Experimental and numerical investigations of dissolution of gypsum in gypsiferrous Iraqi soils

Etudes expérimentales et numériques de la dissolution de gypse dans les sols gypse ferrugineuses en Iraq

Omar Al-Farouk, S. Al-Damluji & Anwar Loay M. Al-Obaidi
University of Baghdad, Iraq
Raid Ramzi Al-Omari
Al-Nahrain University, Iraq
Mohamed Majid Al-Ani & Mohamed Yousef Fattah
University of Technology, Iraq

ABSTRACT
Gypseous soils are distributed in many regions in Iraq and other countries. Large damages that affect structures founded and constructed in or on them occur mainly due to the dissolution of the cementing gypsum. The change in porosity with time is studied herein. Laboratory *oedometer permeability leaching tests* are conducted using sandy soils with gypsum contents greater than sixty percent brought from Khan-Thare, Iraq. Analyses reveal a high effect of dissolution of gypsum on the settlement of structures founded on them.

RÉSUMÉ
Les sols gypseux se trouvent dans de nombreuses régions d'Irak et d'autres pays. Les dégâts qui touchent les structures sont fondées principalement à cause de la dissolution de la cimentation de gypse. Le changement de la porosité avec le temps est étudié et testé. Les tests sont effectués utilisant des sols sablonneux de gypse originaires de Khan-Thare en Iraq qui contienne plus de soixante pour cent de gypse. Les résultats révèlent une forte incidence de la dissolution de gypse sur le scellement des structures en question.

1. INTRODUCTION

Gypseous and *gypsiferrous* soils (the two terms are used interchangeably) are soils plus gypsum ($CaSO_4.2H_2O$) in an amount enough to change or affect their engineering properties. The structure of gypsum that is built in the soil grains during the dry condition closes the outlet of pores among the soil grains just like the action of cement within a concrete mass (Al-Jumaily, 1994). Gypseous soils are usually stiff in their dry state due to the connecting action provided by gypsum. A great loss of strength and increase in compressibility occur when they become in contact with water due to their solubility characteristics as expressed by the following chemical reactions (Buringh, 1960):-

$$CaSO_4.2H_2O\ (s) \leftrightarrow Ca^{+2}(aq) + SO_4^{-2}\ (aq) + 2H_2O\ (l) \text{ ----------------- } (1)$$

$$CaSO_4\ (s) \leftrightarrow Ca^{+2}(aq) + SO_4^{-2}\ (aq) \text{ ---------------- } (2)$$

Leaching is assumed to prevail if water flows through salty soils. Dissolution and washing away of soluble salts will take place. This will lead to progressive collapse of the soil structure and affects the performance of structures established on or within such soils.

Gypseous soils are distributed in many regions of Iraq. They cover about 20% of Iraq's area. Due to this widespread, many construction problems in structures and strategic projects erected on these soils were observed when water comes silently, dissolves gypsum and other rocks and then unexpectedly Karsts hazards occur. Therefore, soil containing gypsum as a cementing agent may be seriously affected upon any change in water content, because water will cause dissolution of gypsum within the soil mass which leads to one or a combination of *three* processes. The *first* is the *collapse of soil structure* due to the breakdown of the bonds between soil particles provided by the gypsum and this process is almost immediate. Al-Jumaily (1994) attributed the sudden collapse of a gypsiferrous soil that takes place just after saturation to the collapse of gypsum structure and the consequent collapse of soil. The *second* process is that of *consolidation*. The *third* is the *leaching* process which prevails when water flow continues through the soil mass. The combination of these processes will cause the soil to settle considerably when loading is applied (Seleam, 1993).

2. EXPERIMENTAL WORK

2.1 Oedometer Permeability Leaching Tests

These tests are carried out using a special oedometer cell for permeability measurement as described by Head (1982). They are conducted in order to study the effect of leaching and the removal of salt by flowing water through the specimen (having different gypsum contents; 0.25, 0.5, 0.75 and 1 gm/l) on compression characteristics, chemical composition and the variation of permeability.

The cell has dimensions of 75mm diameter by 19mm high. It has two lines. The first is for inlet and the other for outlet. The inlet line is connected to an elevated cylindrical tank with an overflow outlet and the other line supplies water to the tank. The elevation of the tank provides a hydraulic gradient equals to (40), corresponding to a head of 76cm. The test is carried out at an applied stress equal to 200kPa.

The test is started, as in the standard consolidation test, doubling the stress every 24 hours until reaching the specified stress for leaching. The stress is kept for 24 hours to represent the pre-consolidation pressure. After

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-820

that, leaching is started by opening the back pressure valve which provides a head of 76cm, collecting the leachate in a graduated cylinder and recording the volume of leachate against dial readings every 24 hours. Therefore, the amount of dissolved gypsum and leaching strain with time can be calculated. After 7 days, leaching is stopped by closing the bottom valve and the specimen is left for 24 hours. The loading program is continued as in the standard consolidation test until reaching 800kPa, and then the load is reduced to 25kPa.

3. LEACHING CHARACTERISTICS

The variation of leaching strain and dissolved gypsum during the leaching process at different percentages of gypsum concentrations in water are shown in Figures 1, 2 and 3. In general, it can be seen that the leaching strain increases with time as the leaching process continues. This behaviour may be due to the continuous dissolution of gypsum that causes a continuous settlement. Also, the leaching strain increases with the increase in the amount of gypsum. Similar results were reported by many researchers such as, Seleam (1988), Al-Beiruty (2003) and, Al-Dulaimi (2004).

Figure (1) shows a significant reduction in leaching strain with time when using different concentrations of gypsum in water. This may be attributed to the increase in the calcium cations (Ca^{+2}) which represent the common ions with calcium cations of the gypsum in the soil. Therefore, the amount of dissolved gypsum decreases, leading to a decrease in leaching strain. Figure (2) shows that there is no variation in the void ratio during the leaching process. The same observation was found by Al-Busoda (1999), Al-Qaisee (2001). Figure (3) reveals that porosity plays an important role since it changes during the leaching process.

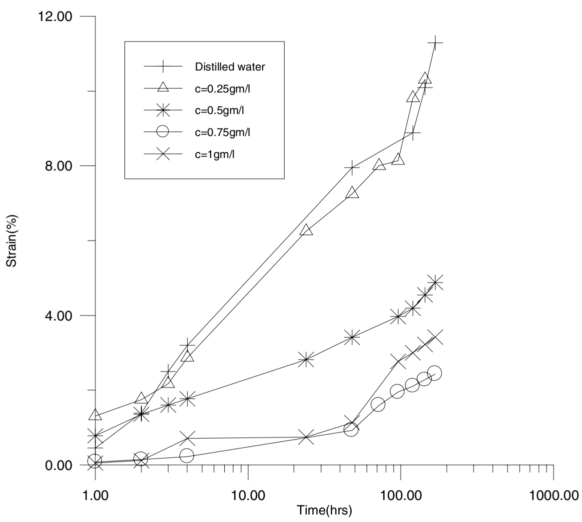

Figure (1) Effect of concentration of gypsum in water on leaching strain.

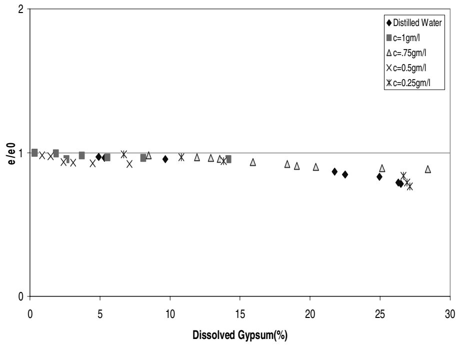

Figure (2) Variation of void ratio during leaching.

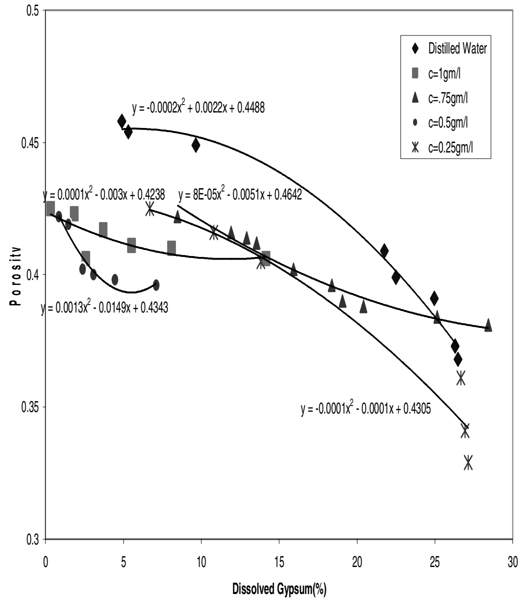

Figure (3) Variation of porosity with dissolved gypsum during leaching.

4. FINITE ELEMENT APPLICATION

The coupled finite element technique is used herein for the solution of the *saturated one phase flow* in a deforming porous gypseous medium. The governing coupled field partial differential equations describing the solubility of gypsum and its transportation are defined. These are: (1) the *equilibrium equation* for the solid phase, after taking the effect of leaching strain into account (creep strain is neglected since the soil under investigation is a sandy one); (2) the *continuity equation* for the water phase after taking the effect of the variation of the mass of gypsum due to dissolution by ground water into consideration; and (3) the *dispersion of gypsum* in solution. The resulting finite element discretization in space of the three above governing equations yields the following system of semi-discrete coupled equations (Al-Obaidi, 2007):

$$\begin{bmatrix} K & L & UC \\ L^T & S & 0 \\ 0 & CP & KT \end{bmatrix} \frac{d}{dt} \begin{Bmatrix} \overline{u} \\ \overline{P} \\ \overline{C} \end{Bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & H & 0 \\ 0 & PC & KD+KV \end{bmatrix} \begin{Bmatrix} \overline{u} \\ \overline{P} \\ \overline{C} \end{Bmatrix} = \begin{Bmatrix} \frac{df}{dt} \\ F \\ -F_3 \end{Bmatrix}$$

------------------- (6)

5. COMPUTER PROGRAM

The finite element method is used as a tool to analyze and calculate the change in displacements, pore water pressures and concentrations due to the dissolution of gypsum from soil by solving Equation (6) (Al-Obaidi, 2007).

Due to the high complication of the problem, several important assumptions are made in order to assess the movement and distribution of dissolved gypsum in pore water. These assumptions are:-

1- According to the results obtained from the experimental work, the porosity **n** will *not* be constant during flow of water and throughout of the soil.

2- The velocities of flow are not constant with time. In other words, flow is not in a steady state condition.

3- The permeability will *not* be constant during flow of water.

4- From the experimental investigation, there is a relation between the velocity and dispersion coefficients. Therefore, the dispersion coefficient will *not* be assumed constant but varies with velocity. The dispersion tensor is assumed *symmetric* (isotropic soil dispersivity).

5- Dehydration or precipitation of gypsum during flow may be neglected in order to simplify the problem.

6. ELEMENT TYPE USED

An isoparametric quadrilateral element is used in solving the problems mentioned above by the finite element method. An eight nodded element is used for all degrees of freedom, which are:-

1- displacements in both x-, and y-directions,
2- pore water pressure, and
3- gypsum concentration.

7. INPUT DATA REQUIRED FOR GYPSEOUS SOILS

7.1 Hyperbolic Model Parameters

Eight parameters are required to activate this model which depend on gypsum content as well as on the condition of test whether if it is under leached or unleached condition. The data in Table (1) are collected from tri-axial test results conducted by Al-Obaidi (2007) on a sandy soil with gypsum content greater than sixty percent. This soil is brought from Khan-Thare which is about 30 km west of Baghdad, Iraq. It can be used as a directive for input data for the computer program.

Area subjected to dissolution $\overline{A}$:-

It is defined as (Al-Mufty, 1997):-

$$\overline{A} = \frac{3\alpha\chi\gamma_d}{nrG_s\gamma_w}$$ --------------------------------- (10)

where:-

$\overline{A}$ = area subjected to dissolution,

r = the effective radius of particles which is taken as $\frac{d_{10}}{2}$,

α = shape factor which is equal to one,

χ = gypsum content,

Gs = 2.32 for gypsum, and

γ_d = dry unit weight for soil.

Number of Gypsum Particles:-

The number of gypsum particles are obtained according to (Al-Mufty, 1997):-

$$\text{No. of particles} = \frac{\chi W_s}{\frac{4}{3}\pi r^3 Gs\gamma_w}$$ ----------------- (11)

Rate Constant:- It is defined as:

$$k' = [0.15 + 8.6v\ ]*10^5$$ ---------- (12)

where k and v are in m/s

Equations 10, 11 and 12 are included in the developed computer program in order to obtain the values of the relevant variables directly.

8. PROBLEM DESCRIPTION:

The problem geometry is shown in Figure (4). The dimensions, cross section and the chosen points are also shown on the same figure. Material properties are shown in Table (1) as extracted from leaching tests. An external load of (200kPa) is applied to the surface to represent the stress applied during leaching. The leaching is done at a gradient equal to (40) corresponding to a head of 76cm so that the flow is assumed to be in a steady state condition.

Table (1) Material Properties of One Dimensional Leaching Using the Special Cell

Modulus Number, k	292
Modulus Exponent, n	1.1
Friction Angle, Ø	34.4
Failure Ratio, R_f	0.77
Poisson's Ratio Parameter, G	0.13
Poisson's Ratio Parameter, F	0.09
Poisson's Ratio Parameter, d	0.05
Coefficient of Permeability (m/sec)	$1X10^{-6}$

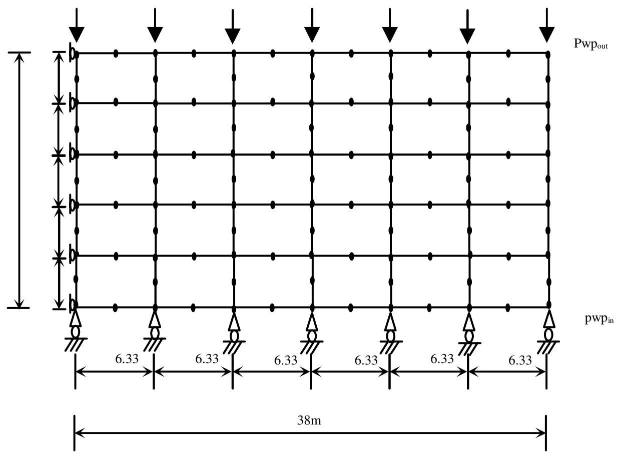

Figure (4) The finite element mesh for one dimensional leaching using a special cell.

9. RESULTS:-

The results as an output from the computer program are plotted in Figure (5) which illustrates the distribution of dissolved gypsum concentration along the sample depth for two different time steps. It is obvious that washing out of gypsum starts at the flow entry and the front of leaching moves forward with time until all gypsum is washed out from the specimen.

An increase in displacements as well as concentrations in different leaching times is encountered using the special oedometer cell as shown in Figure (6).

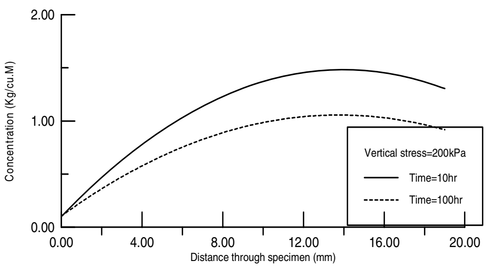

Figure (5) Concentration of dissolution. gypsum

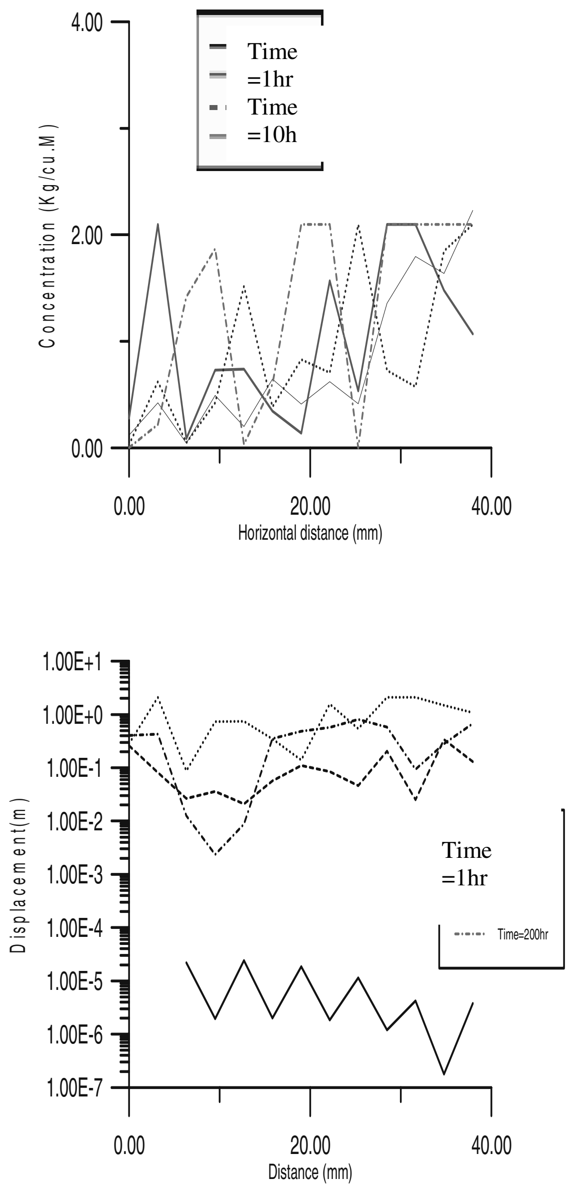

Figure (6) Effect of leaching in one dimensional compression on displacements and concentrations for different times.

10. CONCLUSIONS

1. The initial concentration of water affects axial strain of gypsiferrous soils. This may be attributed to the effects of initial concentration on the dissolution of gypsum which decreases when increasing initial concentrations in water.
2. The oedometer permeability leaching test results reveals that porosity plays an important role in the behaviour of gypsiferrous soils.
3. Displacements continuously increase with time.
4. Displacements decrease with depth. Large displacements occurred near the surface.
5. Dissolution of gypsum decreases with depth.

REFERENCES

Al-Beiruty, M. Z. (2003), “Collapse Potential Determination of Gypseous Soils”, M.Sc. Thesis, Department of Civil Engineering, College of Engineering, University of Baghdad.

Al-Busoda, B.S. (1999), “Studies on the Behaviour of Gypseous Soil and Its Treatment During Loading”, M.Sc. Thesis, Department of Civil Engineering, College of Engineering, University of Baghdad.

Al-Damluji, O. F., (1981), “Non-Linear Soil Behaviour by the Finite Element Method”, M.Sc. Thesis, Department of Civil Engineering, College of Engineering, University of Baghdad.

Al-Damluji, O. F. and Al-Hassanee, H. M. (2006), “Modelling of Iraqi Gypseous Soil Behaviour Under Stress-Flow Dissolution Conditions”, Journal of the College of Engineering, University of Baghdad.

Al-Dulaimi, N. S. (2004), “Characteristics of Gypseous Soils Treated with Calicum Chloride Solution”. M.Sc. Thesis, Department of Civil Engineering, College of Engineering, University of Baghdad.

Al-Jumaily, F. A. 1994, “Gypsum and its Mechanical Effect on the Engineering Properties of Soil”, Journal of Arab Universities, Vol.1, pp.40-50. (in Arabic).

Al-Mufty, A.A. (1997), “Effect of Gypsum Dissolution on the Mechanical Behaviour of Gypseous Soils”, Ph.D. Thesis, Department of Civil Engineering, College of Engineering, University of Baghdad.

Al-Obaidi, A.L. (2007), "Gypseferrous Soil Behaviour by the Finite Element Method", Ph.D. Thesis, Department of Civil Engineering, College of Engineering, University of Baghdad.

Buringh, P.. (1960), "Soils and Soil Conditions in Iraq", the Ministry of Agriculture, Baghdad.

Head K.H., (1982) “Manual of Soil Laboratory Testing”, Vol.2, Pentech Press, London.

Seleam, S. N. M. (1988), “Geotechnical Characteristics of a Gypseuos Soil Including the Effect of Contamination with Some Oil Products”, M.Sc. Thesis, Department of Building and Construction, University of Technology, Baghdad, Iraq.