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Characteristics of Artificial, Gypsified and Natural Gypseous Soils under Leaching Condition

Abstract- *The gypseous soil known as a problematic soil with a collapsibility behaviour, three types of gypseous soils are prepared (artificial, gypsified and natural gypseous soil), special manufactured leaching system used for testing the soil models, the main objectives of this study are testing the soil models in dry and leaching conditions for measuring earth and pore water pressures with displacements and gypsum dissolved of the soil models under monotonic and repeated loads within relatively large physical model. The results at leaching process for three days revealed that the natural and gypsified soils have earth pressures reach about (150 kPa) and (4 to 4.5 cm) for displacements, while pore water pressure increased until reaches about (120 kPa), but for artificial gypseous soil, earth pressures reaches about (300 kPa) and (1 cm) for displacements. TDS and SO3 content measured and reaches to about (1900 ppm) for gypsified and natural soils while reaches about (350 ppm) for artificial gypseous soil. STATISICA program used to verify the results with a very good agreement reaches to 95% of the statistical models.*

Keywords- *natural gypseous soil – gypsified natural soil - artificial gypsified soil– leaching.*

1. Introduction

The gypseous soil as known was a problematic soil upon wetting because of its collapsibility rather than for the main changes in its characteristics. Gypseous soil exposed to several changes in its chemical and physical properties when it is introduced to water [1]. The term of gypseous soils is known as the soil that has a kind of salt is gypsum which can be dissolve in water and movement of its particles or migration of the solution was happened during the leaching process, [2].

Mainly gypsum is found in soil in two forms [3]:

Primary Gypsum: which may consist of gypsum ($CaSO_4.2H_2O$), anhydrite ($CaSO_4$), and alabaster (a fine grained, light colored, compacted, non-crystalline from gypsum).

Secondary gypsum: Wind-blown secondary gypsum forms the gypseous desert area and deposited on other soils, or precipitated from irrigation water.

The researchers study the gypseous soils with different methods using devices for tests such as oedometer and Triaxial leaching permeability tests, with soaking and leaching processes [4] under static and cyclic loads on sandy gypseous soil models.

Al-kaisi (1997), assessed the variation of gypseous soil strength due to its moisture content, the hydraulic conductivity of gypseous soil which controls water percolation downwards in the foundation, was investigated. Leaching process of gypseous foundation soil, which is time and drainage outlet dependent, the alteration of foundation from completely dry to fully saturated case, increase vertical displacements [5].

Al-Banna (2004), manufactured a setup container to provide various flowing and soaking conditions. Dissolution of gypsum is observed by measuring the Total Dissolved Salts (TDS) and sulphate content (SO_3) in the soaked and leached water [6].

Najim (2009), studied the gypseous soil used from Tikrit city with a series of tests including soaking and leaching tests were carried out using steel container. The footing was loaded gradually up to failure at dry and to constant pressure at soaking and leaching process and the corresponding settlements were recorded. The bearing capacity of the gypseous soil reduced and the collapse settlement increased when the water permeates this soil in soaking and leaching states [7].

Al-Obaidi (2014), studied the effect of leaching on the collapsibility characteristics and the behavior of gypseous soil during leaching processes and hydro-mechanical properties. Three types of collapsible soils have been experimented. A series of single and double oedometer collapse tests were carried out using single and multi-steps wetting. And examined the factors influencing the collapse potential on the volume change behavior, ESEM-EDX analysis at different states of the soil samples, variations of the pore-water pressure in

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soil-column test were analyzed. The results indicated that the selected soil samples exhibit a significant collapse volume change in response to single and multi-steps wetting under constant net vertical stress [8].

2. Soil Modelling

Three samples of soils are prepared in laboratory. The first sample is natural gypseous soil bring from Wady-Sheshen region in Salah-Alddin governorate. The second sample is natural gypsified soil prepared in laboratory as method and the third sample prepare by mixing of gypsum treated in facility with the same sand of collected gypseous soil in the second sample, then the kind of gypseous soils used are three (natural, gypsified, and artificial gypseous soil). The artificial gypsified gypseous soil was very hard and solid material because of high surface area for that reason the voids decrease when the artificial gypsum content increased, while the natural and gypsified soils void ratio is increase under increase in gypsum content. Bearing capacity of artificial gypsum was and larger than the natural gypseous and gypsified soils. Secondary or detritus and pre-precipitated gypsum, crystals in surface layers, sometimes crust or re-crystalized from evaporated ground water [1, 2 and 3], and (gypsum burned in the facilities on 130 C^{o} and treated to fine grained with very high of surface area are used in this study. The first aim of this study is to find the difference between natural gypsum soil and artificial or manufactured gypsum soil. In the mixing of the artificial gypseous soil, three samples with different artificial gypseous percent (23, 34, and 51 %). The soil of about 51% gypsum content was used for all samples as a worst state. The kneading and mixing of the artificial gypseous soil done using the mixer or grinder as shown in the Plate 1. Also amount brought of free gypsum (95% secondary gypsum) with help of the General Authority for Geological Survey and Mining / Baghdad.

Plate 1: Mixer of samples materials for the artificial and gypsified soil samples

3. Laboratory Tests Results

The physical properties for the artificial, gypsified and natural soil samples were shown in the Table 1. The gypsum content according to and hydrated method (SO$_3$) as shown in Table 1.

I. Physical and chemical tests

The gypsum content according to (Al-Mufty and Nashat, 2000), [9] and hydrated method (SO$_3$) as shown in Table 1.

Table *1*: Physical properties for three types of soil samples

Sample	N_1	N_2	N_3	Specification
Liquid Limit L.L %	27	24	22	BS:Part2: 4.3, sec.2.6.6[10]
Plastic Limit P.L %	23	20	18	BS:Part2: 4.3, sec.2.6.8[10]
Specific gravity Gs	2.44	2.42	2. 46	ASTM D 845-02 (with kerosene)[11]
γ_{dry} (kN/m^3)	16.15	16.42	16.83	(ASTM- D698: 2012)[12]
O.M.C.%	17.3	16.6	15.9	(ASTM- D698: 2012)[12]
Dry or Al-Mufty method %	51.43	50.37	51.86	(Al-Mufty and Nashat, 2000)[13]
G.C. by SO$_3$ or wet method %	51.65	51.43	52.11	BS: Part3:5.3, sec. 5.6.3[14]
SO$_3$%	24.03	23.92	24.24	------

N_1: Natural soil from Tikrit city (Wady-Shesheen area).
N_2: Gypsified soil prepared in lab using natural gypsum with sand of Wady-Shesheen area.
N_3: Gypsified soil using artificial or processed gypsum in factory with sand of Wady-Shesheen area.

II. Particle size distribution

The particle size distribution for the three soil samples shown in Figure 1, according to wet sieving with kerosene (non-polar solvent) [14 and 15] and (BS: 1377:Part2:1990:9.2, 4.6.4), and Hydrometer test (BS1377:Part2:1990:9.5) according to [16 and 17].
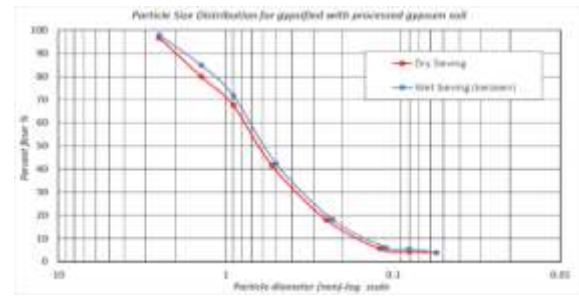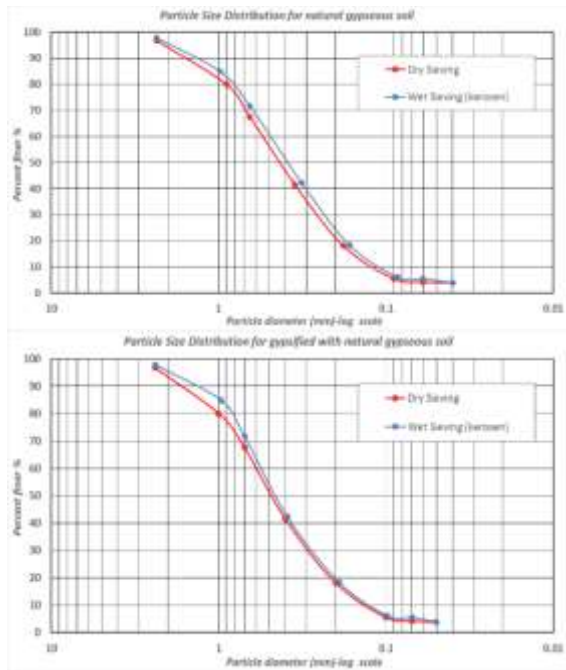
Figure 1: Particle size distribution (natural, gypsified and artificial gypseous soils)

III. Compaction test

According to (ASTM-1557 Modified Procter, Method A) [11], the results of three soil samples for compaction test, as shown in Table 2.

IV. Single collapse test

According to (BS 1377: part 5: 1990) [11] the results for the collapse test, of the three types of soils are shown in the Table 2.

V. Direct Shear test

The direct shear test according to (ASTM-3080-7), [11] is applied to the three soil samples were tested in the direct shear instrument to get shear soil parameters (c and Φ), and the results are shown in the Table 2.

Table 1: summery of the properties of the soil used

Sample	$\gamma_{dry)max.}$ (kN/m^3)	O.M.C.%	C_P%	DRY		WET	
				C (kPa)	Φ (Deg.)	C (kPa)	Φ (Deg.)
N_1	16.35	11.2	6.42	3	37	1	32
N_2	16.52	10.1	5.42	1	38	0	33
N_3	16.83	8.2	0.67	75	35	56	29

4. Methodology

From the previous studies, there are many researchers deal with soaking and leaching processes with small physical models to estimate the geotechnical properties based on the laboratory tests. With relatively large scale model, the soil characteristics are more accurately and clearly studied to evaluate the behaviour of the soil.

Leaching system of large dimensions of the physical model in lab (100 cm length × 40 cm width × 70 cm height) was made, seepage system is manufactured in the workshop and training centre at UOT to achieve that aim. Plate (2) shows physical soaking and leaching system installed in lab.

Plate 2: Two soil model containers were manufactured for soaking and leaching processes.

The model apparatus system for monotonic and repeated loads found in soil lab at UOT consists of three main parts: hydraulic and mechanical system with connection to computerized (PLC) system for store and reading data and transfer it to personal computer. The piston connected with footing (40 cm x 20 cm) to apply loads on the soil model system. As shown in Plate 3.

Plate 3 Computerized PLC of monotonic and repeated apparatus system with physical soil model during testing.

The model apparatus system for monotonic and repeated loads found in soil lab at UOT consists of three main parts: hydraulic and mechanical system with connection to computerized (PLC) system. The piston connected with footing (40 cm x 20 cm) to apply loads on soil model system as shown in Plate 5. The storage tank and graduated cylinder are shown in Plate 4.

Plate 4 Tank storage and graduated cylinder as a part of leaching system model.

The instrumentation for measurements used in the testing program were:
1. Pressure cell with data logger to measure the earth pressures Plate 5.
2. Piezometers with data logger to measure the pore water pressures Plate 6.
3. Linear variation differential transducers with data logger to measure the displacements, as shown in Plate 7.
4. TDS/pH/Temp digital for measuring the total dissolved salts.
5. Pressures and displacements on the surface of the soil models by static and cyclic apparatus loading system.

Plate 5: Earth Pressure Cells with data logger

Plate 6 Data acquisition system for P.W.P.

Plate 7 LVDTs system with data logger.

The data from the model apparatus reading by using SIMATIC V4.0 program transferred to computerized PLC of the static and cyclic system apparatus on the surface of the ballast layer on soil model. While the sensors with data loggers using the (Jmida program) on computer to transfer data measured in the 25 cm depth of 50 cm total soil model layer.

Artificial soil used processed gypsum in factories shown in equation $CaSO_4.1/2H_2O + H_2O \rightarrow CaSO_4.2H_2O$, gypsified using natural gypsum, and natural sandy gypseous soils were collected and prepared to study the behaviour of these types of soils under leaching condition, and loading of static and cyclic was applied on the tested soil model.

The leaching system consists of the container from the two upstream and downstream gates with sandy filters design system, two in the gates and one on the floor with 10 cm thick have six valves for the soaking condition to ensure that the flow continue as a steady state flow with graduated cylinder to achieve the constant hydraulic gradient and velocity of water as shown in Plate 1.

Standard tests were carried out to estimate the soil properties, the artificial gypseous and gypsified soils were prepared given in (Al-Qaissy 1989) [9]. Grinding the soil to the required gradation then the soil can be prepared in the container of soil model with five layers each layer 10 cm thick until reaching the required maximum dry density and optimum moisture content. All the important sensors were placed on the soil at 25 cm level which represents the mid height of the total soil depth. The sensors placed in the physical soil model as shown in the Plate 8.

Plate 8 Piezometers and pressure cells positions during preparing soil model then connected with its data loggers.

After preparing the last layer, laying the ballast (crashed marble with suitable gradation for damping of energy) as the final layer on the soil model, then the test starting by applying the required loads with soil model required condition.

5. Results Presentation

There are twelve models tested within two groups, first group three types of soil samples in dry condition with three models for monotonic and three models for repeated loading, and six models for second group for the three soil samples with leaching process under monotonic and repeated loads. The soil samples used with about 51% gypsum content found in nature in the same area for natural sandy gypseous soil and the others prepared in lab with approximately the same gypsum content, this gypsum content used as a worst percent comparing with other gypsum content such as 23% and 42% gypsum content found in the same area. The procedure of the

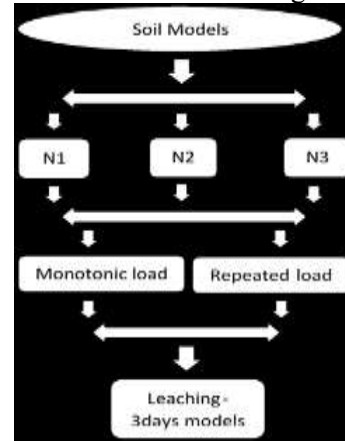testing program included the following tests summarized in the flowchart of Figure 2.

Figure 2 Diagram of testing program.

I. Leaching Models for monotonic and cyclic load

The first group under monotonic load and second group under repeated load for three types of soil models of 50% gypsum content at leaching condition. The models can be summarized in Table 3 as follows:

Table 3: 1st and 2nd groups results for Leaching samples (monotonic and repeated loads).

	Monotonic	load	
Sample	N_1	N_2	N_3
P_{PLC}	350	200	150
Pe	300	150	120
Pw	50	120	90
Disp.	15	35	45
LT	8000	2750	2250
	Repeated	load	
$P_{Dyn.}$	140	80	60
P_{PLC}	300	150	100
Pe	250	100	75
Pw	50	90	70
Disp.	10	30	40
LT	26000	8500	10500
N	52000	9000	21000

Where:
$P_{Dyn.}$ = 40% of monotonic pressure.
Pe = earth pressure (kPa),
P_{PLC} = Pressure of the model apparatus (kPa),
Disp. = Displacement (mm).
Pw = Pore water pressure (kPa).
T = Loading Time (sec.).
N = No. of stress cycles (cycle) = LT × 2.

1) Earth Pressures and displacements for models at Monotonic Load

The surface earth pressure and displacement are (350 kPa) and 10 mm respectively. The earth pressure in model (M1) shows that maximum

load at general shear failure of soil was about (300 kPa) under leaching time of 3 days, the pore water pressure in the model for soil is about (50 kPa). Figure 3 and 4.
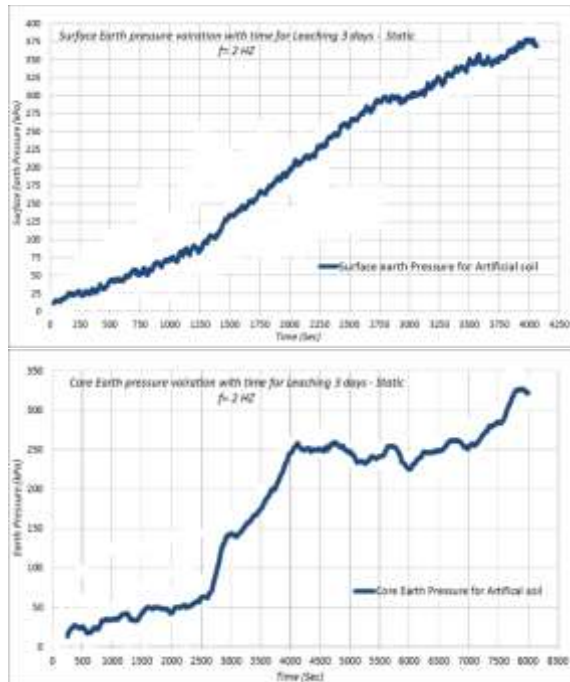

Figure *3*: Surface and Earth Pressures of M1 Model (Monotonic - artificial)
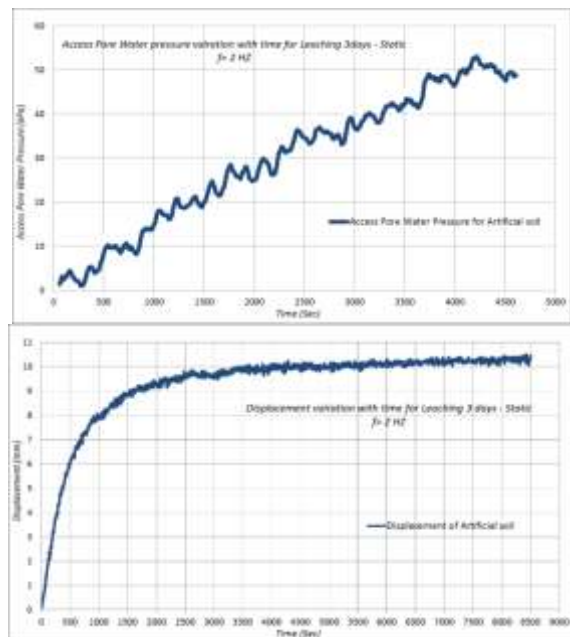

Figure 4: Pore Water Pressure and displacement of M1 Model (Monotonic - Leaching).

The behaviour of the artificial model at leaching process shows that the values of pressures stay very higher than the other models with the same case, and comparing with the other two samples (gypsified and natural models).

The surface earth pressure in the second model was higher amplitude than the earth pressure in the core (with a little amplitude) in the soil model during the test with linear behaviour and low values, give us an indication a different among the three types of soil models. But the behaviour of the displacement was normally similar to other previous models.

The surface earth pressure and Displacement are (200 kPa) and 35 mm respectively. The earth pressure at model (M2) shows that the maximum load at failure of soil was about (150 kPa) at leaching within a 3 days, the pore water pressure in the model shows that the maximum load at failure for soil is about (110 kPa). Figures 5 and 6.
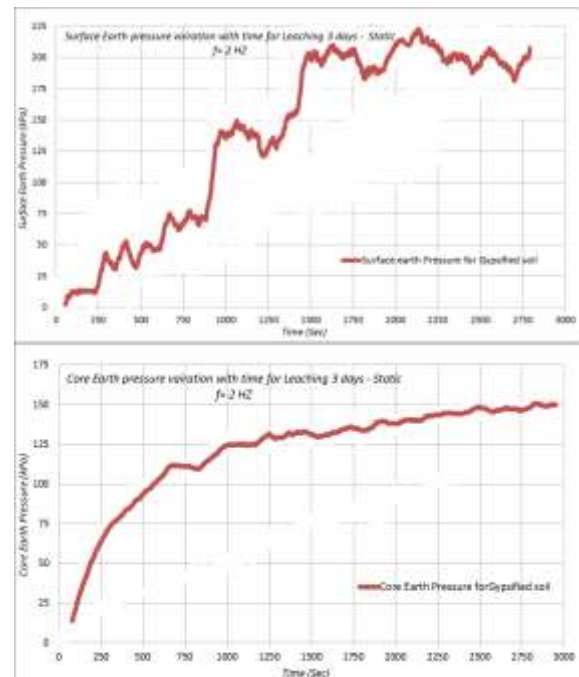

Figure 5: Surface and Earth Pressures, and Displacement of M2 Model (Monotonic – gypsified)

Figure 6: Pore Water Pressure and displacement of M2 Model (Monotonic - Leaching).

At leaching process in this model, the behaviour of gypsified soil as shown in its figures, the apparatus pressure and the PWP amplitude was high while the earth pressure with low amplitude, and the displacement straight forward, that's attributed to the effect of leaching process on the gypsified soil.

The surface earth pressure and Displacement are (150 kPa) and (45 mm) respectively. The pressure earth at model (M3) shows that maximum load at failure of soil is about (100 kPa) with leaching of three days, the pore water pressure in the model shows that the maximum load at failure for soil is about (120 kPa). Figures 7 and 8.
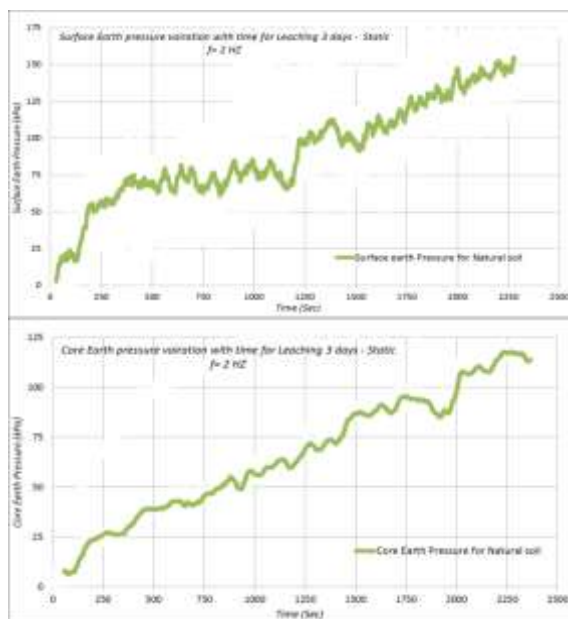

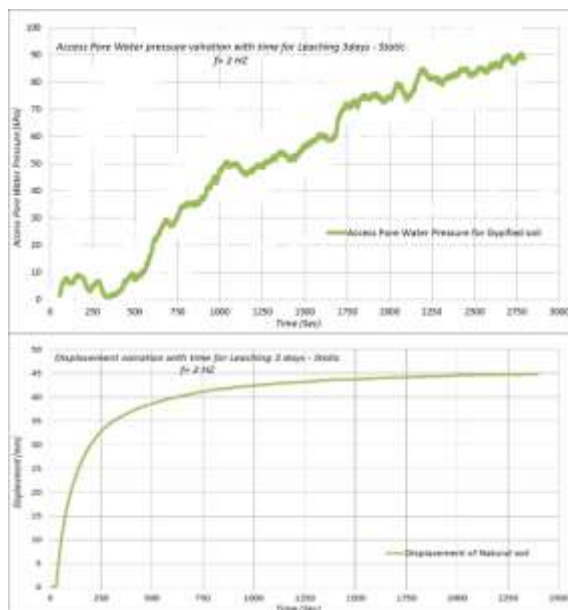**Figure 7: Surface and earth pressures with settlement for M3 Model (Monotonic - Natural)**

Figure 8: Pore Water Pressure and displacement of M2 Model (Monotonic - Leaching).

The behaviour of the natural gypseous soil at leaching process are similar to the gypsified soil, larger values of pore water pressure and displacement, with lower pressures of surface and core earth pressures. The behaviour of displacement was non-linear and with rapid increases within the first time of the test then gradually increases until reaches to the steady rate, the pore water pressure are reverse behaviour with the displacement about linearity, with a little raising at 1750 - 2000 sec, the surface earth pressure has some disturbances in behaviour.

The summery of the bearing pressures for three models of dry condition shown in Figure 9.
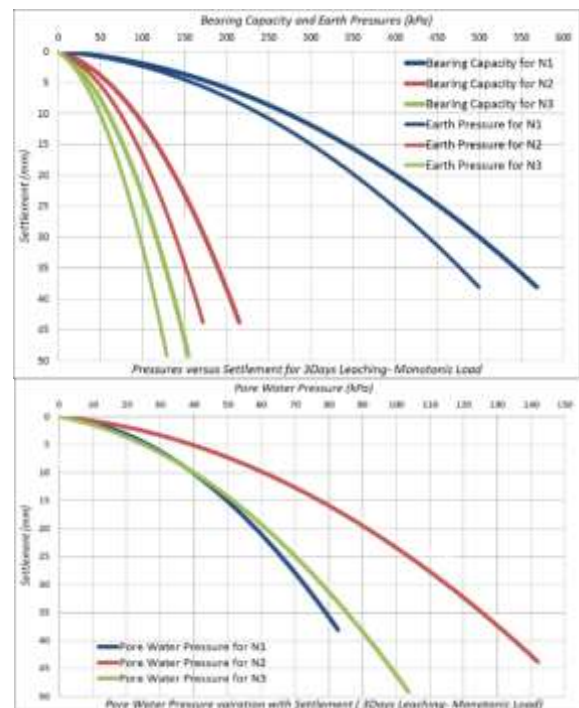

Figure 9: Bearing Capacity with settlement for M1, M2 and M3 Models (Monotonic load).

2) Earth Pressures and displacements for models at Repeated Load

The surface earth pressure and displacement are (300 kPa) and 10 mm respectively. The core earth pressure in model (M4) (under initial cyclic load at failure 140 kPa) reach to about (250 kPa) after leaching three days, pore water pressure in the model reach to (50 kPa) at the end of the test. Figure 9 and 10.
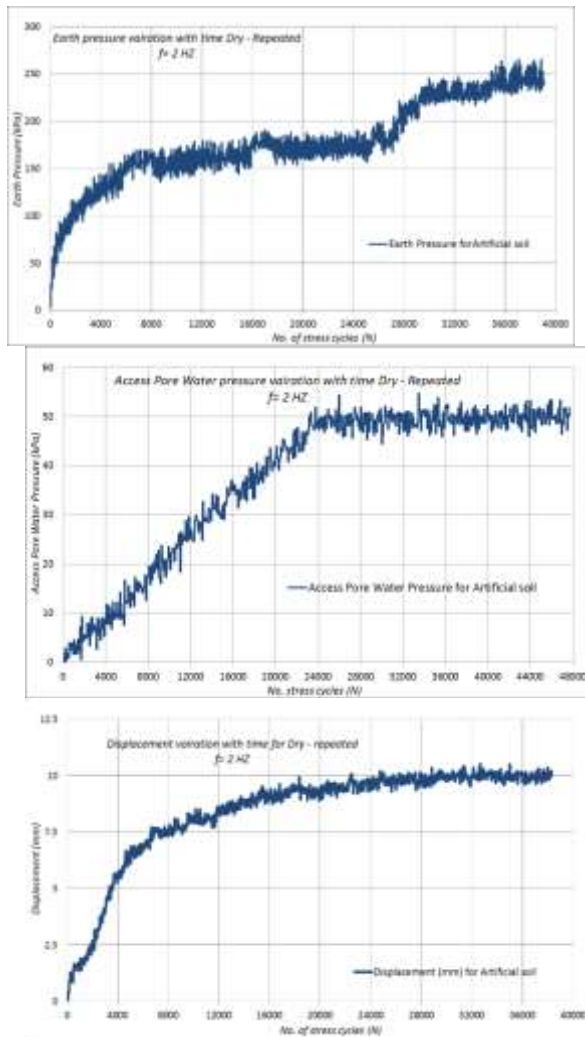
Figure 10 Earth and Pore Water Pressures and Displacement of M4 Model (repeated - Leaching).

Figure 11 Earth and Pore Water Pressures and Displacement of M5 Model (Repeated - Leaching).

At leaching process, the surface earth pressure with lower amplitude than model tested in the previous stage, and linear relationship with a little disturbances are differ comparing with core earth pressure, rapid rising until steady rate reaches then rapid rising between 13000 – 15000 sec then return to the steady rising until the end of the test. While low pore water pressure with linear increasing until 12000 sec then reaches to a constant value until the end of the test, and also low displacement, comparing with natural and gypsified soil types, there are differences among the three types for the same condition.

The surface earth pressure and Displacement are (150 kPa) and 35 mm respectively. The earth pressure in model (M5) under (initial cyclic load equal to 40% from static load at failure 80 kPa) reach to about (100 kPa) with leaching of 3 days, pore water pressure in the model reaches to (120 kPa) at the end of the test. Figure 11.
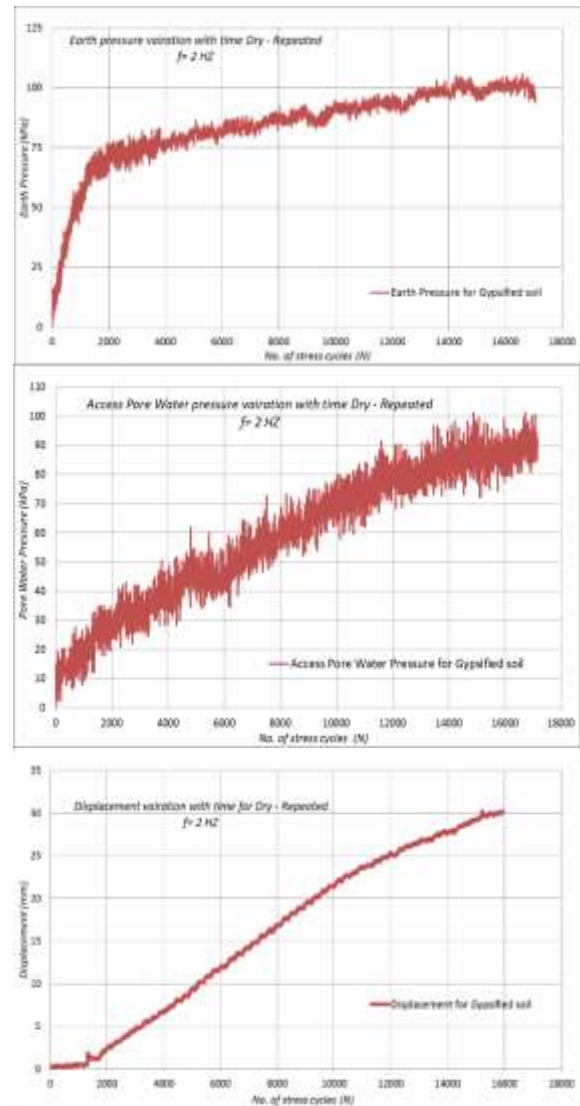
As shown in this model, the surface earth pressure with moderate amplitude has a disturbances during the test, while the core earth pressure was rapidly rising between 0 – 1000 sec then steady rising until reaches to the end of the test, the similar amplitude at pore water pressure with semi-linear relation, the displacement behaviour similar to earth pressure in relation, the behaviour of the model maybe attributed to the gypsified soil characteristics behaviour.

The surface earth pressure and displacement are (100 kPa) and 45 mm respectively. The earth pressure in model (M6) (under initial cyclic load equal to 60 kPa) reaches to about (50 kPa) after leaching in 3 days, and pore water pressure in the model reaches to (130 kPa) at the end of the test. Figure 12.
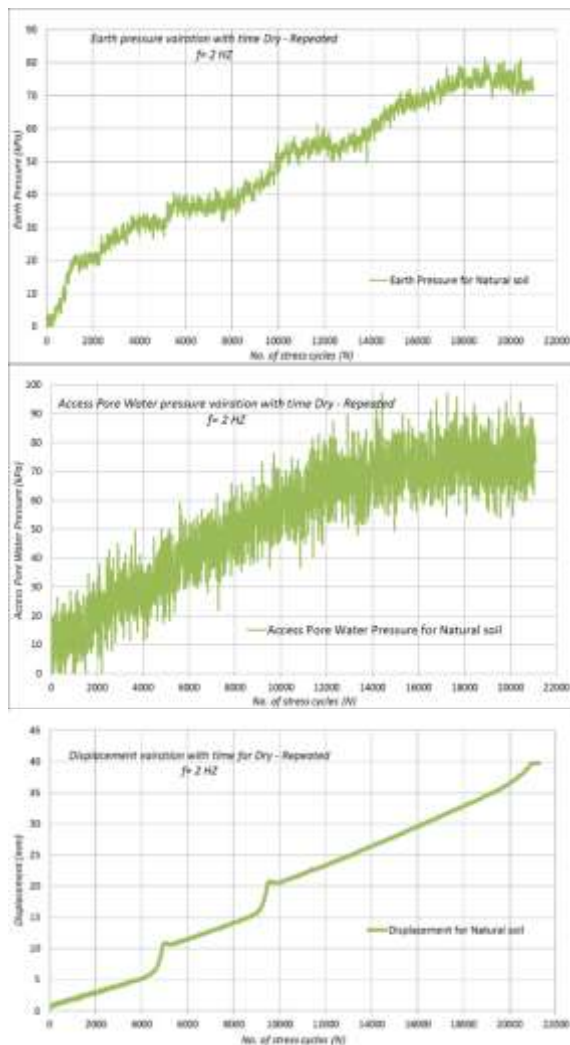
Figure 12 Earth and Pore Water Pressures and Displacement of M6 Model (Repeated - Leaching).

In this model, natural soil behaviour was clearly differ in amplitudes behaviour of the earth and pore water pressures, since little amplitude for surface and core earth pressures with some disturbances in relations during the test, while pore water pressure has higher amplitude than another types that means the pore water pressure carry out the most loads instead of sand particles in the leaching process, that attributed to the natural behaviour of gypsum comparing with artificial soil, also for the same reasons the displacement behaviour has two gaps at time 2500 and 4750 sec.

6. Chemical data for gypseous soil models of the testing program

For determination of SO_3 referring to (BS 1377: Part 3: 1990:5.2, sec.5.6.2) [11] and for determination of TDS referring to (BS 1377: part 3: 1990: 8.3), the tests according to [18], the three types of soil samples tested in soil lab. The method of testing to determine the TDS used TDS instrument directly from dissolved water

before, during and after each test [14, 19 and 20]. After presentation of the results of the TS, TDS, TSS and SO_3 interpretation shows that the results of these parameters in Table 4 as follows:

Table 4 testing results of samples at Leaching condition under monotonic and repeated loads.

Leaching		Monotonic	load
Sample	N_1	N_2	N_3
TDS(ppm)	250	1750	1800
TSS(ppm)	116.3	787.5	810
TS(ppm)	366.3	2537.5	2610
SO_3%	22.32	20.47	19.54
G.C.%	48	44	42
Leaching		Repeated	load
Sample	N_1	N_2	N_3
TDS(ppm)	350	1850	1900
TSS(ppm)	162.8	832.5	855
TS(ppm)	512.8	2682.5	2755
SO_3%	21.86	19.54	19.07
G.C.%	47	42	41

Where:

    TDS = Total dissolved salts for leachate water.
    TSS = Total soluble salts.
    Total Solids = TSS + TDS.
    G.C. = gypsum content.

7. Variation of TDS and Discharge during Leaching Process

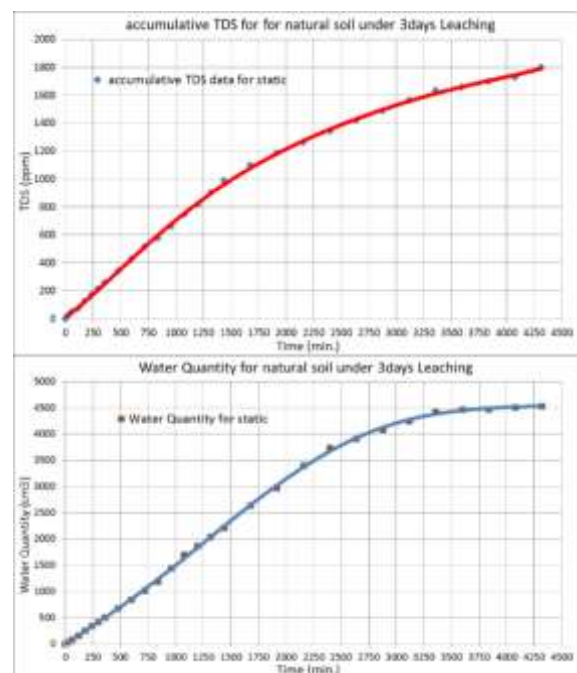The variation of the water quantity and TDS with time shown in (Figures 13 to 18) as follows:

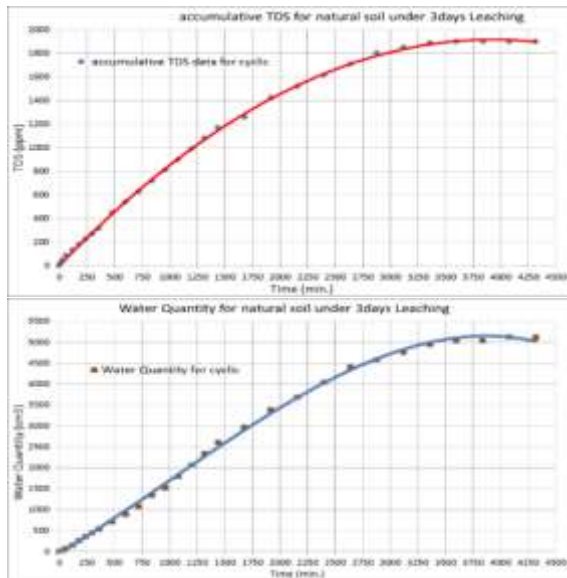**Figure 13 variation of TDS and water quantity (Q) with time for natural soil – Monotonic.**

Figure 14 variation of TDS and water quantity (Q) with time for natural soil – Repeated.

Figure 15 variation of TDS and water quantity (Q) with time for gypsified – Monotonic.
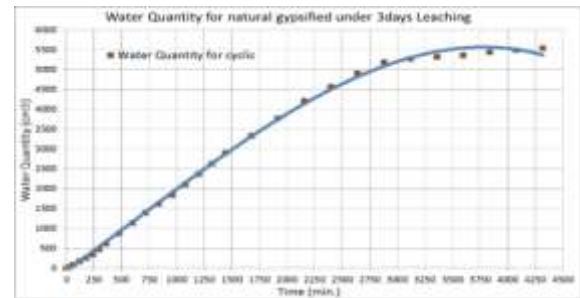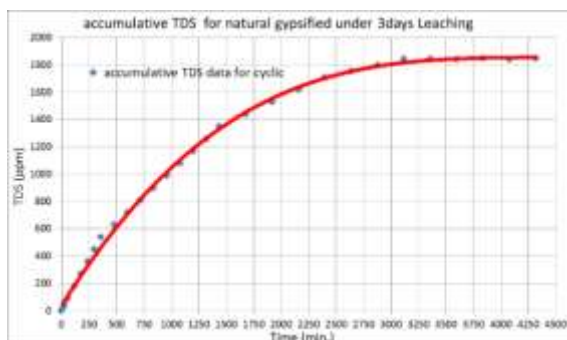

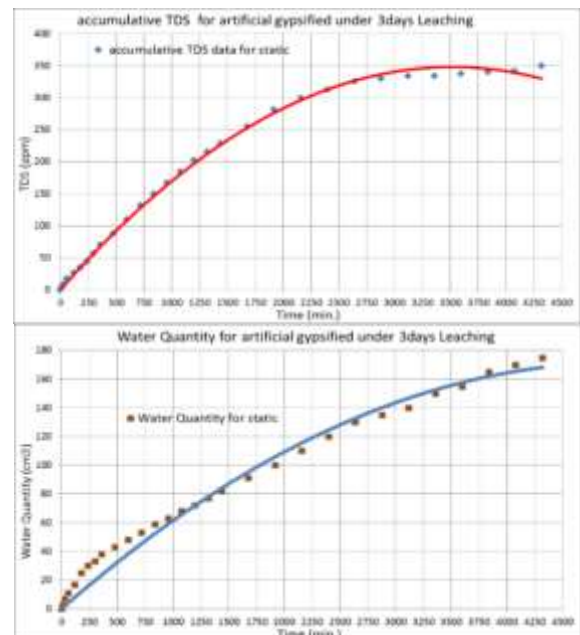**Figure 16 variation of TDS and water quantity (Q) with time for gypsified – Repeated.**

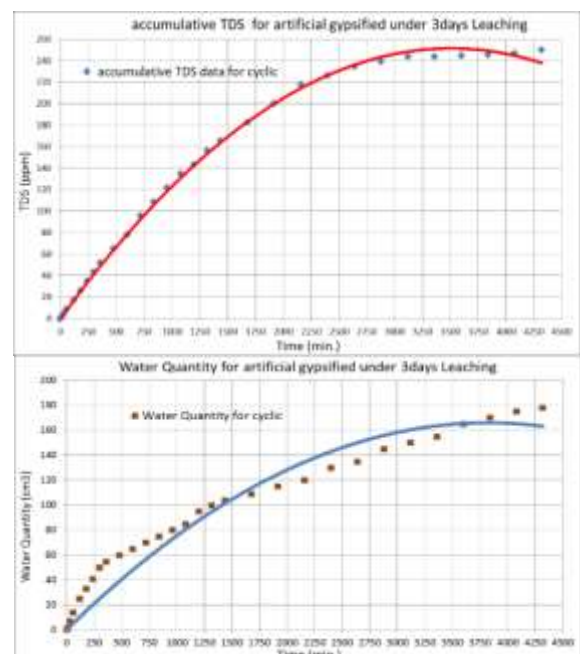**Figure 17 variation of TDS and water quantity (Q) with time for artificial – Monotonic.**

Figure 18 variation of TDS and water quantity (Q) with time for artificial – Repeated.

8. Statistical models

By using STATISTICA program for simulating the experimental work, the 3D contour areas show a good agreement with testing models in lab as shown in (Figure 19) [21]

The results of statistical program can be tabulated in the Table 5 to show the results and made a comparison with the same results obtained in the experimental work.

Table 5: four groups testing results of samples at leaching under monotonic and repeated loads.

Leaching		Monotonic	load
Sample	N_1	N_2	N_3
$Pe_{max.}$(kPa)	300	150	100
$De_{max.}$ (mm)	10	35	45
$T_{max.}$ (sec)	8000	2750	2250
Leaching		Repeated	load
Sample	N_1	N_2	N_3
$Pe_{max.}$ (kPa)	250	100	50
$De_{max.}$(mm)	5	30	40
$T_{max.}$(sec)	26000	8500	10500

where: $Pe_{max.}$ = maximum earth pressure (kPa).
        $De_{max.}$ = maximum Displacement (mm).
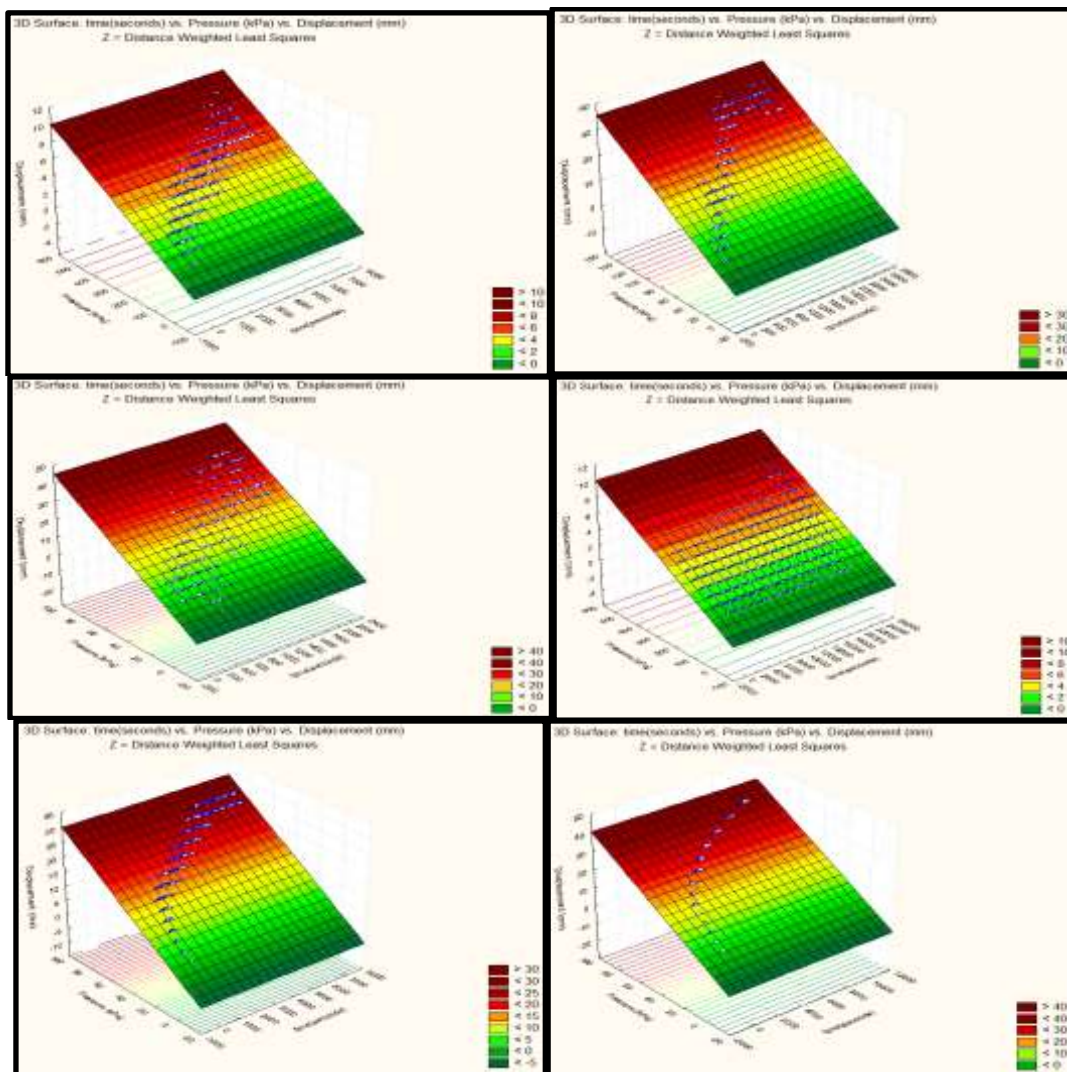 $T_{max.}$ = maximum Time of loading (sec.).

Figure 19: 3D contours areas for M1, M2, M3, M4, M5, and M6.

9. Interpretation Discussion

The soil behaviour at leaching condition was the weak condition for gypsified and natural soil models, at leaching process the bearing capacity of gypsified and natural soils were reducing to the minimum values, but the artificial soil appear that the bearing capacity was much larger difference than the other two types of soils. The displacements appears that has approximately a constant low values in artificial models, while the values increasing in the other two types of soil.

The pore water pressure in the natural and gypsified were clearly increasing with time with a large values comparing with artificial soil while the last one has a very low values in leaching condition that attributed to the higher ability for the strong bonds between gypsum and soil in artificial type of soil because of the treating (kneading and grinding and burning with 130C^o of its particle in the factories to produce a purity gypsum with a higher specific surface) that has a property to made a higher decreasing in the void ratio then decreasing in the permeability to the lower values with a higher increasing in bearing capacity and lower the displacement behaviour.

The TDS values affected also among the three types of soil models in the leaching process, the values for natural and gypsified were between 1750 to 1900 ppm while in artificial soil the values between 250 and 350 ppm, that means the artificial soil has wide different in some geotechnical characteristics such as permeability and void ratio, also collapsibility and compressibility, also in gypsum dissolution. The artificial soil behaviour give indication that this soil has very higher bearing capacity than natural and gypsified soils, especially when increasing gypsum content over than about 40%.

The statistical models shows that the soil models of three days of leaching for three different soil samples (natural gypseous soil, natural gypsified and artificial gypsified soils) under monotonic and repeated loading have a good agreement between the experimental and theoretical models with about 95%.

10. Conclusions

The artificial gypseous soil does not acceptable in geotechnical study, while the gypsified behaviour give a closest results comparing with natural gypseous soil.

Chemical and also physical changes was happening in the artificial gypseous soils. The artificial composition were changed to equilibrium condition after hydration process

before the preparing the sandy gypseous soil samples.

The behaviour of the natural gypsum are different after burning at (130C^o) with mixing and grinding to produce gypsum with very higher surface area because of the change happen at the structure of salts particles when lose the water between the bonds of the salt, this new properties give the artificial soil strong bonds with sand after reactions rapidly with adding of water.

The gypseous soil characteristics more accurate at larger scale model (1/10 full scale) than small sample models, and using the instrumentations that compatible in scale for measuring the soil properties.

It can be concluded after leaching process that the artificial gypseous soils has very high bearing capacity and very low displacement with very little permeability that deals to reducing water to flow through the soil, while the gypsified and natural soils have a high reduction of bearing capacity values and high increasing in permeability and displacement values at leaching condition.

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