LEACHING BEHAVIOR OF GYPSEOUS SOILS

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ABSTRACT

A series of laboratory tests were carried out on disturbed soil samples containing different gypsum contents. The soil samples were obtained from al-Jazeera south-west of Iraq. Tests were performed to obtain the physical and mechanical properties of the soil. In addition; permeability-leaching tests were conducted by using oedometer and large-scale Rowe cell apparatus to obtain the variation of the coefficient of permeability, dissolved gypsum and leaching strain with time. All samples were tested under similar conditions, e.g. the hydraulic gradient, vertical stress and leaching period. The soil samples designated N_1, N_2, and N_3 are obtained from depths (0.5-0.75), (1.0-1.25), and (3.25-3.5) m and having gypsum content (31.43), (51.37), and (4.86) percentage respectively. Results of experimental work show that the coefficient of permeability, the percentages of dissolved gypsum and leaching strain measured from the oedometer test are higher than that measured from large-scale Rowe cell test for the same soil sample. The gypseous soil with higher gypsum content exhibited significant amount of leaching strain.

الخلاصة

اجريت سلسلة من الفحوص المختبرية على عينات مشوشة من التربة ذات محتوى جبسي مختلف. تم الحصول علي العينات من منطقة الجزيرة جنوب-غرب العراق. تم اجراء الفحوص الرئيسية للخواص الفيزياوية والميكانيكية لعينات التربة لغرض تصنيفها والاستفادة من نتائج هذه الفحوص في تفسير تصرف التربة إثناء عملية غسل الأملاح القابلة للذوبان من التربة. بالإضافة إلى ذلك تم أجراء فحص النفاذية-الغسل باستخدام جهاز الاوديوميتر وخلية رو ذات القياس الكبير لغرض حساب تغيير معامل النفاذية ونسبة الجبس المذاب وانفعال الغسل مع الزمن. تم فحص جميع العينات تحت نفس الظروف من الإجهاد العمودي والانحدار الهيدروليكي وفترة الغسل. استخدمت ثلاثة عينات من التربة في هذه الفحوص وتم ترقيمها N_1 وN_2 وN_3 والمستخرجة من الأعماق (0.5-0.75), (1.0-1.25) و (3.25 -3.5) متر وذات محتوى جبسي (31.43), (51.37) و (4.86) بالمائة على التوالي. إن معامل النفاذية ونسبة الجبس المذاب وانفعال الغسل التي تم الحصول عليها من فحص الاوديوميتر هي أعلى من تلك التي تم الحصول عليها من فحص خلية رو. هذا وان الانفعال بالغسل كبير في التربة ذات المحتوى الجبسي العالي.

KEY WORDS

Gypseous soil, Dissolution, Leaching, Gypsum, and Experimental Work.

INTRODUCTION

Gypseous soil appear to be strong, stable in their natural dry state, weak and collapsible under wetting generating large amount of settlement. The main cause of settlement is the dissolution of gypsum under wetting. The gypseous soil forms approximately (27-36) percentage of Iraqi soils (Al-Kaabi, 2007). Nashat (1990) studied the influence of soaking on the compressibility and strength of gypseous soil. He concluded that soaking and leaching of gypsum leads to large reduction in undrained shear strength. Ismael (1993) carried out laboratory and field tests on a gypsiferous sandy silt soil. The results of tests indicate that leaching increases the permeability, void ratio, and compressibility. Al-Ani and Seleam (1993) studied the effects of initial water content and soaking pressure on the geotechnical properties of gypseous soils. They concluded that the increase in initial water content leads to decrease the collapse potential, the volumetric strain, and the compression index. Ismael and Mollah (1998) studied the effect of leaching on the properties of cemented sand deposits (natural and leached soil specimens). The results of tests indicate to an increase in the compressibility due to leaching. Al-Busoda (1999) studied the effect of leaching on the geotechnical properties of gypseous soil experimentally. The results indicate that 2.5% of dehydrate calcium chloride decreased the coefficient of permeability and the percentage of dissolved gypsum better than 5%. Al-Qaisee (2001) studied the behavior of gypseous soils under different preconsolidation pressures and different periods of soaking; also the collapse of soil during leaching using the oedometer permeability-leaching test. The test results indicate that void ratio remains constant with time for normally consolidated specimens and increases for overconsolidated specimens. Al-Rawi (2003) studied the effects of long-term soaking on the engineering properties of gypseous soil. The results obtained show that increasing the soaking period for both flowing and stable water basins decreases the percentage amount of gypsum, which remains stable in the case of gypsum saturated water basin. Mahdi (2004) conducted a non-standard field plate loading tests in six selected locations of gypseous soils. The soil was tested in its natural moisture content and after complete soaking with water. The results of tests indicated that soaking decreases the values of stiffness module, which causes an increase in settlement. Al-Obaidi (2007) investigated the leaching behavior of gypsiferous soils by using permeability-leaching oedometer test.

EXPERIMENTAL WORK

The samples were extracted by using handle excavation, with helping of a shovel, then labeled and encased in nylon cases. The laboratory tests were carried out according to the program given in Fig. 1. Note you have to omit Shear strength test and the direct shear test from Testing Program.

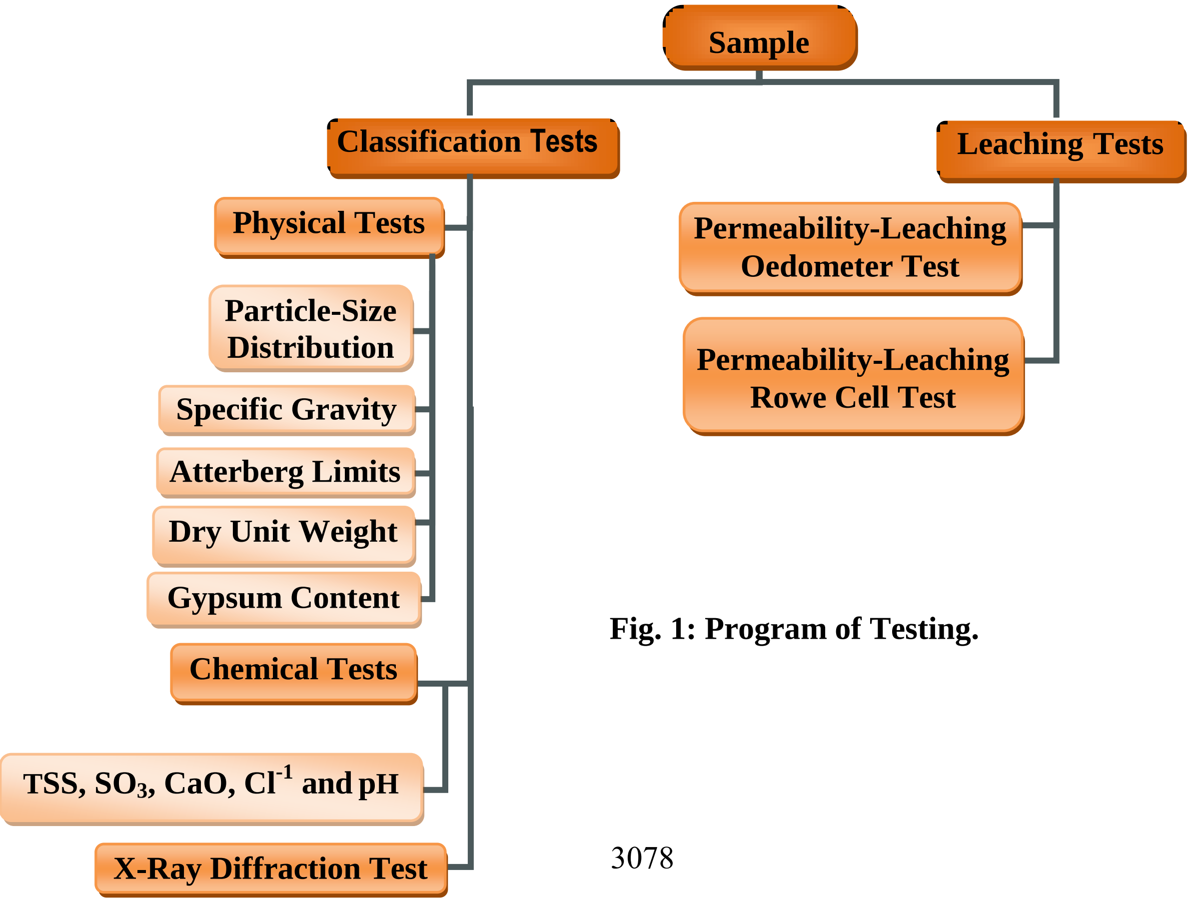


Fig. 1: Program of Testing.

CLASSIFICATION TESTS

Soil samples were classified according to the American Society for Testing and Materials (ASTM) specifications and British Standards (BS).

Particles-Size Distribution

The presence of gypsum in soil sample affects the results of particle-size distribution due to the cementation of soil particles by gypsum and its dissolution in water. Accordingly, modifications in some details of test procedure are needed to take care of the presence of gypsum in soil.

The particle-size distribution of different samples has been tested according to the standard method ASTM 422-79 (dry sieving) and by using kerosene as non-polar solvent (wet sieving). The wet sieving method involved washing the soil samples upon sieve No.200. The fraction of soil sample retained on sieve No.200 is oven dried at 45ºC and then analyzed using dry sieving. The results of particle-size distribution of the soil samples are given in Table 1 and Fig. 2.

Table 1: Classification of Soil Samples.

Sample No.	USCS
N_1	Poorly graded sand with gravel (SP)
N_2	Poorly graded sand with gravel (SP)
N_3	Poorly graded sand (SP)

Gypsum Content

The gypsum content of the soil samples was calculated by using the method proposed by Al-Mufty and Nashat (2000). In this method, the gypsum content was calculated according to the following formula:

$$\chi_{CaSo_4.\varepsilon H_2o} = \frac{W'_{s,45^oC} - W_d}{W_{s,45^oC}} * \frac{136+18\varepsilon}{36} * 100 \qquad (1)$$

$$\varepsilon = \frac{2(W_{s,45^oC} - W_d)}{W'_{s,45^oC} - W_d} \qquad (2)$$

Where χ is the gypsum content; ε is the number of hydration water molecules in the hydrated calcium sulfate molecules; $W_{s,45^oC}$ is the weight of soil sample oven dried after 24 hours at 45ºC; $W'_{s,45^oC}$ is the weight of soil sample after being flooded by distilled water and oven dried at 45ºC after 24 hours and W_d is the weight of soil sample oven dried at 105ºC after 24 hours.

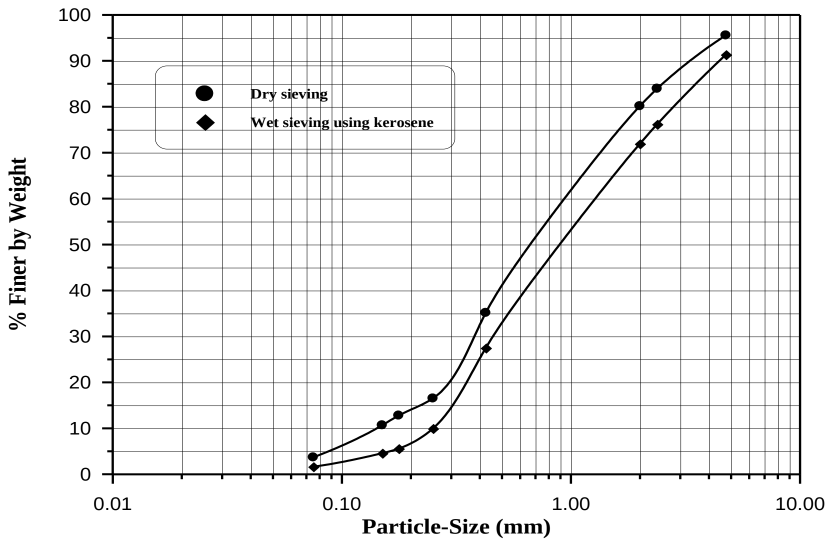
The results of gypsum content tests are given in Table 2. The distribution of gypsum in the tested sandy soil samples is present in the form of coarse inclusions.

Table 2: Gypsum Content of the Soil Samples.

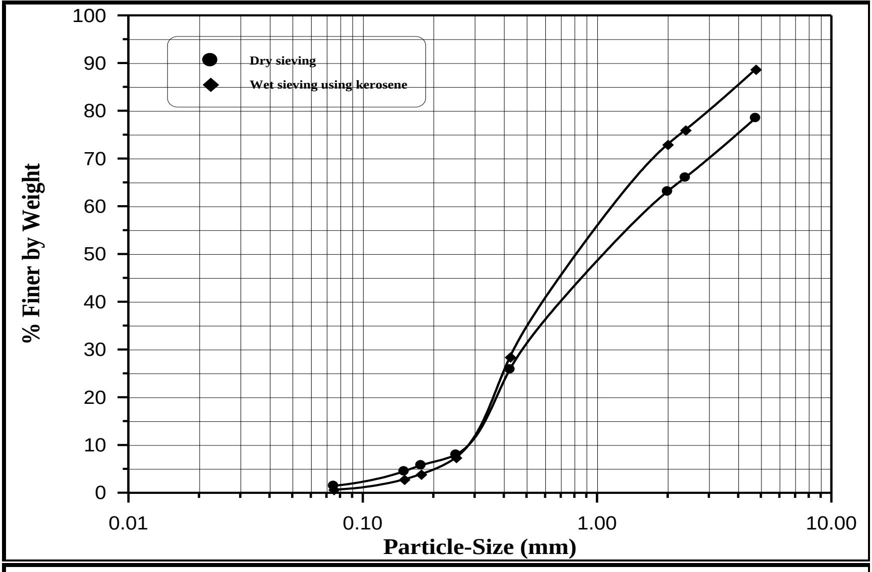
Sample No.	Gypsum Content %
N_1	31.43
N_2	51.37
N_3	4.86

Specific Gravity

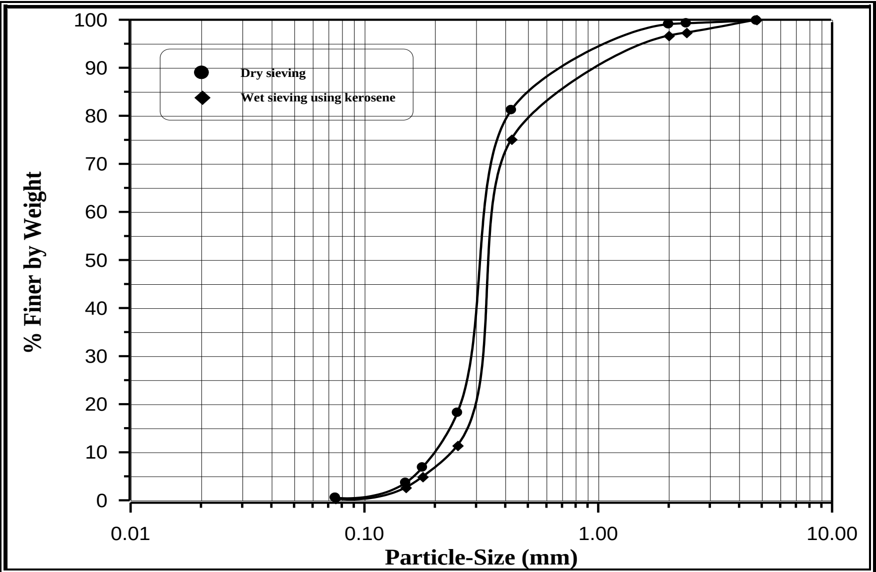
The specific gravity of the tested samples was determined according to the BS 1377:1975, Test 6 (B). Kerosene was used instead of water to avoid solving of gypsum (Head,1984). The test results indicate that the specific gravity decreases with the increase of gypsum in the soil sample due to the low specific gravity of gypsum. The specific gravity of gypsum is 2.32.



Sample N_1



Sample N_2



Sample N_3

Fig. 2: Particle-Size Distribution Curves of Soil Samples.

Atterberg Limits

Atterberg limits (liquid and plastic) were measured according to the BS 1377: 1975. The liquid limit was carried out according to test 2(A) using the cone penetrometer method on soil passing sieve No.40. The plastic limit was carried out according to test 3. To prevent the loss of the water of crystallization, the drying temperature must not exceed 80°C (Head,1984).

Dry Unit Weight

The minimum dry unit weight of the tested soil samples was determined according to the test described by Head (1984). It is widely accepted as a standard test for sandy soils. The maximum dry unit weight was determined according to ASTM D2049-64T (Bowles,1986). The tests results of Atterberg limits, Specific gravity, Dry unit weights, and Gypsum content are given in Table 3.

Table 3: Physical Properties of the Soil Samples.

Sample No.	Liquid Limit L.L (%)	Plastic Limit P.L (%)	Initial Void Ratio e_o	Specific Gravity Gs	Minimum dry Unit Weight (kN/m^3)	Maximum dry Unit Weight (kN/m^3)
N_1	29	NP	0.77	2.44	12.2	14.87
N_2	45	NP	0.93	2.42	10.87	13.71
N_3	25	NP	0.61	2.49	14.29	15.99

Chemical Tests

The chemical composition of the tested soil samples was calculated from several chemical tests. The results of chemical tests are given in Table 4.

Table 4: Results of Chemical Tests.

Sample No.	TSS %	SO_3 %	CaO %	Cl^{-1} %	pH
N_1	32.43	17.15	10.37	0.09	7.7
N_2	52.64	29.1	16.75	0.09	7.7
N_3	5.07	2.79	1.71	0.18	8.3

X-Ray Diffraction Test

X-ray diffraction test was carried out primarily to identify the mineral phases (classification of soil minerals into clay minerals and non-clay minerals). These tests indicate that non-clay minerals predominantly consist of quartz and gypsum while the clay minerals predominantly consist of palygorskite and mica. The results of x-ray diffraction tests are given in Table 5.

Table 5: Results of X-Ray Diffraction Tests.

Sample No.	X-Ray Diffraction	
	Non-Clay Minerals	**Clay Minerals**
N_1	Quartz, Gypsum, Calcite, Dolomite and Hematite	Palygorskite, Mica and Kaolinite
N_2	Quartz, Gypsum, Feldspar and Dolomite	Palygorskite, Mica, Montmorillonite and Kaolinite
N_3	Quartz and Gypsum	Palygorskite, Mica, Montmorillonite and Kaolinite

REMARKS ON SOIL PROPERTIES

The classification tests provide a reliable indication about the engineering characteristics of the soil. The particle-size distribution was found to be relevant in the engineering classification of most soils. In addition to the initial gypsum content, the chemical composition of gypsum and the distribution of the gypsum in the soil has significant role in the classification of gypseous soils.

There is a small difference between the dry and the wet methods of particle-size distribution of the soil sample as shown in Fig. 2. This difference results from washing the soil by kerosene on sieve No.200. The washing reduces the sharp edges of the soil particles and destruction some of the particles cementation resulting from the presence of minerals that dissolve in kerosene.

Atterberg limits play an important role in the classification of cohesive soils, which affect on the scale of magnitude of their many properties such as compressibility, permeability, and strength. The liquid limit increased with increasing the initial gypsum content as shown in Table 3. The presence of gypsum in the soil reduces the importance of Atterberg limits effects on the soil properties. The specific gravity is decreases with increasing the initial gypsum content as shown in Table 3 due to the lower specific gravity of gypsum, which is equal to 2.3.

LEACHING TESTS

A series of permeability-leaching tests conducted on samples of different gypsum contents by using the permeability-consolidation cell and large-scale Rowe cell. The tests were performed under similar conditions such as vertical stress, hydraulic gradient and leaching period. The hydraulic gradient was chosen in order not to affect the orientation of soil particles during leaching process (Al-Khuzaie, 1985). The measured data from these tests are the coefficient of permeability, dissolved gypsum percentage, and leaching strain.

Permeability-Leaching Oedometer Test (PLOT)

The permeability-leaching test was conducted by using a special oedometer cell called the permeability-consolidation cell of dimensions 75 mm in diameter and 19 mm in height. Fig. 3 shows the schematic diagram of the setup used in testing. The test consists of three stages: dry compression stage, saturation stage, and leaching stage. The soil samples were tested under vertical stress of 200 kPa and hydraulic gradient of 57 (Karkush,2008).

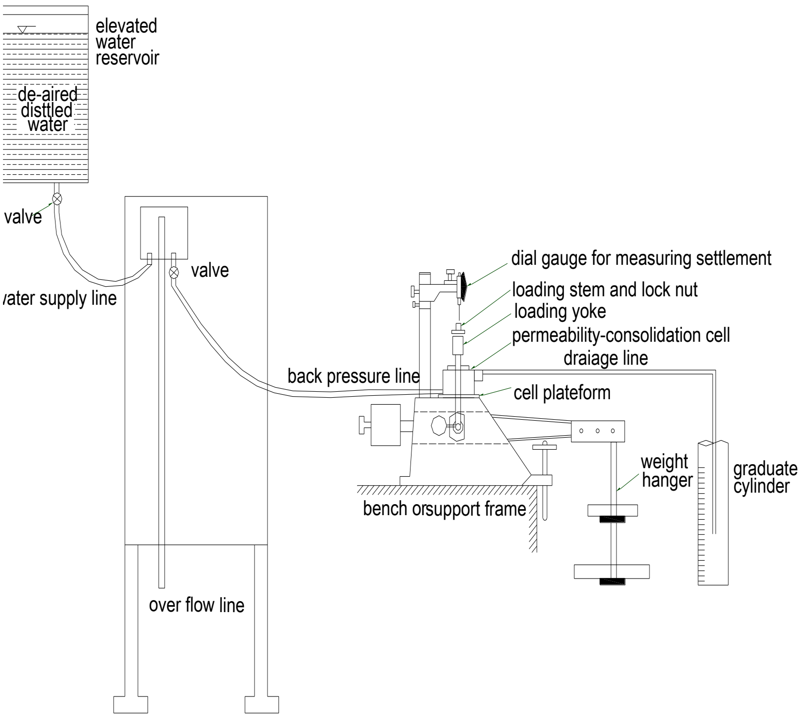


Fig. 3: The Schematic Diagram of Permeability-Leaching Test by Oedometer.

The duration of leaching stage is divided into intervals, at the end of each interval record the volume of leachate collected in a graduate cylinder to measure the change in the coefficient of permeability with time assuming laminar flow (Head, 1988).

$$k = \frac{Q_L}{60\, A_C \; i \; t} \tag{3}$$

where k is the coefficient of permeability in the flow direction (m/sec), Q_L is the volume of leachate (ml) in time t, A_C is the cross-sectional area of soil sample (mm^2), i is the hydraulic gradient ($\Delta h/H$), t is the time (min), Δh is the difference in head (mm), H is the height of soil sample (mm). Also, record the change in the height of the soil sample to calculate the leaching strain.

Permeability-Leaching Rowe Cell Test (PLRCT)

The permeability-leaching test using Rowe cell consists of three main stages: Saturation stage, Consolidation stage and Leaching stage. Large samples of Rowe cell (151.4 mm in diameter and 50 mm in height) are used to test under vertical stress of 200 kPa and hydraulic gradient of 50. The schematic diagram of the used system is shown in Fig. 4 (Karkush,2008).

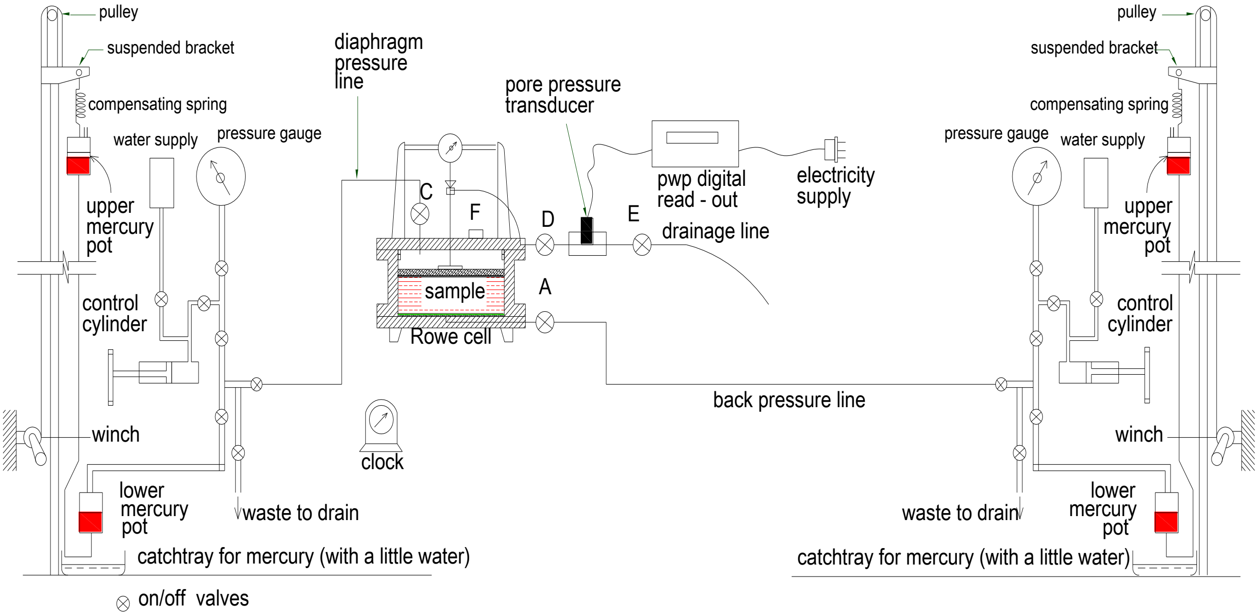


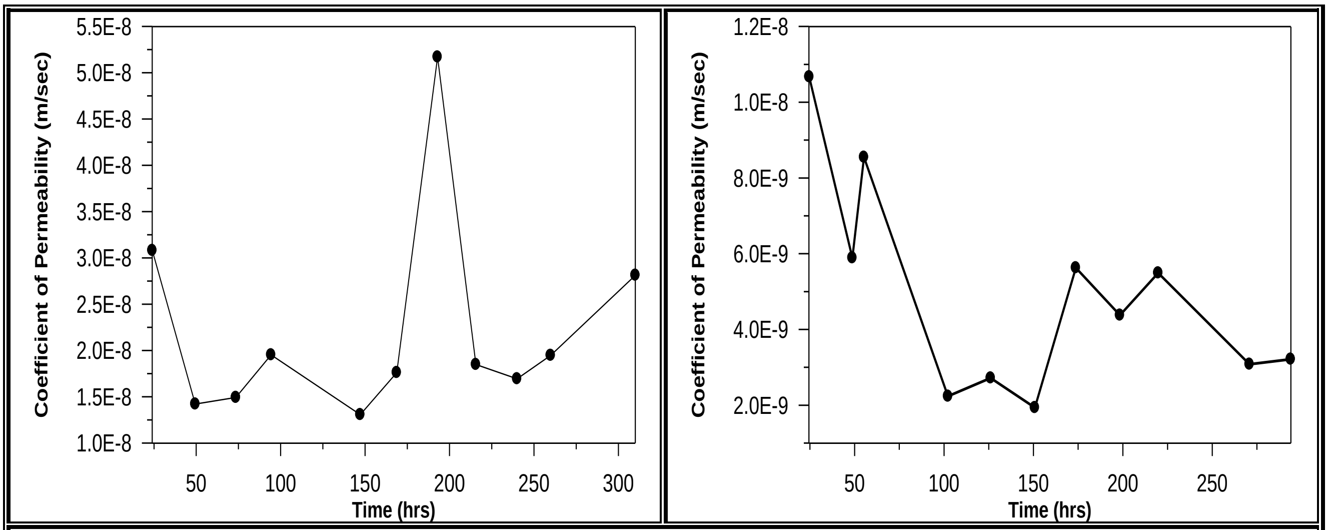
Fig. 4: The Schematic Diagram of Permeability-Leaching Test by Rowe Cell.

RESULTS AND DISCUSION

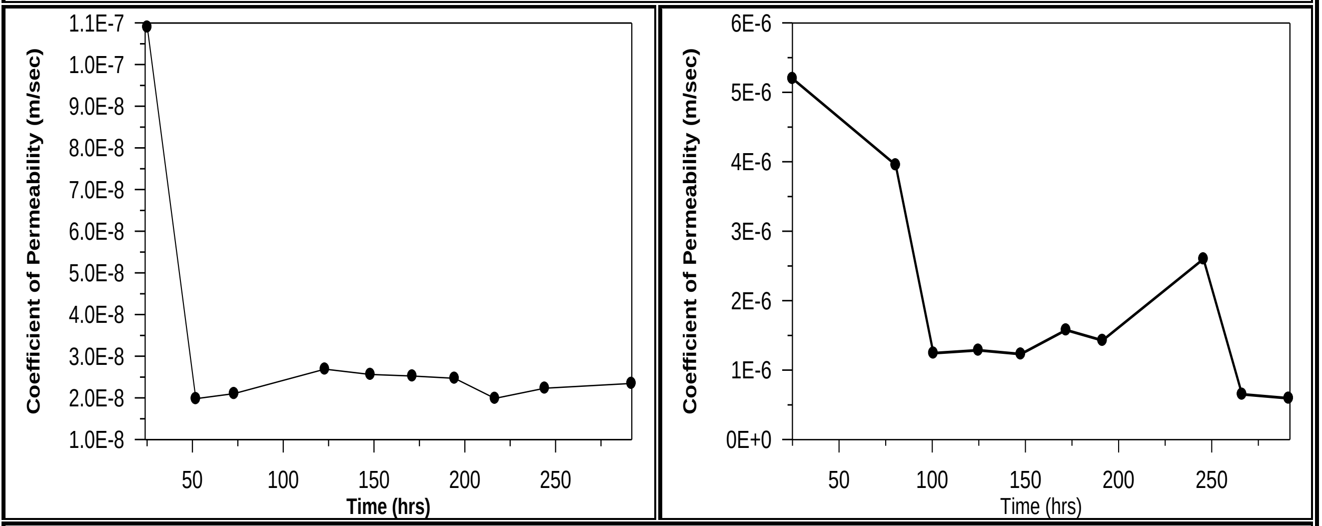
The variation of the coefficient of permeability k with time for the three tested soil samples N_1, N_2, and N_3 are shown in Fig. 5. In general, the coefficient of permeability resulting from Oedometer test decreases rapidly with the time in the first 50 hrs of time of tests.

For the three samples tested by large-scale Rowe cell, the permeability coefficient is unsteadily oscillated with time as shown in Fig. 5. The higher effective radius of soil particles means more coarse grains and consequently affects the reorientation of the soil particles during leaching process.

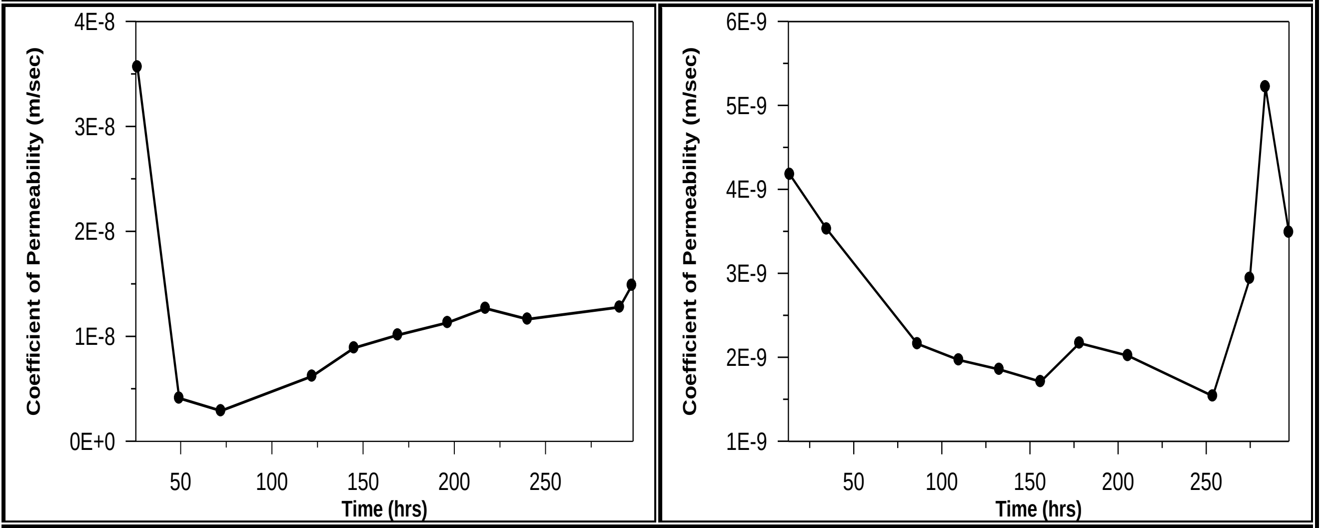
The final values of the coefficient of permeability were much lower than its values at the beginning of the test. The percentage of the initial gypsum content and dissolved gypsum plays a significant role in the variation of the coefficient of permeability with the time. The coefficient of permeability resulting from the oedometer test is higher than that resulting from Rowe cell test. This difference may be due to the difference in the stages of testing procedures adopted in the present study or the small difference in hydraulic gradients between the two types of tests. The variations in the percentage of dissolved gypsum and the percentage of leaching strain with the time obtained experimentally from oedometer test for the three tested soil samples are shown in Fig. 6. While, for the three tested soil samples by Rowe cell are shown in Fig. 7. The soil of initial gypsum content exceeding 50% can be treated as gypsum containing soil. The non-uniform distribution of gypsum in the soil sample leads to a difference in strain value.



(a) Sample N$_1$ (b)

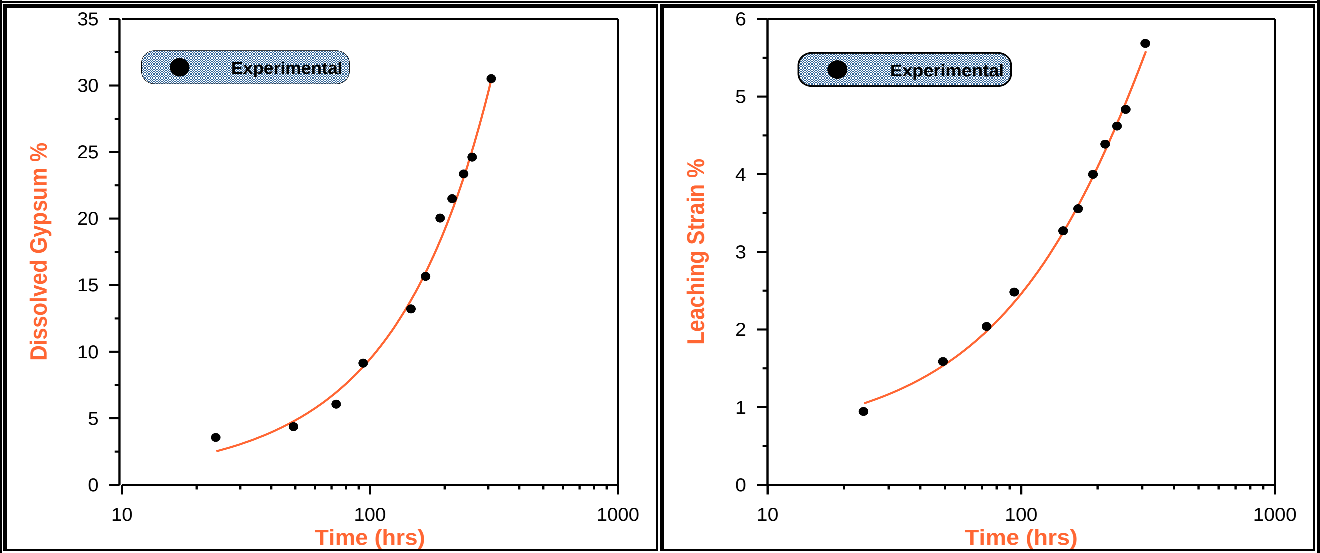


(a) Sample N$_2$ (b)

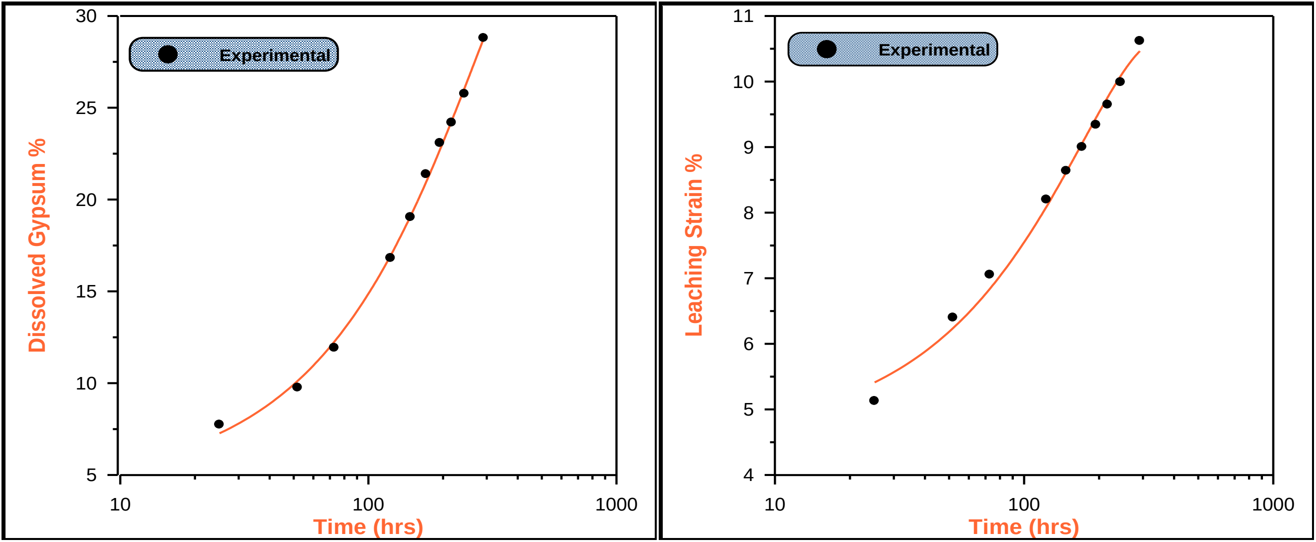


(a) Sample N$_3$ (b)

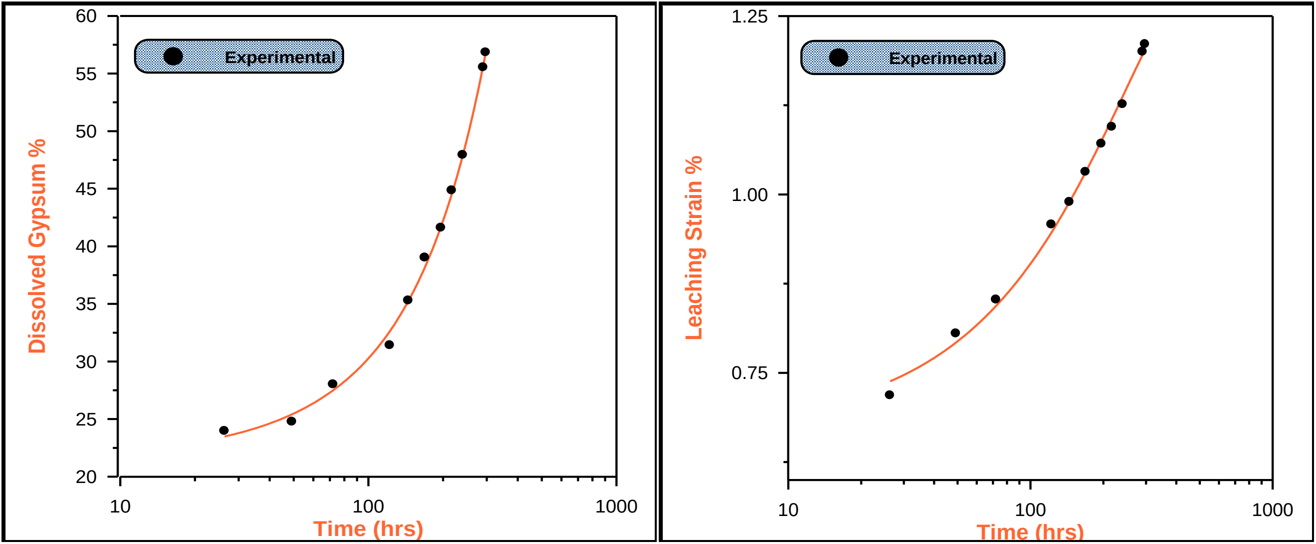
Fig. (5): Coefficient of Permeability for the Samples Tested by (a)- Oedometer and (b)- Rowe Cell.



(a) Sample N_1 (b)

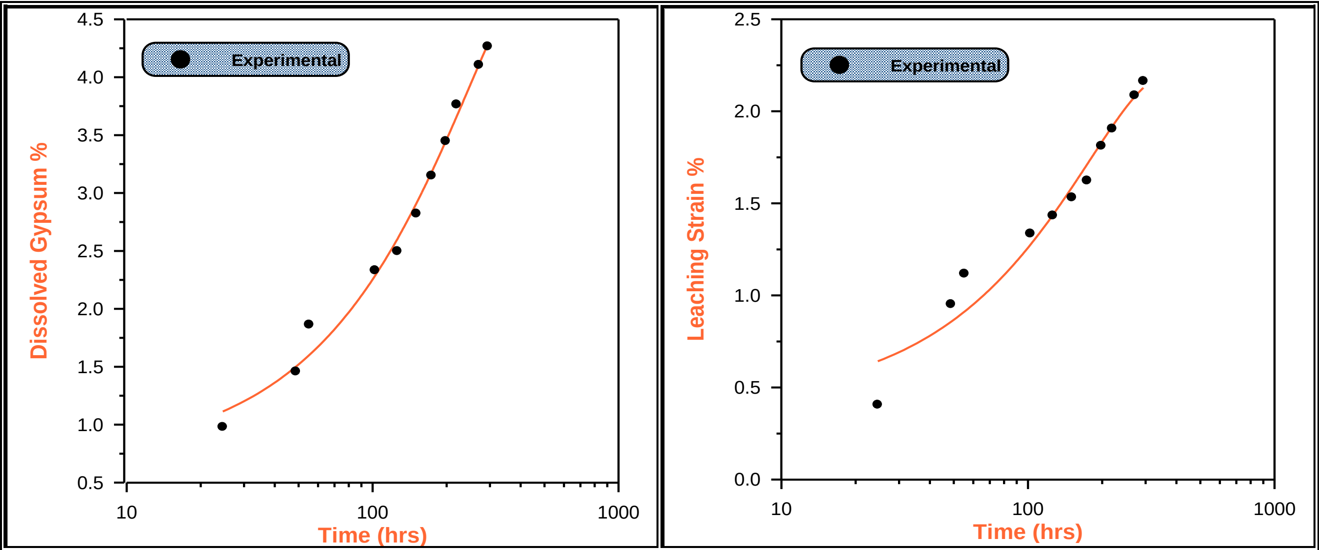


(a) Sample N_2 (b)

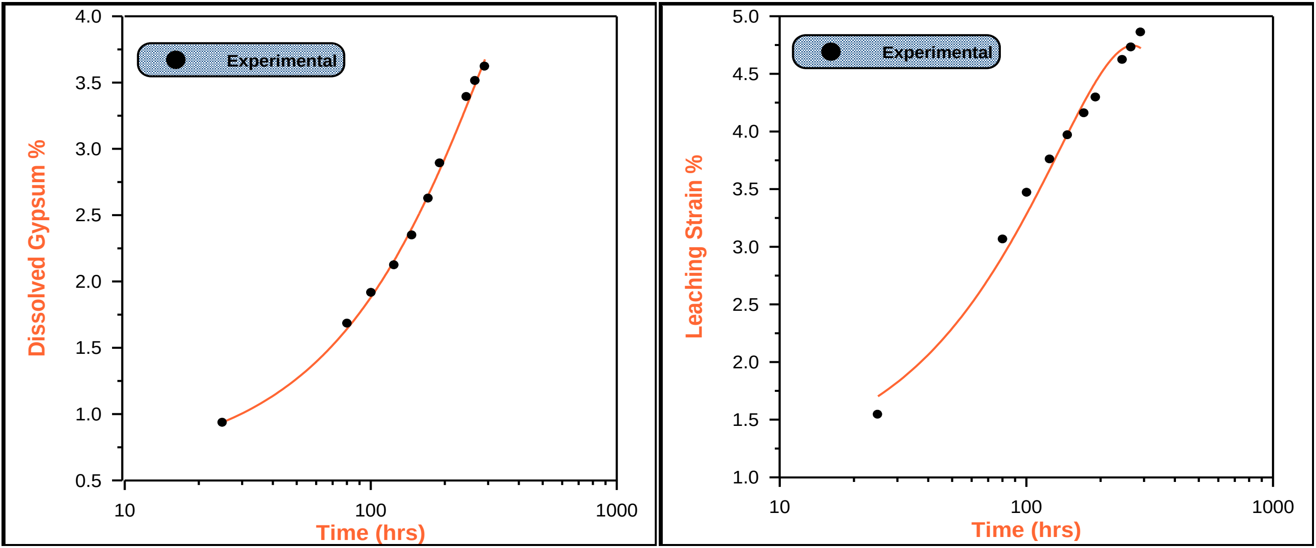


(a) Sample N_3 (b)

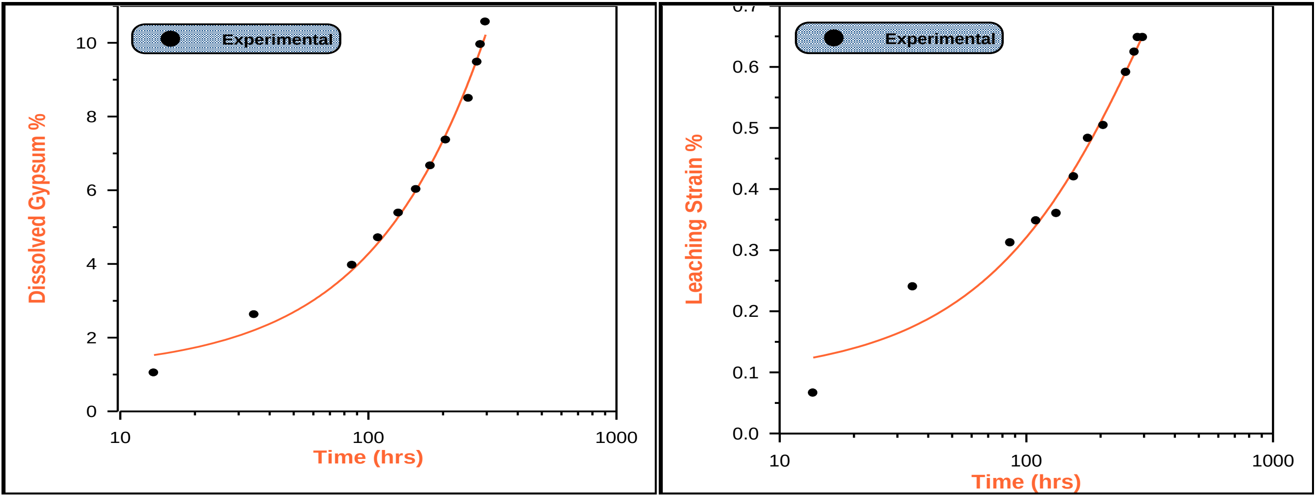
Fig. (6): Experimental Results for Samples N_1, N_2 and N_3 Tested by Oedometer: (a)-Dissolved Gypsum versus Time and (b)-Leaching Strain versus Time.



(a) Sample N_1 (b)



(a) Sample N_2 (b)



(a) Sample N_3 (b)

Fig. (7): Experimental Results of Sample N_1, N_2 and N_3 Tested by Rowe Cell: (a)- Dissolved Gypsum versus Time and (b)- Leaching Strain versus Time.

CONCLUSIONS

- The gypseous soil samples exhibit significant amount of leaching strain, which is larger than the initial settlement and has no definite endpoint upon the continuation of gypsum dissolution and leaching from a soil sample;
- For soil samples with high gypsum content, there is an increase in the percentage of dissolved gypsum in leaching water, consequently the leaching strain increases;
- The percentage of dissolved gypsum in leaching water decreases upon progressing of leaching process (time of leaching);
- The coefficient of permeability, the percentages of dissolved gypsum and leaching strain measured from the oedometer test are higher than that measured from large scale Rowe cell test for the same soil sample and under the same conditions, but under different sizes of soil samples;
- The permeability-leaching test by using large-scale Rowe cell gives more reliable results than those by using the ordinary permeability consolidation-cell (oedometer test).

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