Effect of Pollution on the Mechanical Properties of Clay Soil in Basrah (Garmatt Ali Zone), Iraq

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Abstract- **The effect of pore fluid chemistry on the engineering properties of soil in Garmatt-Ali zone of Basrah was investigated. The tested soil is described as silty clay of low plasticity. The pore fluid was altered to include distilled water, raw sewage, and solutions of various salts such calcium carbonate, magnesium sulphate, and calcium chloride. Also, the solutions of salts were used with different concentration (0.25, 0.5, 0.75, 1.0 normality).**
The prepared samples of soil were tested after different exposure periods.
The test program included determination of shear strength characteristics, consolidation characteristics, and Atterberg limits. The changes in shear strength, coefficient of permeability, void ratio – effective stress relationship, and Atterberg limits were recorded with the change in exposure period or the concentration of pore fluid solution.
Generally, it was found that there are reductions in the shear strength of soil when the pore fluid is changed from distilled water to solutions of salts or raw sewage. Also it was found that there is a change in the calculated values of permeability, upon changing the type of pore fluid. The coefficient of consolidation for polluted soil was found to be less than that for the reference samples with distilled water.

I. Introduction

In the solution of many engineering problems it is necessary to improve the properties of soil, whether as a foundation material or as a material of construction in embankments, dams, and other civil works. In these conditions, soil should be capable of sustaining the applied loads without serious deformation and it should maintain its strength and stability indefinite(1).

In general, the more desirable properties of a soil are mobilized and improved by a reduction in the moisture content. Conversely, an increase in moisture content is generally accompanied by deterioration of strength and bearing capacity, especially in cohesive soil (1) . Clays are composed of fine crystalline particles, which have been formed by chemical reactions between minerals. Clays are sticky when wet, and can be molded or shaped. When dry, they form hard clods or pattern of square cracks along the surface of the ground. Clays are usually hard to work and drain poorly (2). Some clay particles, especially those in the coarser clay fractions, are composed of minerals such as quartz and the hydrous oxides of iron and aluminum, another is the complex alumina silicates. Three main mineral types, kaolinite, illite, and montmorillonite are atpresent recognized, although other groups vary markedly in plasticity, cohesion, and adsorption. Kaolinite is the lowest in each case and montmorillonite is the highest. Therefore, it is important to know which clay type dominates or codominates any particular soil(3). Various types of activities including; agriculture, industry, and transportation, produce a large amount of wastes and new types of pollutants. Soil, air, and water have traditionally been used as sites for the disposal of all these wastes(4). Many of these are returned to the soil. However improper handling and disposal may cause soil pollution. Waste products may be in gas, liquid or solid form. The most important gases are carbon dioxide (CO2), carbon monoxide (CO), nitrogen dioxide (NO2) and sulfur dioxide (SO2)(4). Another type of pollutants that have effects on the engineering properties of soil is salts. Mathewson (5) found that calcium carbonate act as a source of calcium which leads to reducing osmosis stress (osmotic potential) between the water of soil and the clay layers. Also, he pointed out that the existence of calcium carbonate leads to lowering the value of plasticity index through its action as a carnivore materials to the deposit granules or they form covers for the granules. AL-Rawi et al.(6) reported that the depression of some soils is attributed to its high content of calcium carbonate. Daham (7) pointed out that the existence of calcium carbonate increases the deposit shearing resistance by forming covers surrounding deposit granules, so it stops the activity of salts and increases the attractive force between the particles of deposit. Giroud and Bottero(8) illustrated that the existence of chloride ion in deposits causes increase of its compressibility because of chloride salts existence such as sodium chloride causes flocculation processes and increasing in liquid limit. AL-Yasry(9) studied the effect of calcium chloride on soil permeability and found that the soil permeability increases with increasing calcium chloride content.

The shear strength of soil, on one hand, is one of the most important characteristics of many soil mechanics problems such as stability of slopes, ultimate bearing capacity, lateral earth pressure, and friction developed by piles. On the other hand, the consolidation of a soil stratum and subsequent settlement of the superstructure, also play an important role in foundation engineering.

The objective of this study is to examine the effect of changing the pore fluid chemistry on the shear strength, consolidation characteristics, and Atterberg limits of Basrah (Garmatt Ali zone) soil. The used pore fluids include raw sewage and solutions of different salts such as calcium carbonate, magnesium sulphate, and calcium chloride. Samples of soil are mixed with these fluids at the saturation level and then tested after different exposure periods.

II. Experimental Work

In this study, the tested soil was taken from Garmatt-Ali zone of Basrah. Generally, Basrah soils consist of soft and compressible stratum. Samples were collected, manually, from the upper 1.5m of soil strata. The disturbed samples of soil were packed in three bags (50-60)kg each and transported to the Soil Mechanics Laboratory at the University of Basrah. The excavating process was performed using a mechanical excavator (shovel). The specific gravity for soil specimens was determined according to ASTM D854-58(10). The liquid and plastic limits tests were performed according to ASTM D424-59 and ASTM D423-66(10), respectively. Grain size distribution was determined according to ASTM D422-79.(10) A set of sieves ranging in size from NO.4 to NO.200 was used and a pan was placed under the set to collect all grains passing NO.200 sieve. Hydrometer analysis (a sedimentation test) was used for soils passing sieve NO.200. The grain size distribution curve of soil sample is shown in Fig(1). According to the unified soil classification system, the soil is classified as (CL), silty clays of low plasticity. Unit weight and water content test were performed according to ASTM D2216-80 and ASTM D2927-71.(10) The moisture content was determined as the percentage of the mass of free water that can be removed from a material, usually by heating at

1050C(11). The moisture content-dry density relationship of soil was obtained by the standard Procter compaction tests following the procedure of ASTM 1557-79.(10) The unconsolidated undrained triaxial compression test(UU) was carried out according to ASTM D 2166-85(10) using a constant strain compression machine with a rate of speed 1mm/min. Consolidation and swelling test were carried out according to (ASTM D2435-70)(10) by using odometer cell. The period of test was 6 days for 6 load increments, each load was left for 24 hours. After the last increment was left on 24 hours, unloading was started by lowering the load every one hour. and swelling index reading were recorded. The results of these tests for the natural soil are shown in Table (1).

Table (2) illustrates the composition of the studied soil. The results were obtained by X-ray diffraction analysis. The test was carried out by the State Company of the Geological Survey and Mining in Basrah.(12)

The chemical analysis of the soil was also carried out by the State Company of the Geological Survey and Mining in Basrah and the results are shown in Table(3).

The characteristics of raw sewage were determined at the same day of collecting and as summarized in Table(4). Hydrogen ion activity (pH) was measured using PW 94.18- PHILIPS meter(13). Electrical conductivity (EC) was measured using TOA-CM-8ET-JAPAN meter(13). Total suspended solids (TSS) and total dissolved solids (TDS) were measured according to standard methods(13). Biological oxygen demand (BOD5) was measured using the Winkeler Azide Modification(13).

III. Preparation of Samples

The natural disturbed soil obtained from the site had been oven dried and manually pulverized. The specified amount of fluids, to reach the saturation level, was added at room temperature in low stream and thoroughly mixed by hand with the dry soil until uniform paste was obtained. The paste, then, was remolded into a sufficient number of large samples which were waxed and stored until the time of test. The fluids used included distilled water, raw sewage, and solutions of various salts such as calcium carbonate, magnesium sulphate, and calcium chloride.

Four different types of fluids had been used as a soil pore fluid in this study. These fluids are:

1) Distilled water
2) Calcium carbonate ($CaCO_3$) solution
3) Magnesium sulphate ($MgSO_4$) solution
4) Calcium chloride ($CaCL_2$) solution
5) Raw sewage

The concentrations of salt solutions were 0.2N, 0.5N, 0.75N, and 1.0N for the shear strength test and 0.5N and 1.0N for the consolidation test and Atterberg limits testes.

The specimens were tested after different time intervals from remolding. Table(5) gives the details of salts concentrations and period of exposure used in this study along with the results of UU and consolidation test.

IV. Results and Discussion

Atterberg Limits and Indices

The index properties of the natural soil used in this study are shown in Table (6). The liquid limit is 44, the plastic limit is 34 and the plasticity index is 10 for the natural soil. Therefore this soil can be classified according to the (unified classification system) as silty clay of low plasticity (CL). The concentration of calcium carbonate in this natural soil is 0.21 Normality, calcium chloride is 0.09 Normality and magnesium sulphate is 0.25 Normality.

After the soil samples were mixed with the used salts in different concentrations, the index properties became as depicted in Table (6). This table and Fig. (2) illustrate the effect of calcium carbonate on index properties of soil. It can be noticed that after adding this salt the values of liquid limit and plasticity index are larger than those of the natural soil. This may be attributed to the low solubility of calcium carbonate as powder in water which leads to increase the surface area of clay soil then to increase the water content needed to reach the saturation state. However increasing the salt concentration from 0.5N to 1.0N causes the decrease of L.L and P.I.

Also it is clear that the plastic limit of salted soil is lower than that of the natural soil, due to that any type of added materials to the natural soil will adsorb some water from the natural soil. The effect of adding calcium chloride to the natural soil on the atterberg limits is shown in Table (6) and Fig. (3). The same behavior is noticed for soil polluted with this salt as that of calcium carbonate.

Table(6) and Fig.(4) illustrate the effect of magnesium sulphate on atterberg limits of the tested soil. It can be noticed that the liquid limit and plasticity index for polluted soil are larger than those of the natural soil, and the plastic limit is lower than that of the natural soil. Also it can be noticed that the liquid limit and plasticity index increase with the increase of magnesium sulphate concentration, while plastic limit remains constant with increasing the salt concentration. This result can be justified since the magnesium ion many restrict the movement and availability of water. Soils with high Mg are soils having high water retention, slow to very slow infiltration rate and hydraulic conductivity which are associated to low porosity and to deficient internal drainage.(14)

V. Shear Strength of Soil

The results of unconsolidated undrained (UU) traixial compression tests for soils polluted by salts are shown in Tables (7), (8), and (9).

Fig (5) illustrates the variation of shear strength (Cu) of soil with time for two samples, in the first the pore fluid is distilled water while in the second is raw sewage.

The shear strength (Cu) of soil with distilled water is 24.45 kN/m2 and the internal angle of friction is u=0. Cu is found to increase with time. The shear resistance of a soil in an undisturbed condition may be considerably greater than its strength after being remoulded at the same moisture content. The shear strength of the remoulded sample frequently increases with time after remoulding without any change in moisture content.(15) The entire undisturbed strength may not be regained. This strength regain has been explained either by changes in particle arrangement and interparticle forces, or by changes in adsorbed water.

Adding raw sewage to the investigated soil leads to increase of shear strength of soil as compared to the reference sample (Fig.5). This increase may be attributed to that the organic chemicals(16), which exist in raw sewage, dissociate in water to produce cations which may improve soil structure.

From Tables (7), (8), and (9) it can be seen that the Cu values of the soil polluted by the three salts $CaCO_3$, $MgSO_4$, and $CaCL_2$ are less than that for reference sample. Also Cu decreases with the increase of the exposure time. Increasing the concentration of $MgSO_4$ and $CaCL_2$ solutions from 0.25N to 1.0N leads to a decrease of Cu values, while increasing the concentration of $CaCO_3$ solution causes an increase of Cu of soil.

The reduction in shear strength, as compared with reference sample, of polluted soils may be attributed to;

1- the flocculated structure of Ca or CO ions may replace the ions which are originally present on the clay surface. The resultant flocculated structure is expected to have high void ratio(17),

2- the magnesium is highly hydrated and the magnesium ions have high water retention then causing clay peptization and affecting the porosity and the hydraulic conductivity of the soil(18), and

3- the high solubility of calcium chloride in water leads to dispersion of the soil and then increases the permeability and consequently decreases the shear strength of soil(2).

VI. Consolidation properties of soil

Table (10) gives the consolidation characteristics of the soil with different pore fluids. It can be seen that both consolidation coefficient (CV) and compression index (CC) decrease for the polluted soil as compared with the reference sample having the distilled water as pore fluid. These results are due to the precipitation of different salts in voids between the particles of soil. However, increasing the concentration of the three used salts from 0.5N to 1.0N leads to increase CV and CC, although, their values remain below those for the reference sample.

The effect of pore fluid chemistry on the swelling index (Cs) is also illustrated in Table (10). Cs increases for soils polluted with $MgSO_4$ solution as compared with the reference sample. Increasing the concentration of this solution from 0.5N to 1.0N leads to further increase in Cs. However, 0.5N solutions of $CaCO_3$ and CaCL2 in addition to the raw sewage cause Cs to decrease. Increasing the concentration of solutions of these two salts to 1.0N increases Cs to larger value than that for reference sample.

Figs (6) and (7) shows the relationships between the effective stress and void ratio for soils treated with distilled water, raw sewage and $CaCO_3$ solutions. As compared with the reference soil sample with distilled water, the void ratio is larger for soil polluted by raw sewage and smaller for soil polluted by $CaCO_3$ solutions. Increasing the concentration of $CaCO_3$ solution from 0.5N to 1.0N further decreases the void ratio of soil. This may be attributed to the precipitation of calcium carbonate in the soil voids.

Conclusions

Based on the present experimental investigation, and limited to both the materials tested and the tests procedures employed, the following conclusions could be drawn:

1- The shear strength of soil is affected upon by both type and concentration of the chemicals in the pore fluid and the time of exposure to these chemicals.

2- Generally, there are reductions in the shear strength of soil when its pore fluid changed from distilled water to $CaCO_3$, $MgSO_4$, and $CaCl_2$ solutions.

3- The shear strength of soil with pore fluid of $CaCO_3$, $MgSO_4$, and $CaCl_2$ solutions decreases as the time of exposure increases.

4- When the pore fluid is raw sewage, the shear strength of soil increases with the time of exposure.

5- The increase of solution concentration leads to an increase in shear strength of soil in case of $CaCO_3$ but it remains smaller than the natural soil and a reduction in shear strength for both $MgSO_4$ and $CaCl_2$.

6- The consolidation coefficient (CV) and the compression index (CC) decrease when the pore fluid changes from distilled water to solutions of $CaCO_3$, $MgSO_4$, $CaCl_2$, and raw sewage. For high concentration of salts CV and CC values tend to increase considerably.

7- For the case of $MgSO_4$ solution the swelling index (CS) of soil increases higher than the value of soil mixed with distilled water. However, for other solutions CS, value is lesser than that of reference sample.

8- One – dimensional consolidation of the samples of different pore fluids showed that the relationship between voids ratio and logarithm of consolidation stress is dependent on both the type and concentration of the chemicals in the pore fluid.

VII. References

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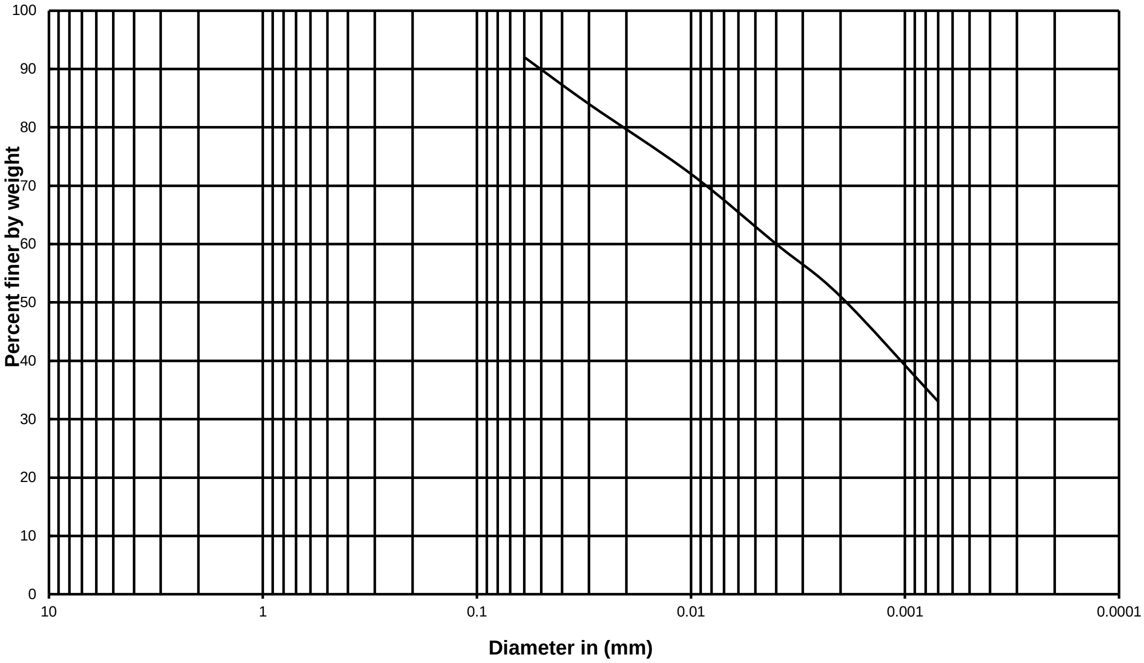

Fig. 1: Grain size distribution

Table I Engineering properties of investigated soil

Property	Value
Depth of sampling(m)	1.5
Liquid limit L.L.(%)	44
Plastic limit P.L.(%)	34
Plasticity Index P.I.(%)	10
Specific Gravity (GS)	2.65
Passing N0.200 sieve(%)	51
Unified Classification system	CL
Natural moisture content (%)	21
Bulk density (gm/cm^3)	2.0
Dry density (gm/cm^3)	1.66
Saturation density (gm/cm^3)	2.05
Optimum moisture content (%)	19.73
Maximum dry density (gm/cm^3)	1.635
Saturation moisture content %	32
Voids ratio(original)	0.6

Table II Mineral analysis of investigated soil

	Mineral	Rate %
Clay Mineral	Montmorillonite	12
	Kaolinite	2
	Illite	8
	Playorskite	7
	Chlorite	2
other Minerals	Calcite	18.8
	Gypsum	1.1
	Quartz	37
	halite	1.1
	feldspar	4

Table III Chemical Analysis of Investigated Soil

Parameter	Value
Mg (%)	0.1300
Ca (%)	1.7222
CL (%)	0.24282
HCO_3 (%)	0.0183
CO_3 (%)	0
pH	7.81
Cu (%)	$7*10^{-4}$
Mn (%)	0.034796
Zn (%)	0.0023
Na (%)	0.5370
K (%)	0.0896
Total salts %	1.856
Organic matter %	0.284
Ni (%)	0.064699
Pb (%)	$11*10^{-4}$
Cd (%)	$18*10^{-4}$
$CaCO_3$ (Normality)	0.21
$MgSO_4$ (Normality)	0.25
$CaCl_2$ (Normality)	0.09

Table IV Raw Sewage Characteristics

Parameter	Value
pH	8.00
T.S.S.	1000 mg/l
T.D.S.	600 mg/l
BOD	50 mg/l
EC	1040 mg/sec

Table V Material Concentration and Period of Exposure

Material	Concentration	Test	Period of exposure					
			24h	1w	2w	3w	4w	5w
Distilled water		UU	x	x	x	x	x	x
		Consolidation	x	-	-	-	-	-
Raw sewage		UU	x	x	x	x	x	x
		Consolidation	x	-	-	-	-	-
$CaCO_3$	0.25N	UU	x	x	x	x	x	x
		Consolidation	-	-	-	-	-	-
	0.5N	UU	x	x	x	x	x	x
		Consolidation	x	-	-	-	-	-
	0.75N	UU	x	x	x	x	x	x
		Consolidation	-	-	-	-	-	-
	1.0N	UU	x	x	x	x	x	x
		Consolidation	x	-	-	-	-	-
$MgSO_4$	0.25N	UU	x	x	x	x	x	x
		Consolidation	-	-	-	-	-	-
	0.5N	UU	x	x	x	x	x	x
		Consolidation	x	-	-	-	-	-
	0.75N	UU	x	x	x	x	x	x
		Consolidation	-	-	-	-	-	-
	1.0N	UU	x	x	x	x	x	x
		Consolidation	x	-	-	-	-	-
$CaCl_2$	0.25N	UU	x	x	x	x	x	x
		Consolidation	-	-	-	-	-	-
	0.5N	UU	x	x	x	x	x	x
		Consolidation	x	-	-	-	-	-
	0.75N	UU	x	x	x	x	x	x
		Consolidation	-	-	-	-	-	-
	1.0N	UU	x	x	x	x	x	x
		Consolidation	x	-	-	-	-	-

h : hour
w : week
x : test is done
- : test is not done

Table VI Atterberg Limits for Natural and Polluted Soil Samples for 24 Hours Period of Exposure

Type of Soil	Concentration normal	Liquid Limit	Plastic Limit	Plasticity Index
Soil with distilled water	Natural	44	34	10
Soil polluted by $CaCO_3$	0.5N	55	29	26
	1.0N	46	30	16
Soil polluted by $CaCl_2$	0.5N	46	21	25
	1.0N	43	24	19
Soil polluted by $MgSO_4$	0.5N	51	27	24
	1.0N	58	27	31

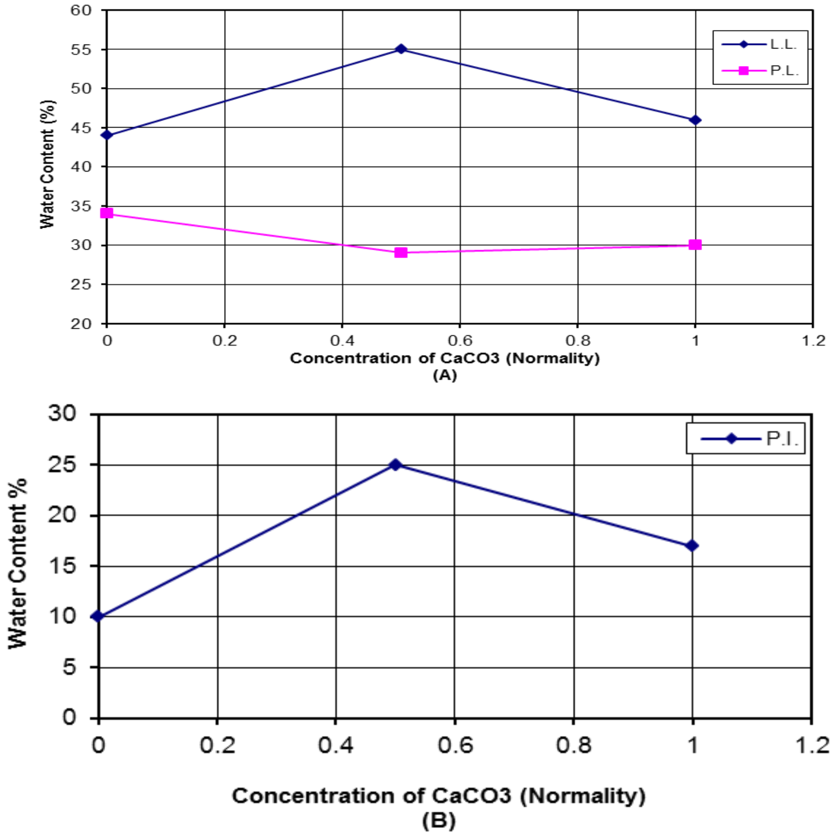

Fig. (2)Effect of Calcium Carbonate on Atterberg Limits

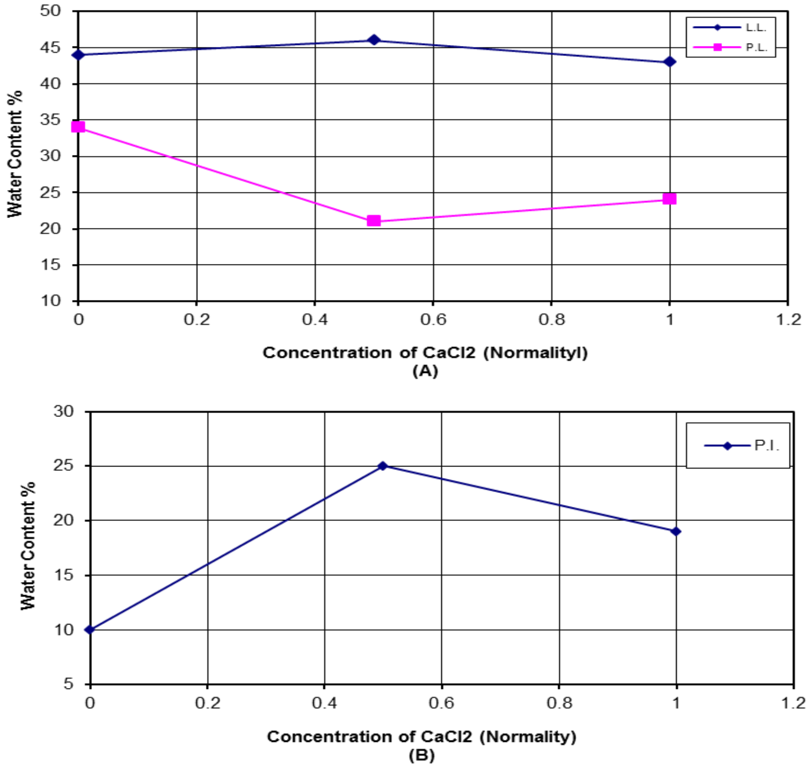

Fig (3) Effect of Calcium Chloride on Atterberg Limits

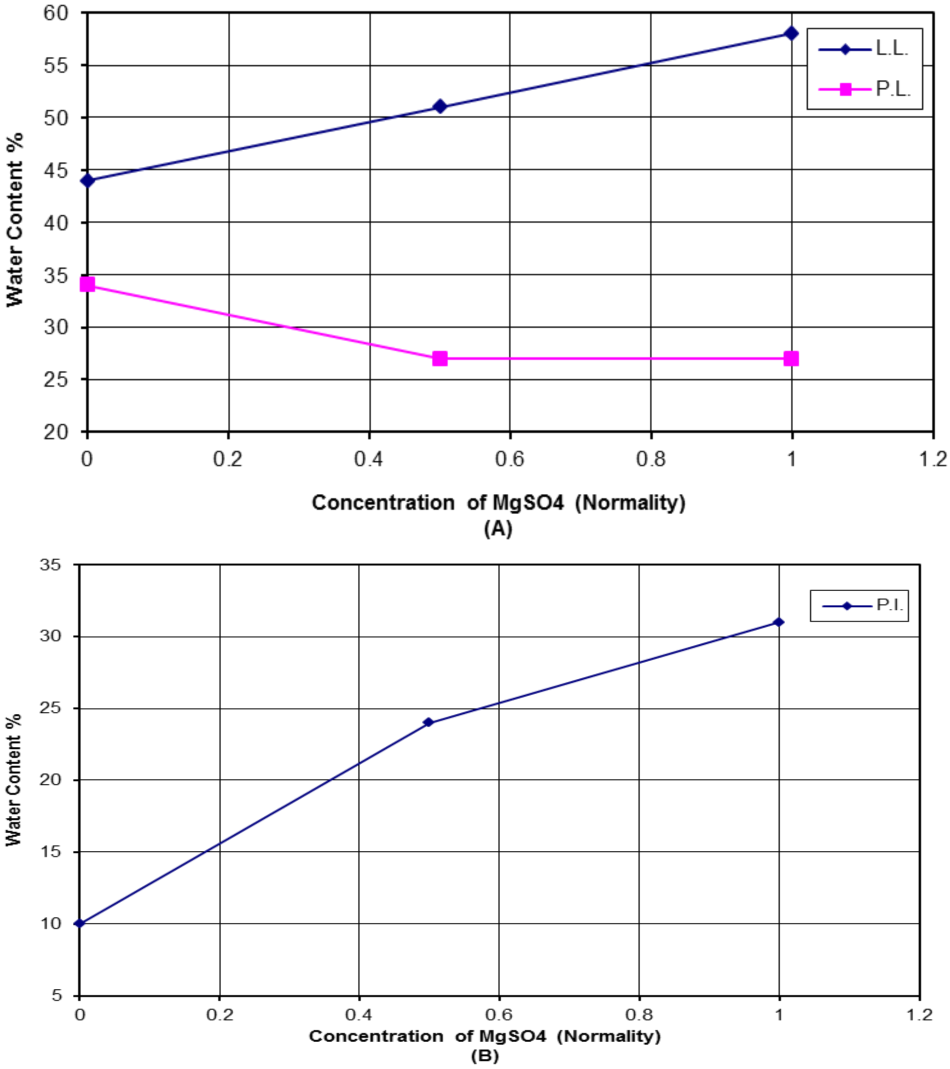

Fig (4) Effect of Magnisum Sulphat on Atterbarg Limits

Table (8) Shear Strength of Soil Polluted by Magnesium Sulphate

Concentration of Salts	Value of (Cu) kN/m^2											
	24 Hours		1 week		2 weeks		3 weeks		4 weeks		5 weeks	
	Individual	Average	Individual	Average	Individual	Average	Individual	Average	Individual	Average	Individual	Average
0.25 N	20.0	24.3	18.9	19.55	17.5	18.0	12.5	13.1	11.8	12.3	11.0	11.5
	24.0		19.6		18.2		12.8		12.2		11.6	
	29.5		20.2		18.3		13.9		12.9		11.9	
0.5 N	20.2	20.7	18.2	18.6	16.9	17.5	11.8	12.15	10.7	11.2	9.9	10.2
	20.6		18.4		17.6		12.0		11.1		10.3	
	21.3		18.6		17.9		12.65		11.8		10.4	
0.75 N	17.5	18.0	17.2	17.5	16.3	16.5	10.7	11.0	9.8	10.3	6.9	7.4
	17.9		17.5		16.5		10.9		10.4		7.5	
	18.6		17.8		16.7		11.4		10.7		7.7	
1.0 N	16.1	16.5	15.9	16.3	15.4	15.8	9.8	10.3	8.8	9.4	5.9	6.6
	16.6		16.4		15.7		10.2		9.2		6.4	
	17.0		16.6		16.3		10.9		10.1		7.5	

Table (7) Shear strength of soil polluted by calcium carbonate

Concentration of Salts	Value of (Cu) kN/m^2										
	24 Hours		1 week		2 weeks		3 weeks		4 weeks		5 weeks
	Individual	Average	Individual	Average	Individual	Average	Individual	Average	Individual	Average	Individual
0.25 N	19.8	20.2	12.2	12.5	11.7	12.1	11.85	11.95	11.6	11.8	11.2
	20.1		12.4		12.0		11.9		11.8		11.6
	20.7		12.9		12.6		12.1		12.0		11.7
0.5 N	20.53	20.4	13.4	13.75	13.0	13.27	12.9	13.07	12.7	13.0	12.85
	20.4		13.85		13.3		13.0		12.9		12.9
	20.6		14.0		13.51		13.3		13.4		12.8
0.75 N	20.2	20.5	13.5	14.0	13.4	13.65	13.1	13.35	13.0	13.3	12.8
	20.6		13.9		13.8		13.3		13.25		13.1
	20.7		14.6		13.75		13.65		13.65		13.49
1.0 N	20.3	20.6	14.2	14.6	13.4	14.0	13.5	13.75	13.3	13.5	13.25
	20.7		14.6		14.1		13.8		13.4		13.35
	20.8		15.0		14.5		13.95		13.8		13.75

Table (9) Shear Strength of Soil Polluted by Calcium Chloride

Concentration of Salts		Value of (Cu) kN/m²											
		24 Hours		1 week		2 week		3 week		4 week		5 week	
		Individual	Range	Individual	Range	Individual	Range	Individual	Range	Individual	Range	Individual	Range
0.25 N		16.9		14.0		12.8		10.5		9.3		8.2	
		17.5	17.4	14.6	14.5	12.1	13.25	10.8	10.75	9.7	9.8	8.5	8.7
		17.9		14.9		13.85		10.95		10.4		9.4	
0.5 N		15.2		13.5		12.4		9.7		9.0		7.4	
		15.6	15.7	13.8	14.0	12.7	12.65	9.9	9.95	9.3	9.25	7.7	7.7
		16.3		14.7		12.85		10.25		9.45		8.0	
0.75 N		14.1		12.7		10.96		9.2		8.3		6.7	
		14.3	14.4	12.9	13.0	11.25	11.35	9.4	9.4	8.5	8.6	6.9	7.0
		14.8		13.4		11.83		9.6		9.0		7.4	
1.0 N		11.32		9.53		7.4		6.25		6.15		5.5	
		11.41	11.52	9.8	9.89	7.9	7.85	6.75	6.95	6.5	6.55	5.8	5.8
		11.83		10.35		8.25		7.85		7.0		6.2	

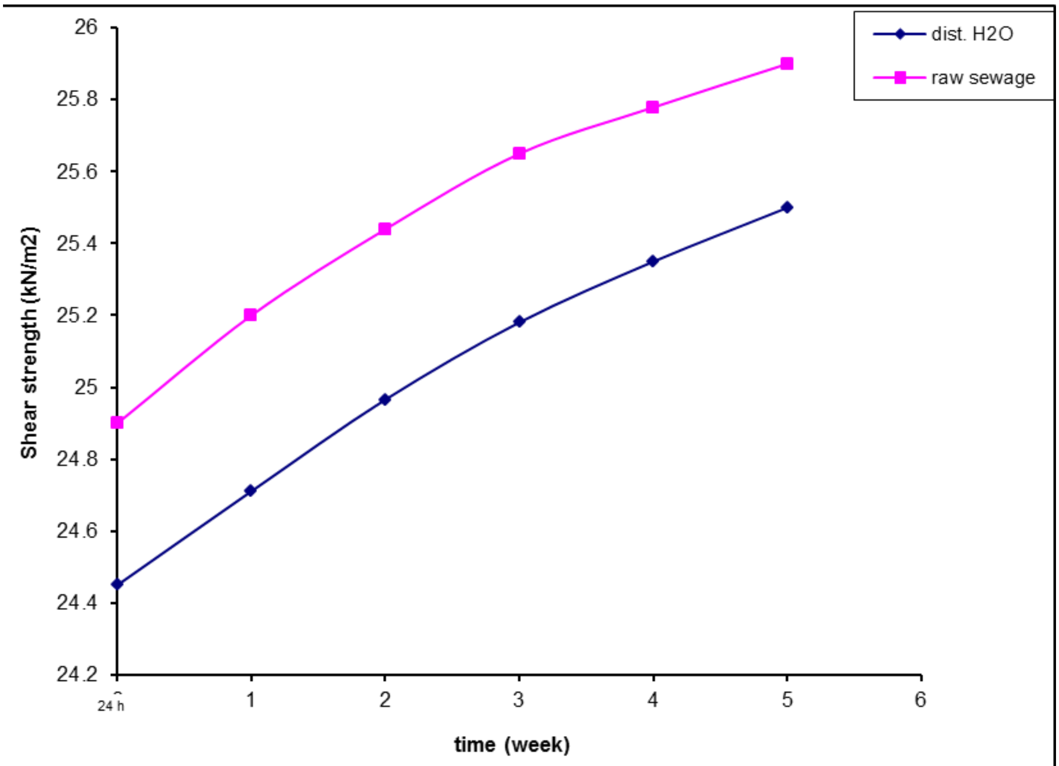

Fig. (5) Shear strength - time relationship of soil with distilled water and raw sewage as pore fluid

Table X Consolidation Characteristics of Clay Soil

Concentration	Fluid types	C_V m^2/year	C_C	C_S
	Distilled water	6.113	0.296	0.043
	Raw sewage	1.783	0.22	0.029
0.5 N	**$CaCO_3$**	0.883	0.274	0.010
	$MgSO_4$	1.586	0.203	0.056
	$CaCl_2$	1.380	0.190	0.030
1.0 N	**$CaCO_3$**	2.526	0.283	0.048
	$MgSO_4$	4.792	0.252	0.075
	$CaCl_2$	4.350	0.230	0.060

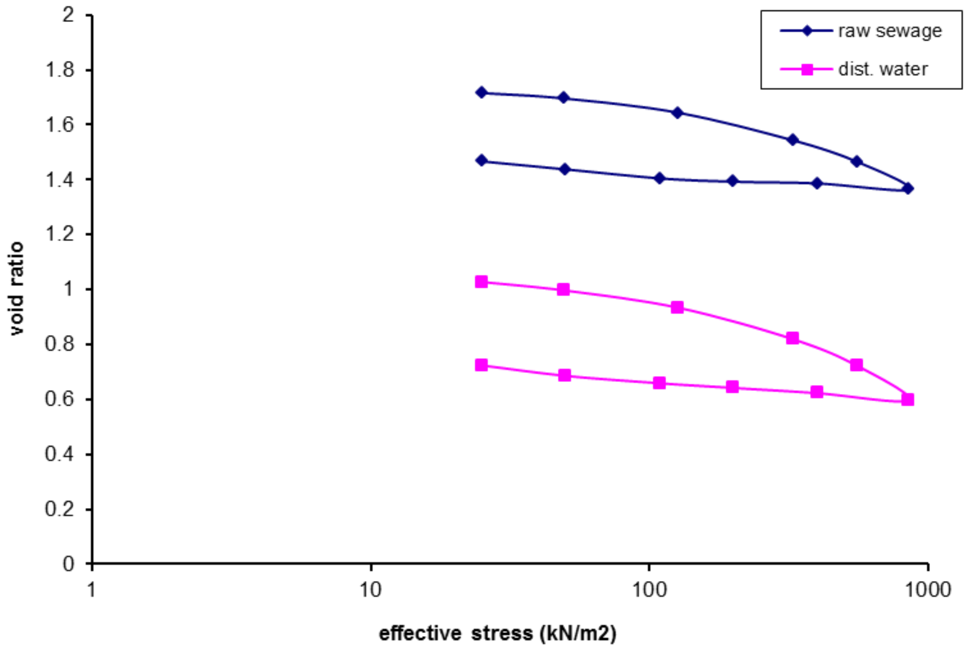

Fig. (6) effective stress -void ratio relationship soil with distilled water and raw sewage

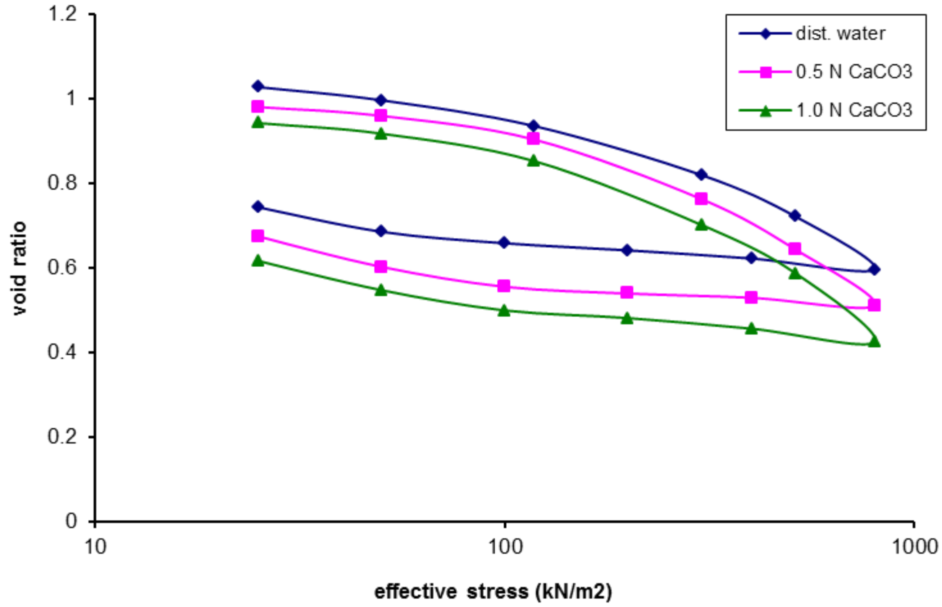

Fig. (7) effective stress - void ratio relationship for soil with distilled water and CaCo solution