parts of the former USSR. Gypseous soils can be found mainly in Russia, Iran, Saudi Arabia, Oman, China, Algeria and Egypt. In these countries the gypseous soils cover about 10% to 36% of the total area of each country.

More recent figures (***Al-Banna, 2004)*** reported that gypseous soils cover about 724000 km^2 of the world; this estimation depends on the UNISCO maps, Figure (1)

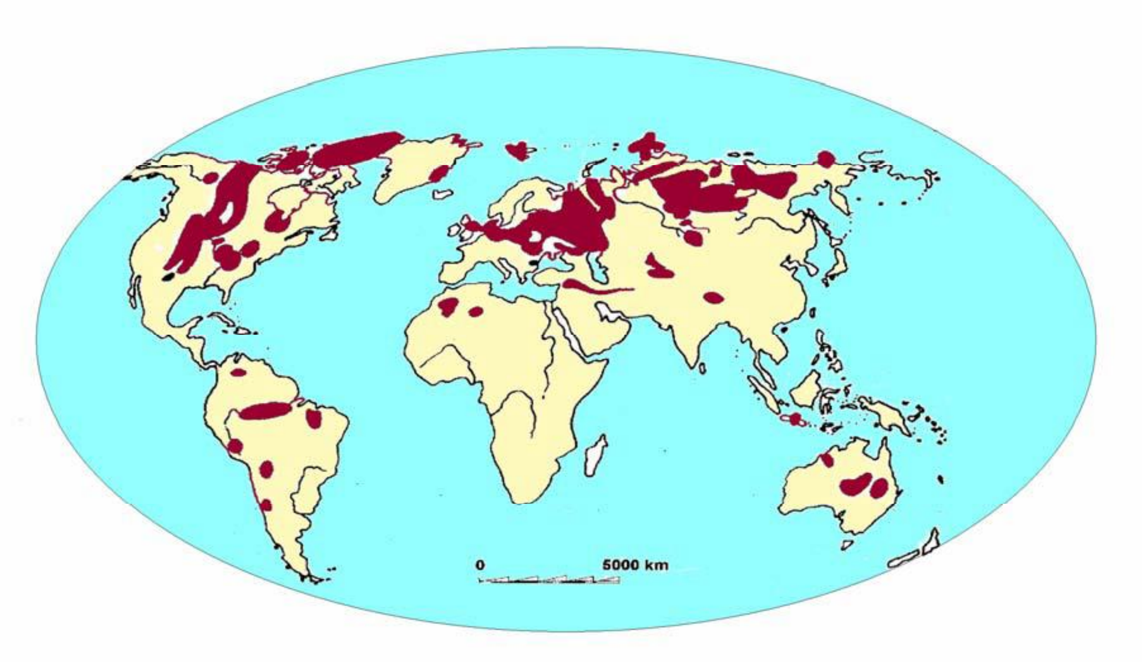

Figure (1): Distribution of gypseous soils in the world (after FAO, 1990)

In Iraq, ***Ismael (1994)*** estimated that about 31.7% of the area of Iraq is covered with gypseous soil with gypsum percentage ranging between (10-70%)**.** In the upper parts of the AL-Jazirah area where the gypsum content varies from (3-10) %, the annual rainfall exceeds 350mm in this area. While the lower parts of it, where the annual rainfall is less than 250mm contain higher percent of gypsum and may exceed 50%. Thus, these soils are concentrated in Anna, Baiji, Faluja, Heet, Karkuk, Mosul, Najif, Nassiriya, Ramadi, Samarah, and Tikrit as shown in Figure (2).

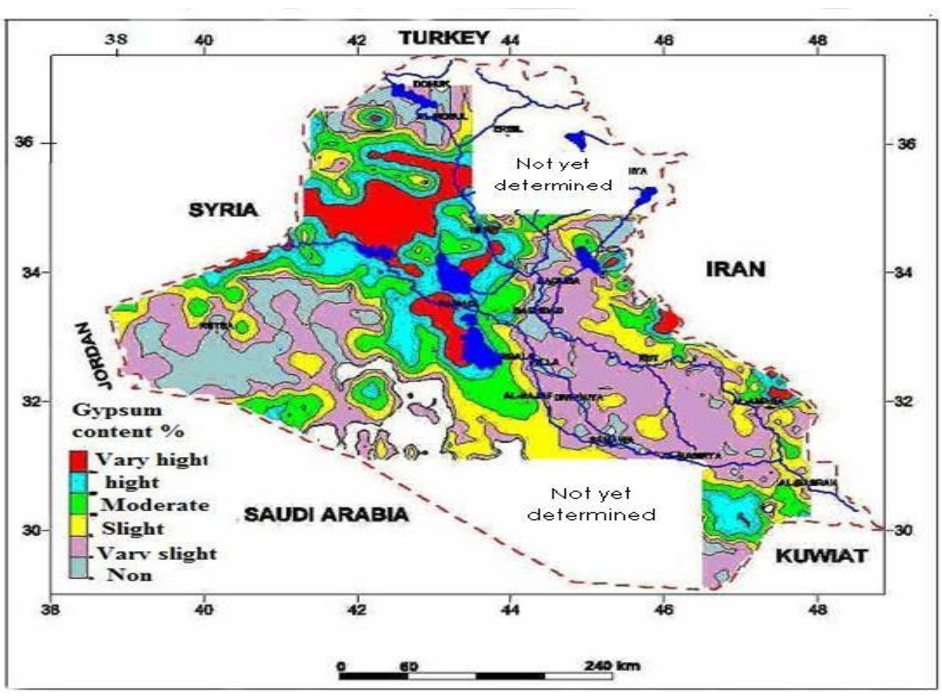

Figure (2): Distribution of gypseous soils in Iraq at depths (250-1500) mm, (after Al-Kaabi, 2007).

II. Effect of Gypsum Content and Leaching on the Properties of Gypseous Soil

Laboratory models

Many researchers investigated the effect of gypsum content and leaching on the properties of gypseous soil by conducted series of laboratory tests using manual or modified equipment. Table below content brief description for this study:

Author	Description of work
Seleam (1988)	studied the effect of gypsum contents and leaching on properties of (undisturbed) sandy gypseous soil with gypsum content between (26 %), (60%) and (80 %), she reported that the gypseous soil exhibited a very high shear strength due to the cementation action the internal fraction (ø), and the shear parameters decreased during the leaching due to the reduction the cementation. Also, it was concluded that the total volume change and compression index (Cc) decrease with increasing the gypsum content, as results of increasing the cementing action of gypsum. The compression index increases during the leaching of soil due to the reduction in the cementing action of gypsum.
Nashat (1990)	Examined the behavior of gypseous soils in Iraq by conducting a laboratory testing program on samples taken from Baiji, Tellafer and Al-Dour in Iraq. The leaching process was conducted under various hydraulic gradients and different stress levels. The hydraulic conductivity fluctuated with time with a general decreasing trend. This fluctuation was attributed to the voids enlargement as a result of gypsum removal and blocking of some flow paths resulted from leaching collapse. It has been shown that the hydraulic conductivity tends to increase with the increase of hydraulic gradient and decreases with the applied stress level. The strain-time behavior revealed that the continuous dissolution of gypsum caused correspondingly a continuous settlement. The strain-logarithm of the effective vertical stress relations approached straight lines for the leached soils. It was pointed out that under low stresses (less than 100 kPa), the leaching strain was proportional with the hydraulic gradient whereas, this behavior reversed when the stress level increased. It was found that leaching is responsible for approximately half or more of the expected settlement. From the results of consolidated undrained conventional triaxial compression tests, it was reported that the leaching process softened the soil and increased its plasticity
Al-Busoda (1999)	studied the effect of leaching on the geotechnical properties of a gypseous soil taken from Tikrit at Saladdin governorate in Iraq. Two types of tests were utilized namely; the triaxial-permeability leaching test and the oedometer-permeability leaching test. The permeability exhibited slow rate of reduction before reaching a constant value. It was inversely proportional to the applied stress. No fluctuation with time was observed. Higher and more accurate values of the permeability coefficient were obtained from the triaxial-permeability leaching tests. The leaching strain increased linearly with the increase of percentage of dissolved gypsum and that the void ratio remains almost constant during leaching under high stresses. It has been reported that the soil compressibility increases due to leaching. The coefficient of volume compressibility (m_v) and the compression index (c_c) were reduced whereas the swell index (c_s)was unaffected. A reduction in shear strength was noticed due to leaching. This reduction was attributed to the cohesion intercept due to the loss of cementing material. It was suggested that the collapse associated with leaching process tends to keep the overall particles contact area constant. So, an approximately constant friction angle was recorded. A theoretical prediction was suggested to estimate leaching strain from the given values of leaching stress and soil permeability.
Al- Qaissy (2001)	conducted an extensive program of laboratory tests on Al-Tharthar soil (with 79% gypsum content). A series of permeability-leaching tests was carried out under different values of over-consolidation ratio, stress level

	and soaking period. It was concluded that the void ratio remains almost constant for normally consolidated specimens, whereas it increases with time in a proportional manner to the over-consolidation ratio and soaking period for over-consolidated specimens. The time required to achieve a certain degree of leaching was inversely proportional to the over-consolidation ratio and soaking period. Higher values of soil permeability were recorded for over-consolidation samples compared to that of normally consolidated ones.

Numerical and Analytical Investigations

Numerical methods have proved successful in approximating the effects of many factors, which render the stress-deformation behavior highly complex and nonlinear. The numerical methods show promise of incorporating a number of other factors. These factors, which are influenced in deformation behavior of soils and rocks, are physical structure, porosity, density, stress history, loading characteristics, existence and movement of fluids in the pores, time-dependent or viscous effects in the solid skeleton and the pore fluids, and geologic features. Moreover, the initial success of the finite element method has indicated that some of these factors have a more significant effect than had been expected **(Mansor, 2005)**.

Author	Description of work
Al-Mufty, (1997)	Utilized partial differential equation for governing the *mass-transport* to assess the variation of gypsum content of the soil during dissolution by ground water flow. The bounding surface plasticity model was applied with some modifications to formulate the constitutive stress-strain relationship. Solving the problem by finite element method showed that the collapse amount depends on the initial water content and initial void ratio before wetting, and the shear strength parameters were affected by the leaching percentage and by the amount of gypsum in the soil.
Al-Jubair, (2002)	Studied the stress deformation of gypseous soils using the boundary surface plasticity model. The finite element method was used to solve *equilibrium* and *continuity* equations in coupled analysis. Then, he solved the continuity equation for steady state in order to calculate the pore water pressure needed in solving the partial differential equation of mass-transport that used for describing the phenomenon of gypsum dissolution and its transport by flowing water. The adopted approach showed a good agreement between the results of the presented model and the experimental results, which were carried out on over-consolidated gypseous samples, obtained from other authors. A continuous increase in settlement was observed when the leaching process continued.
Al-Obaidi, (2007)	presented a theoretical work to study the behavior of gypsouse soils. The computer algorithm solves the three equations *equilibrium, flow* and *advection-dispersion* equations. She used some of the results obtained from the experimental work as input data in the developed computer algorithm. The results as compared with experimental works showed that there is a work relationship between dissolution of gypsum and time of leaching which affects displacement, pore water pressure and dissolved gypsum or concentration.
Karkush (2008)	developed a numerical model simulating the behavior of gypseous soils of different gypsum content and exposed to surcharge and water head at the same time. The numerical model solves three partial differential equations *equilibrium* equations, *continuity* equations and *mass-transport* equations at the specified time. The obtained results from the numerical model, which are the variation of dissolved gypsum and leaching strain, show more reliable results in agreement with those obtained experimentally using large scale Row cell.
Namiq and Nashat (2011)	examined the influence of leaching on volume change of gypseous soil by a laboratory testing program (One dimensional compression) were conducted in Rowe cells on relatively undisturbed soil samples from a site in northern Iraq. He found that conventional consolidation tests and interpretation procedures are not applicable to the gypseous soil investigation and derivation of a phenomenological expression that characterizes stress-strain time relations during leaching of the gypseous soil.

III. CONCLUSIONS

Some of the major conclusions include:

1. The leaching of gypsum causes serious damages to structures that are constructed on gypseous soils.

2. The flow of water through the soil increased initially with time due to the enlargement of voids and then decreased due to the collapsing of soil structure until it reached a steady state condition.
3. The strength parameters reduced due to leaching. The solubility of salts was proportional to the applied consolidation pressure.
4. The leaching strain increased linearly with the increase of percentage of dissolved gypsum.
5. The soil compressibility increases during the leaching due to the reduction in the cementing action of gypsum. The coefficient of volume compressibility (m_v) and the compression index (c_c) reduced.
6. The total volume change decrease with increasing the gypsum cntent

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