CHEMICAL AND PHYSICAL EFFECTS ON ENGINEERING PROPERTIES OF GYPSEOUS SUB-GRADE SOIL

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Abstract:

Using unsuitable material will often result in premature failure of pavement surface and reduction in the ability of pavement to carry the design traffic load.
The use of locally natural materials of gypseous soils is necessary to minimize the construction cost. The chemicals and physical tests carried out on this gypsies soil brought from western region of Iraq indicates clayey sand particles with 63% gypsum content. The chemical and physical effects on behavior of gypseous soil is studied by leaching using modifying the standard odometer apparatus to be able for testing a large cell of CBR mold under loading values (44.5;178;311)N with different hydraulic gradient values (2;6;10) for sixty days. For this purpose, fifty four CBR samples are prepared at a 95% relative to modified AASHTO compaction. The geotechnical properties of wetting gypseous soils due to the large damages that affect the structures founded and constructed on it. It is observed that the total leaching strain increases, as the surcharge load and hydraulic gradient increase. The results show that the value of CBR increasing with increasing compactive effort (dry density) after leaching gypseous sub grade soil. Decreasing voids particles by compactive effort, cause increase cementing materials which bond the soil particles together and increasing the stiffness. This can has an economic effect in pavement design as this increase in CBR% can transfer unsuitable material into suitable sub-grade gypsum soil.

Keywords: Road construction; flexible pavement; Sub-grade; Gypsum soil; CBR.

التأثير الكيمياوي و الفيزياوي على الخصائص الهندسية لتربة أساس الطريق الجبسية

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الخلاصة :

استخدام مواد غير ملائمة ضمن طبقات الطريق في التصميم تؤدي إلى عدم تحمل الأثقال المسلطة عليه و بالتالي حصول فشل في الطريق. استخدام التربة الطبيعية ضمن موقع التنفيذ (التربة الجبسية) يقلل من كلفة المشروع. لذا تم إجراء الفحوصات الفيزيائية و الكيميائية لتربة موقع المشروع حسب نظام التصنيف الموحد فكانت من نوع تربة رملية طينية و تحتوي على جبس بنسبة ٦٣% في المنطقة الغربية من العراق. تناولت هذه الدراسة تأثير الخواص الفيزيائية و الكيميائية من خلال غسل التربة

الجبسية باستخدام قالب فحص نسبة التحمل الكاليفورني تم تحويره لتسليط الأحمال التصميمية المناظرة لإنشاء طريق وهي (٤٤.٥: ١٧٨ :٣١١.٥) نيوتن و بتسليط انحدار مائي قدره (٢و٦ و١٠) .و لهذا الغرض تم تحضير ٥٤ نموذج و كانت نسبة الرص ٩٥% و الفترة الزمنية لغسل التربة الجبسية بحسب الانحدار المائي المذكور هو لغاية ٦٠ يوم. أظهرت التجارب ضعف التربة الجبسية حين تتعرض للماء و حصول الانهيار فيها خصوصا بزيادة الانحدار الهيدروليكي و الأحمال المسلطة . أجريت مقارنة لنسبة التحمل الكاليفورني للتربة الجبسية بعد الغسل مع مقدار كثافتها الجافة بنسبة رص ٩٥% أظهرت النتائج زيادة نسبة التحمل الكاليفورني مع زيادة نسب الرص و الكثافة الجافة للتربة الجبسية بعد الغسل. و بذلك بالإمكان استخدام التربة الطبيعية في الموقع كأساس لطبقات الطريق بدلا من استبدالها.

Introduction:

Soil is a foundation material for all structures, as highways and airports which may be the form of undisturbed in situ sub-grade material or transported and reworked embankment material. Gypsum is one of the soluble salts that can have determined effects on pavement, building and earth structure, (Fooksand French, 1977) and (Subhi, 1987).

When salt bearing soils are subjected to soaking, increases in moisture content can take place causing dissolution of some gypsum. In practice, soaking can take place in different ways such as local shallow wetting, deep local wetting, slow and uniform rise of ground water level. The magnitude and character of such development depend on the type of soil, initial gypsum content, relative amount of leached salts, soil properties, and acting loads, (Petrukhin V.P. and Boldyrev C.B., 1978).

Many studies have been made on gypseous soils in Iraq because they are covering a wide area of the surface in Iraq. The gypseous soils in Iraq are distributed in Mousel; Baigi; Tikrit; Samarah; north west of Baghdad; Anna; Heat; Ramadi; Faluja; Najef and Nassirya,(El-Janabi,1995).

(Al-Jumaily ,1994) reported that the effect of gypsum content on soil properties depends upon the amount of salt content, purity of water and its salt concentration, flow velocity and the area of gypsum in contact with water.

(Al-Qaissy, 1989) dealt with a clayey silty soil with (1,9,18 and 38%) gypsum content and he found a reduction of 0.15 in specific gravity when the gypsum content increases from 1% to 38 % .

(Subhi, 1987) found for compacted soil that the maximum density decreases with the increases in gypsum content, while the optimum moisture content decrease or increases with the increase in gypsum content depending on the grain size of the added gypsum.

(Sheika, 1994) found out that the compression index decreases with the increase in gypsum content due to the increase in the cementing bound of gypsum .

(Barazanji ,1984) investigated the infiltration characteristics of Al-Jazirah gypsum soil .He showed for some soil texture and initial water contents that the infiltration rate increases with the increase in gypsum content.

(Klein and Hurlbut,1985) reported that gypsum contains: 32.6% Calcium Oxide (CaO), 46.5% Sulpher trioxide (SO_3) and 20.9% combined water (H_2O).As a result of dehydration gypsum ,the first 1.5 molecules of (H_2O) in gypsum are lost relatively continuously between 0^oC and about 65^0C perhaps with only slight changes in the gypsum structure leading to bassanite ($CaSo_4.1/2\ H_2O$).At about 70^0C, the remaining (1/2 H_2O) molecule in bassanite is still retained relatively strong ,but at about 95^0C,it is lost and the structure transforms to that of anhydrite ($CaSo_4$).

(Al-Mufty ,1997) reported that a large amount of the hydration water molecules are lost if gypsum is heated to (170^0C), forming plaster of pairs (Bassanite),($CaSO_4.1/2\ H_2o$), but if heating continues to more than (200^0C),anhydrite starts to form with the complete loss of hydration water

Anhydrite gypsum ($CaSO_4$) having specific gravity of (2.96), is heavier than gypsum having specific gravity (2.32).the chemical proportions of gypsum and anhydrite are shown in **Table (1).**
(Harwood, 1988) pointed out that cements are the crystals, which grow into existing pore space. They may or may not, totally occlude the available pore space.

(James and Kirkpatrick, 1980) pointed out that the rate of solution of many substances is determined by the rate of transport of soluble components across the boundary layer attached to the dissolved solid.

Gypsum is sparing soluble salt, its solubility in pure water at 20^oC is (2gm/l), but it varies with the presence of other salts and temperature (Nashat, 1990).
(James and Lupton, 1978) carried out several experiments leading to the following general equation governing the solution of soluble minerals:

$$d_m/d_t = kA(C_s - C)^m \qquad \ldots\ldots(1)$$

t = time, second

A= area of gypsum,(m^2)

C_s = the saturation concentration in solution,($^{Kg}/_L$)

C = the concentration in solution, ($^{Kg}/_L$)

m= constant equal (1) for gypsum ($CaSO_4.2H_2O$)

K= the solution rate constant, ($^m/_{sec}$) for gypsum and ($m^4/_{sec}$) for anhydrite.

They added that the solution rate constant (k) depends on many factors such as:

(1) Flow Velocity of water: the rate of dissolution of gypsum increases linearly as the flow velocity increases from zero to 0.7($m/_s$).
(2) Construction of other Salts in the soil: the dissolution rate (K) increases with the increase in the concentration of NaCL.
(3) Temperature: they are found that the dissolution rate constant (K) at gypsum increases 3.25 times when the temperature increases from 5^0C to 23^0C.

Ramiah,(1982),found out that the solubility rate of gypsum increases to its maximum when the temperature increases to 40^oC then it decreases after that degree.
Razouki et.al.1994 studied the problems of gypsiferous soil in Iraq. They concluded that increasing the applied pressure increases the rate of dissolution of gypsum in water.

Sheikha 1994 concluded that the rate of total soluble salts is high for lower values of permeability, and low for high values of permeability.
The presence of gypsum in a soil, change the original engineering properties of the soil.
The foundation problems associated with a collapsible soil have been correlated with collapse potential (C_p). Clemene and Finber, 1981 defined the collapse potential, as follows:

$$C_p = {}^{\Delta}{}_{ec} / (1 + e_o) = \Delta H / H_o \qquad \ldots\ldots (2)$$

Where:
C_p = collapse potential
Δ_{ec}= change in void ratio upon wetting
e_o = natural void ratio
ΔH = change in height upon wetting
H_o = initial height

(Lambe and Whitman, 1979) reported that the leaching of the salt in the pore fluid of soils containing soluble salts could cause an increase in the permeability.
(Arutyyan and manukyan ,1982) reported that during the process of dissolution of gypsum from the soil, the permeability increases sharply first but subsequently, decreases then remains constant.
(El-Rawi,1995) pointed out that such an increase in CBR can have a serious economic effect in pavement design as this increase can transfer unsuitable sub-grade soil after SORB specification (1983) with CBR< 4% into suitable sub-grade soil with CBR > 4% .

The purpose of this study is to investigate the chemical and physical effects on the properties of gypsum soil and use it as a suitable subgrade in civil engineering projects.
So that ,it is very important to study the characteristics of gypseous soils and their soluble salts constituents in order to understand their behavior under different conditions to have a proper design for foundation and sub grade.

Materials Properties and Testing Program:

The experimental work were carried out on the soil samples taken from Al-Anbar University at Al-Ramadi city .Samples were taken from (0.75-1.25m) depth below the natural ground surface, and then placed in double nylon bags. The soil samples were taken to the transportation laboratory (Al-Mustansiria University) for testing. Disturbed samples are mixed carefully by hand before conducting any test to be homogeneous.
Ordinary drinking water is used through this study when preparing the specimens and leaching process.

Classification tests are performed including physical, chemical tests and X-ray diffraction test. This test was carried out at the State Company of Geological Survey and Mining in Baghdad. The physical tests include specific gravity, Atterberg limits, grain size distribution and water content, **Figure (1)** and **Table (2).** A series of leaching tests is conducted using special equipment by modifying CBR molds,

Table (2), shows the results of physical and chemical properties of the soil samples used as a sub-grade material. The entire tests were carried out according to ASTM vol. 04.08, (1989) and B.S, 1377, (1975) standard specifications. Specific gravity is determined according to BS 1377, (1975) test No.6B .But instead of distilled water used Kerosene because of dissolving action of gypsum by water(Head,1980). Grain size distribution is determined according to (ASTM 422-1979) but with dry sieving. Grain size distribution curve for soil samples is shown in **Figure (1).** In this study, the gypsum content is done according to the method presented by (Al-Mufty and Nashat, 2000):

$$x\% = \frac{W45c - W105c}{W45c} \times 4.778 \times 100 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

X = gypsum content by weight, %

$W_{45}{}^{o}{}_{C}$ = weight of sample at 45^{0}C

$W_{105}{}^{o}{}_{C}$ = weight of sample at 105^{0}C

The moisture density relationships for both standard and modified compaction tests are obtained using rammer method. All tests were carried out according to (ASTM D1557-78, method B), (1989) for modified compaction and according to (ASTM D698-78, method A), (1989) for standard compaction. Its appear from **Figure (2)** that the maximum modified dry density of 18.5 kN/m^3

takes place at an optimum moisture content of 11.5% ,while the maximum standard dry density of 16.4kN/m^3 take place at optimum moisture content of 13.5%.

Preparation of soils for Permeability leaching tests:

The CBR mold was used to preparation specimens for permeability- leaching test with some modifications. The modified mold has an internal diameter of 152.4 mm (6in.) and of 177. 8mm (7in.) height provided with an extension collar 51mm (2in.) in height and a base plate that can be fitted to either end of the mold .A circular spacer metal disk of 150.8 mm diameter and 61.4mm (2.416 in.) height is used to obtain a thickness of compacted specimens that conforms to the thickness 116.43 mm (4.584in.) of specimens in ASTMD1557-78(1989).Manufactured base plate is used additionally to the above parts. Tap water is similar to ground water in the field, as water can infiltrate into the aground from irrigation or leaky water pipes. The water supply system to the leaching mold has two elevated cylindrical tanks. Each tank has a floating ball. The upper tank is manufactured to be standby and provides the water to the lower tank. The hydraulic gradient is determined at the difference of elevations between the water surface of lower tank and water surface of leaching CBR mold. Water supply system is shown in **Figure (10).** The inlet rubber tube of leaching cell is connected with water distributer, which takes the water from the bottom of the lower tank.

Strength tests:

The California Bearing Ratio test is a comparative measure of the shearing resistance of a soil. it's the load required to force a standard piston (with an area of 3in^2,(1935mm^2) the soil at a certain depth, expressed as a percentage of the load required to force the piston at the same depth into a standard sample of crushed stone, (Head,1982). The piston moves at a speed of 0.05 in/min (1.27 mm/min). Usually penetrations of (0.1 or 0.2) inches are used to calculate the CBR values , as follows ,[Youder and Witczak, (1975); Croney,(1977) ; Head, (1982) ; AASHTO,(1986)] .

$$CBR_{0.1} = \frac{P_{0.1}}{P_{s0.2}} \times 100 \qquad \text{.....................} (4)$$

$$CBR_{0.2} = \frac{P_{0.1}}{P_{s0.2}} \times 100 \qquad \text{.......................} (5)$$

Where:

$P_{0.1}$, ($P_{0.2}$) = load required to force a standard piston [0.1, 0.2] inches into the soil,

$Ps_{0.1}$,($P_{s0.2}$) = load required to force a standard piston [0.1,0.2] inches into a standard sample of crushed stone $Ps_{0.1}$= 3000 1bs,(13.34 kN) and $Ps_{0.2}$ = 4500 lbs.,(20.01) kN . Specimens of soil for the CBR test are molded using the standard CBR mold provided with an extension collar 51 mm (2 in.) in height and a perforated base plate that can be fitted to either ends of the mold. A circular spacer disk made of metal of 150.8 mm diameter and 61.4 mm height is used to obtain a thickness of compacted specimens that cc 8 ns to the thickness 116.43 mm of specimens in ASTM $D_{1557-78}$(1989). Modified proctor compaction is carried out to ASTM $D_{1557-78}$ (1989). This will allow the determination of the CBR at 100% relative modified proctor compaction.

Selected Surcharge load

Surcharge load during leaching and penetration of sub grade CBR samples are placed to simulate the actual or estimated weight of pavement thickness to be placed on top of sub grade soil (Youder and witzak, 1975; Wright ,1996).
According to AASHTO (T193) and ASTM (1983.87), the minimum surcharge load is considered to be (44.5N). Following(O' Flaherty ,1988), each annular weight (5 1bs) is equivalent to 63.5 mm of flexible pavement thickness.

Thus, the expected maximum thickness of pavement over the original sub-grade soil may reach 90 cm. for this reason, it was decided to use, (311.5N) surcharge load as the upper limit in this study. Accordingly, it was decided to adopt the following surcharge load namely (44.5; 178 and 311.5 N) for this work.
The number of blows per layer required to achieve the 95% relative compaction may be affected by the surcharge load. Two sets of CBR sample for 311.5N surcharge load are prepared. Each set consists of three specimens compacted in five layers with 10, 25 and 56 blows/layer for the first, second and third specimens respectively. The surcharge load is placed on the top of samples in CBR mold and each specimen is then subjected to the penetration test.

Result And Discussions:

Gypseous soils are strong when dry, but the presence of water decreases the resistance of these soils when they are subjected to soaking or leaching. The main reason of high strength unleached soil contains high gypsum and other salts contents which act as cementing materials between soil particles and they increase the resistance of the soil to collapsing.
Otherwise, the soil will not be regarded as suitable for sub grade. In order to study the effect of leaching on Al- Anbar gypseous soil, three values of hydraulic gradient are used and various soils samples are prepared at 95% relative modified compaction to be leached under constant head ,(i= 2; 6 and 10) for times, (t = 4 ;7 ;14 ;30 and 60) days leaching periods and under surcharge loads;(44.5 ;178 and 311.5) N.

To get more reliable result, two samples are prepared for each surcharge loads, each leaching period and the test is repeated for each hydraulic gradient.
The results of CBR tests are illustrated in **Figures (3 to 5),** it obvious from these figures that the leaching period has a significant effect on the strength of the gypseous soil tests. The increase in leaching period causes a significant decrease in CBR values especially for samples of low surcharge loads.

The reason for such behavior of leached gypsum is the high void ratio and the existence of root-hole structure in this soil. The removal of the cementing agents from the soils causes a decrease of the preconsolidation pressure and an increase in the compressibility of the soils. The accumulative leaching strain and dissolved gypsum increase with the increase in leaching period then they remain constant.

Gypseous Soil during Leaching Process:

The term of "leaching strain" refers to the strain which caused by gypsum leaching and surcharge loads. The relation between leaching strain and time for modified odometer permeability leaching test at three surcharges loads ; (311.5 ; 178 and 44.5) N. shown in **Figures (6 to 8).** In general, it is found that the leaching strain is very low at the beginning of leaching, and the void ratio increases with increase in the dissolved gypsum until the void ratio reaches a certain value. This behavior may be attributed to the low stress applied to the sample. It is observed that the total leaching strain increases, as the surcharge load and hydraulic gradient increase. This behavior could be related to the soil particles more susceptible to collapse at high surcharge load. The enlargement of the voids due to removal of soluble salts and the collapsing of soil structure occurs at the same time. However, in the early stage, the enlargement of the voids is dominant, while the collapsing of soil structure seems to be the major process in the later stage.

Behavior of Gypseous Soil after Leaching Process:

The design of flexible pavement thickness requires the CBR value corresponding to that thickness. So that to achieve the correct CBR value should be established a correlation between the surcharge load and strength after leaching gypsum soil.
The thickness of the pavement structure depends mainly on the CBR values of the sub grade soil, which in turn depends on the thickness of pavement structure. The thickness of pavement structure above the sub grade is initially unknown. Accordingly, it is necessary to establish a relationship between the thickness of pavement structure and the strength; (CBR) values achieved this, by replacing the surcharge load by the corresponding thickness of pavement. The 36 blows per layer are adopted in this work for compaction CBR samples to achieve 95% relative modified AASHTO compaction. The number of blows per layer required to achieve the 95% relative compaction may be affected by the surcharge load. For this purpose, three surcharge loads are considered (44.5; 178 and 311.5) N for this purpose. CBR values are calculated using Eqs. (4 and 5) and Governing CBR is plotted versus each of dry density and number of blowes per layer in **Figure (9)** for cases of (44.5, 178 and 311.5) N surcharge loads. It can be shown in **Figure, (9)** that increased the percent of CBR by increasing dry density of gypsum soil after leaching. This could attributed to many reasons : decrease of voids cause increase in values of cohesion c and the angle of internal friction and then strength cementing materials which bond the soil particles together by compactive effort.

Conclusions :

The following conclusions can be obtained from this study:

1.The surcharge loads (44.5; 178 and 311.5) N have a significant effect on the CBR values (12;22 and 40)% respectively at i = 2 respectively of the tested gypsum soil. Hence, an increase in surcharge loads causes an increase in CBR value.

2. The effect of surcharge loads increases with the increase in leaching periods.

5. Drop in CBR values (40; 32 and 25) % due to increasing hydraulic gradient values (2; 6 and 10) respectively at surcharge load 311.5 N.

6. The accumulative leaching strain and dissolved gypsum increasing with the increase in leaching period then they remain constant.

7. At the beginning of leaching test, the permeability increases with the increase in leaching period then the value of permeability remains constant.

8. The permeability increases with the increase in hydraulic gradient for the same leaching period.

9 Increasing in CBR value can have a serious economic effect in pavement design as this increase can transfer unsuitable sub-grade gypsum soil before leaching into suitable sub-grade soil.
10. Increasing compactive effort after leaching gypsies sub grade soil increasing CBR value.

11. After leaching increasing compactive effort increasing cementing of microstructure

gypsies' soils.

Recommendation for future work:-

1- Determine effect leading of gypseous soil on strength pavements.

2- Investigation of microstructure gypseous soil under leading.

3- Strength in site effect of leading on the mechanical properties of gypsies soil.

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Table (1) chemical properties of gypsum and anhydrite (Al-Mufty, 1997)

Type	CaO	SO_3	H_2O
gypsum	32.6	46.5	20.9
Anhydrite	41.2	58.8	0

Table, (2) Results of geotechnical properties of the soil used

Properties	value
Depth	(0.70 to 1.3),m
Specific gravity	2.4
Liquid Limit,(L.L)%	38
Plastic Limit,(P.L)%	20

Soil Classification,(ASHTO)	A-2-6 (0)
Soil Classification,(USCS)	Sc
Total soluble salts, (T.S.S)	68.73
Total,(So_3)%	31.24
PH	7.4
Gypsum content,%	63

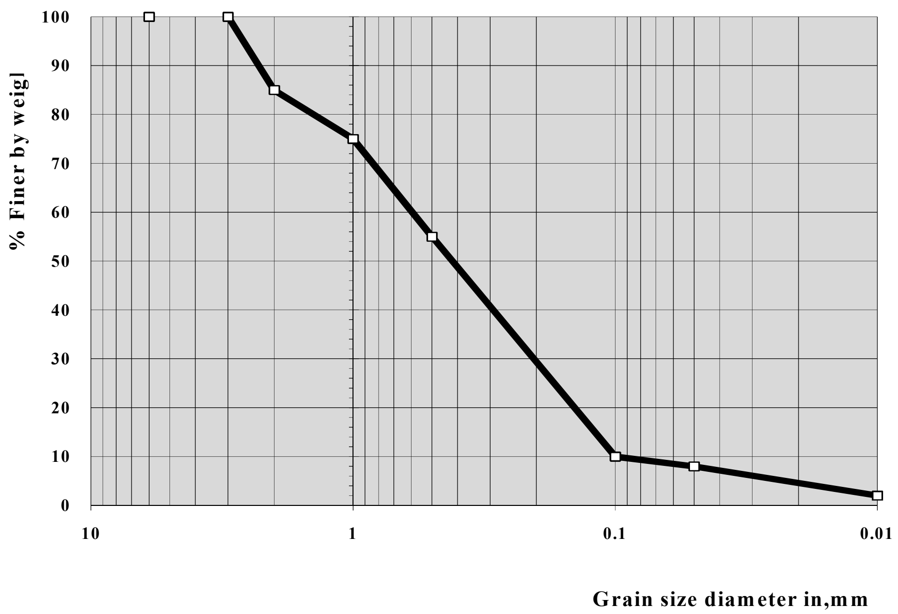


Figure 1 Grain size distribution Diagram for soils

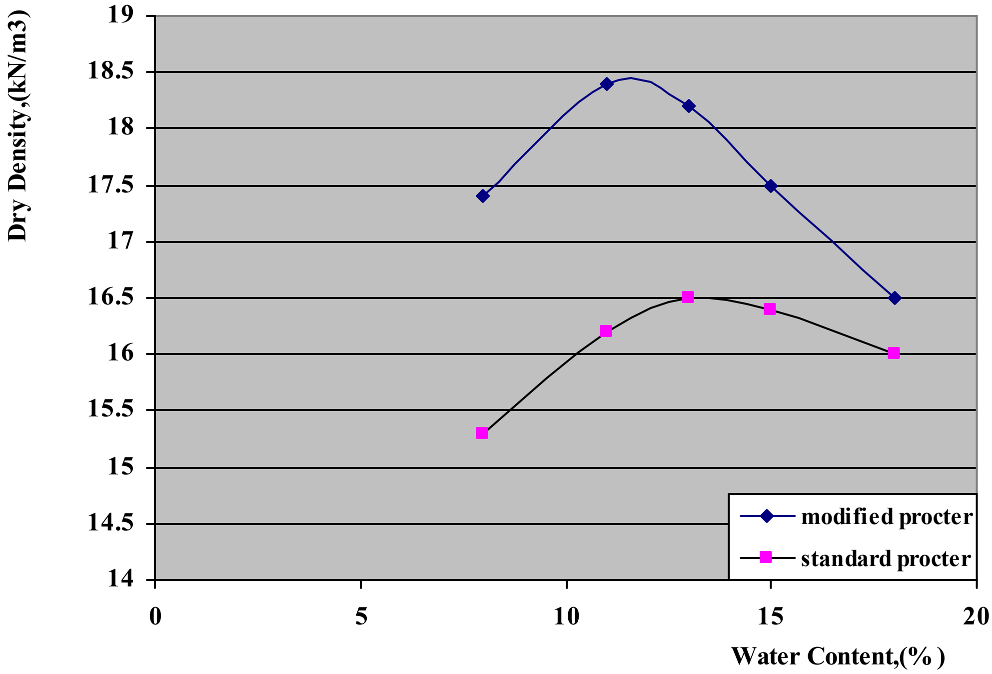
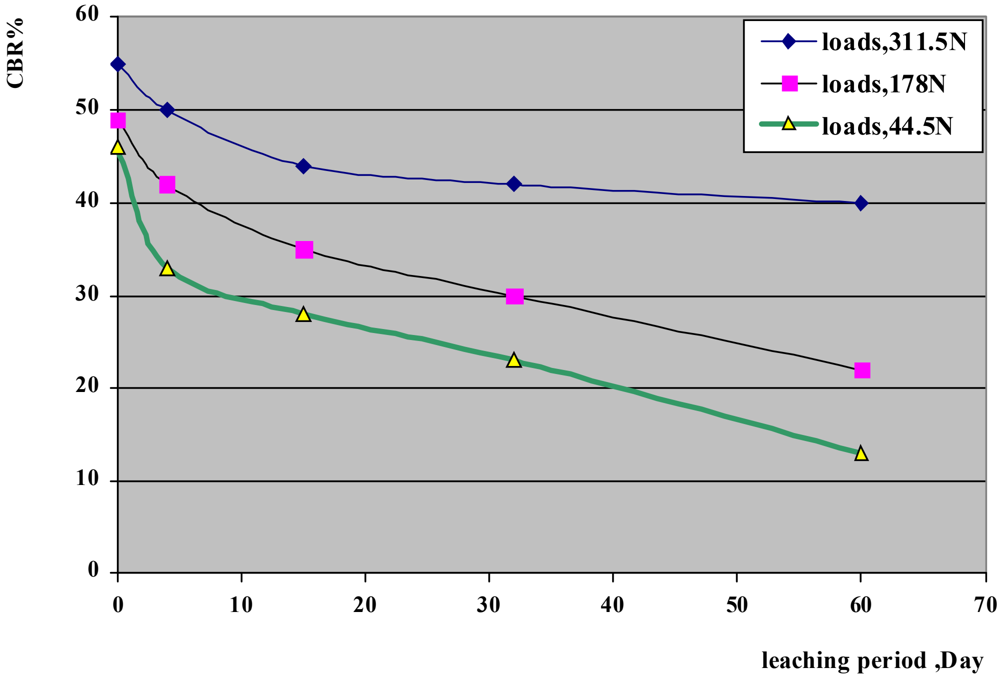
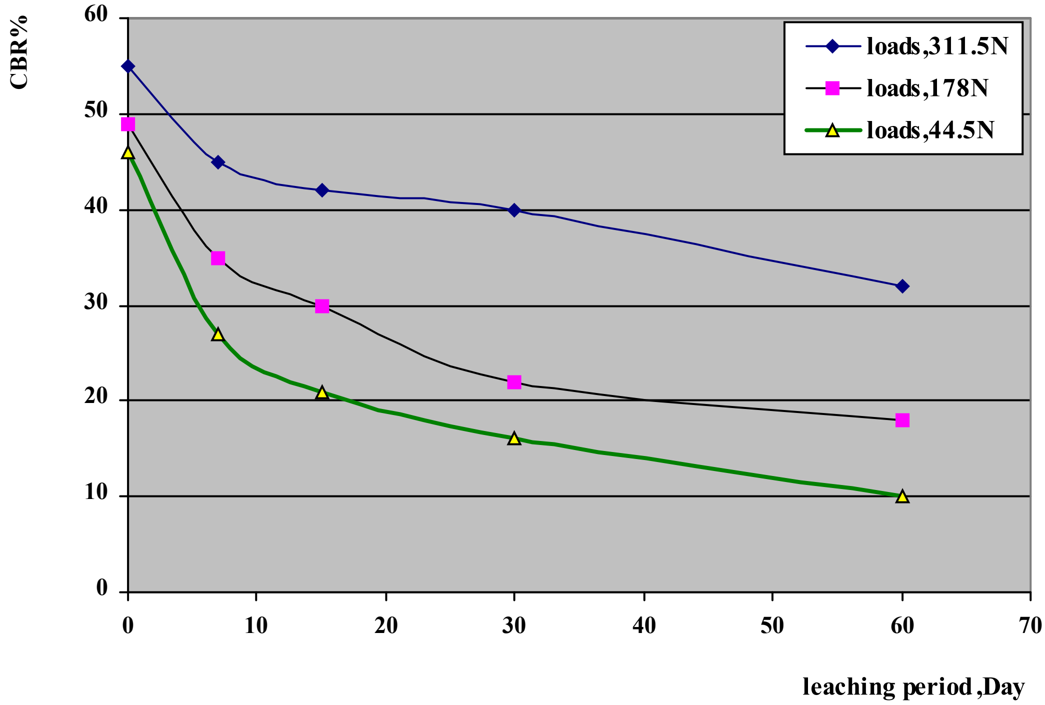


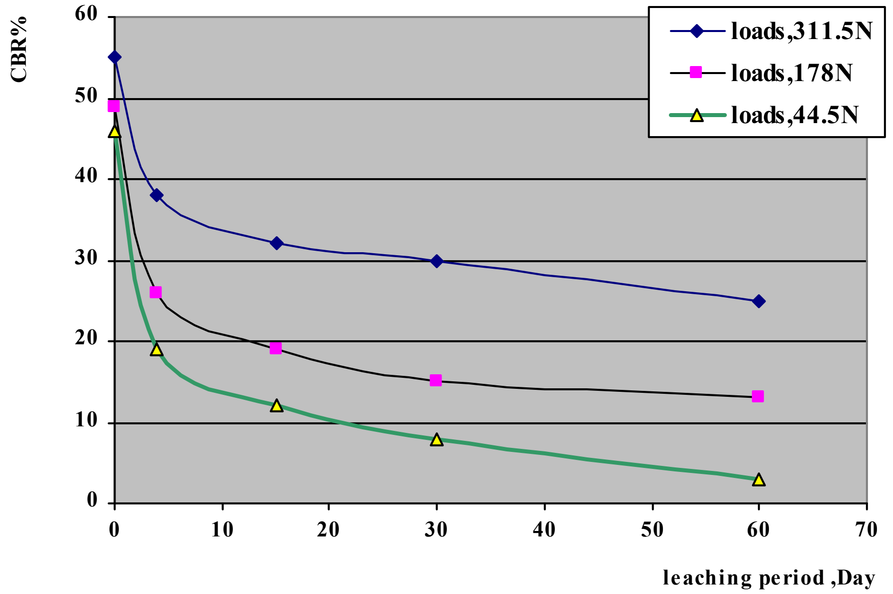
Figure (2), Procter compaction curves for samples.



Figure(3) Effect of leaching periods on CBR under various surcharge loads with, (i=2)



Figure(4) Effect of leaching periods on CBR under various surcharge loads with, (i=6)



Figure(5) Effect of leaching periods on CBR under various surcharge loads with, (i=10)

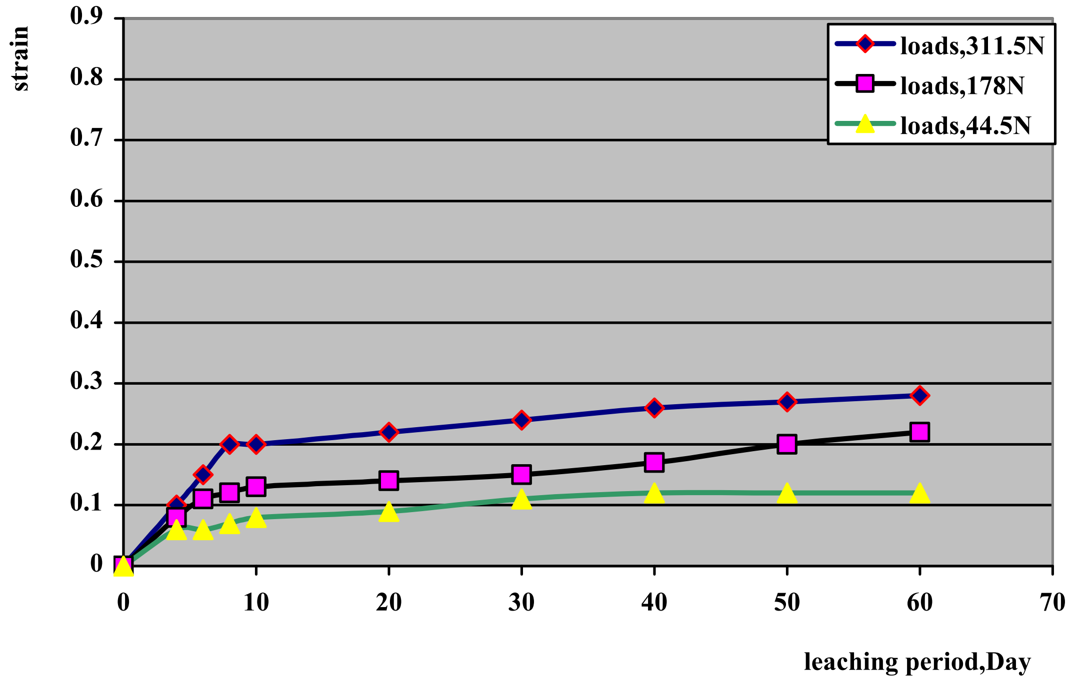


Figure (6) leaching strain versus time relation with i=2

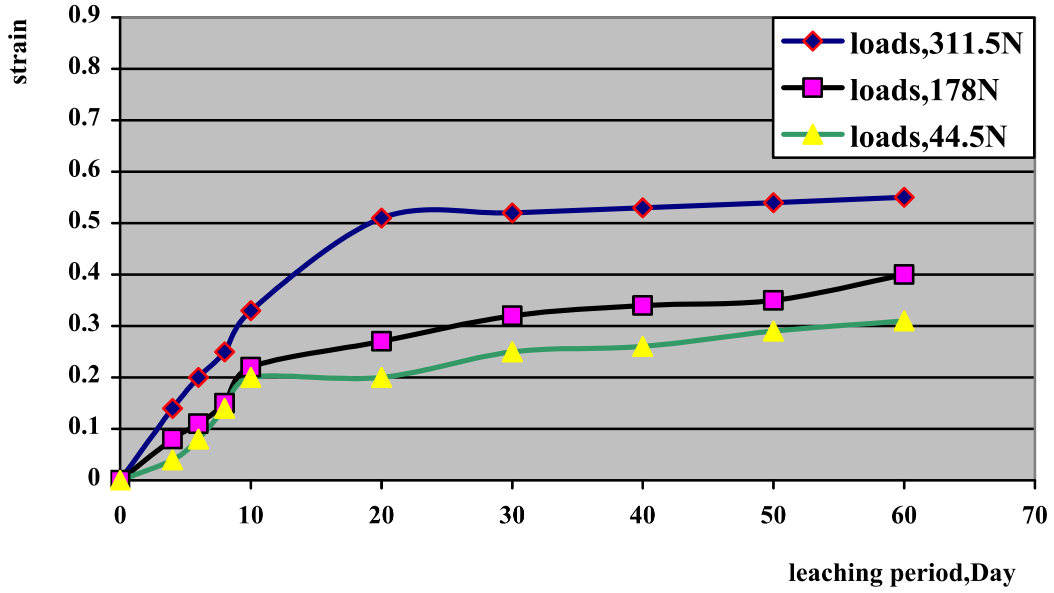


Figure (7) leaching strain versus time relation with i=6

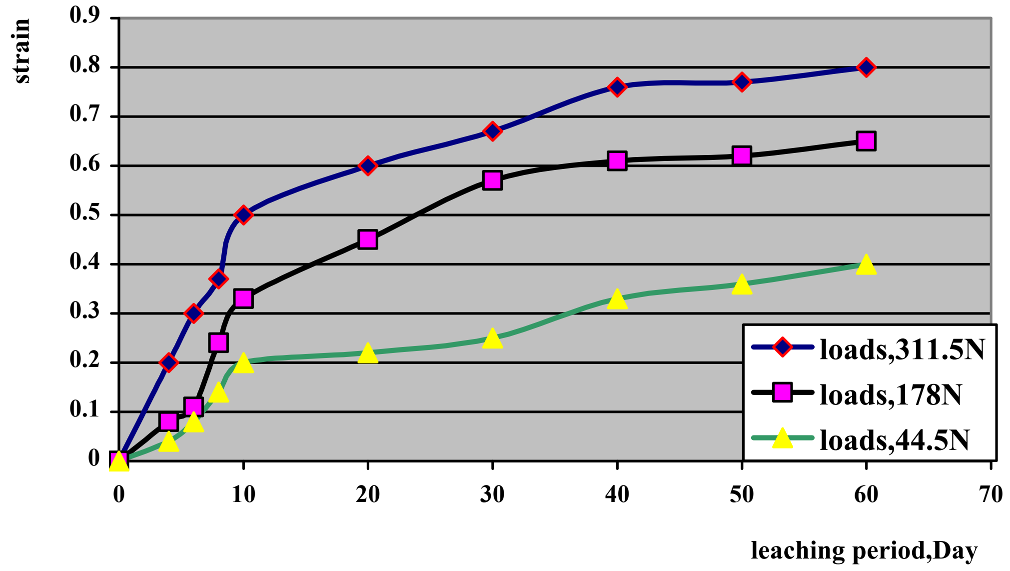


Figure (8) leaching strain versus time relation with i=10

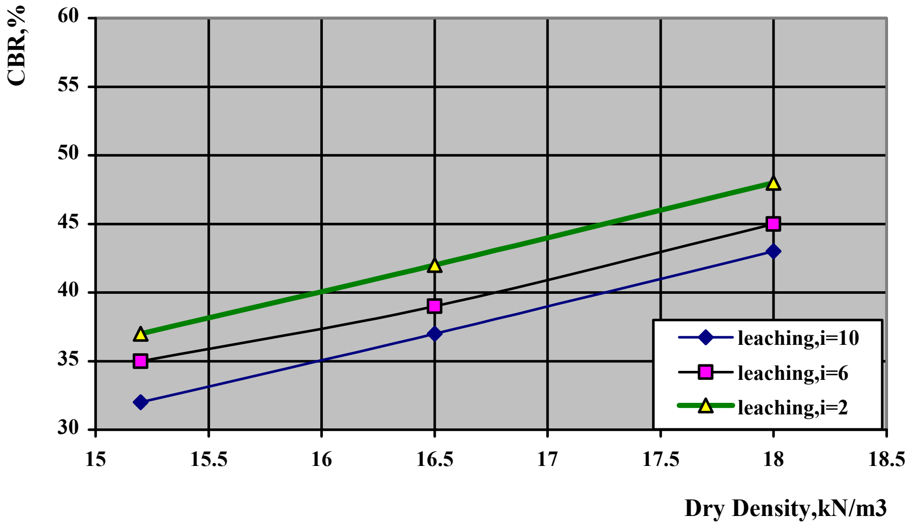


Figure (9) Relationship between CBR% and Dry Density after leaching

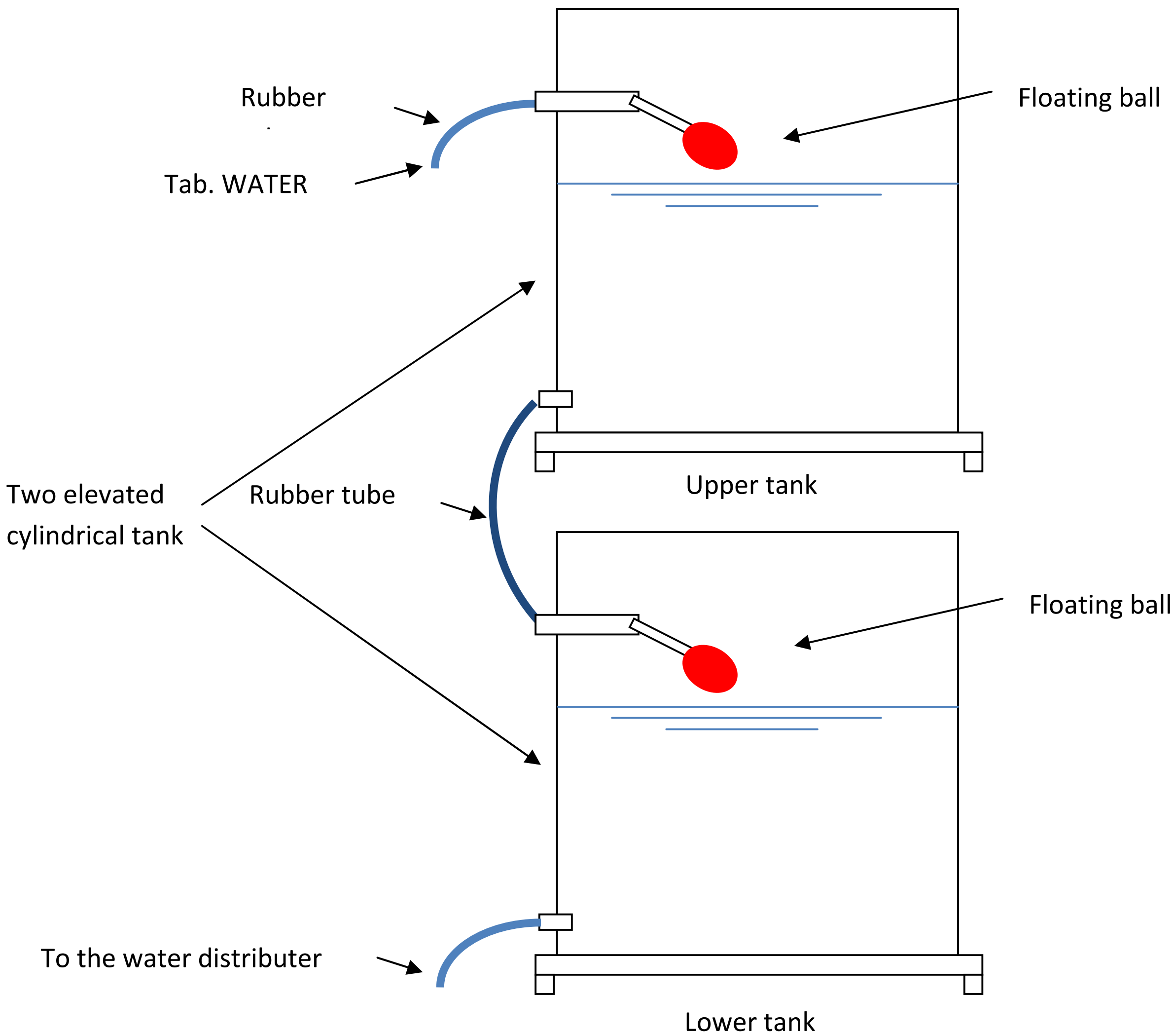


Figure (10) Water supply system

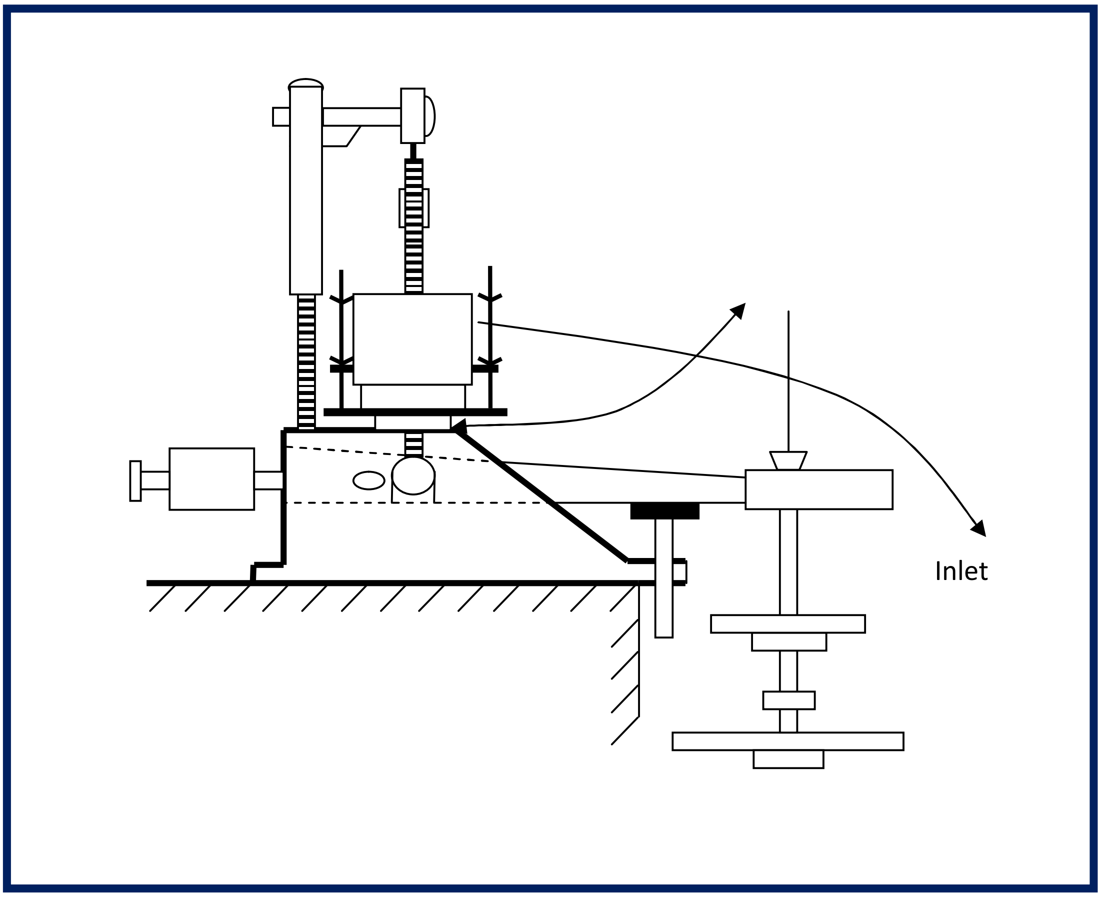


Figure (11) Arrangement of the modified oedometer

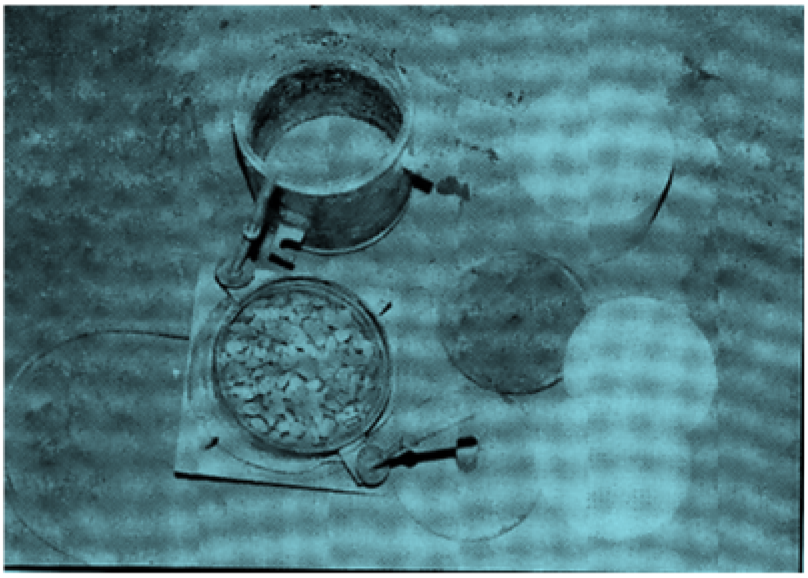


Plate (1) Parts of modified leaching mold

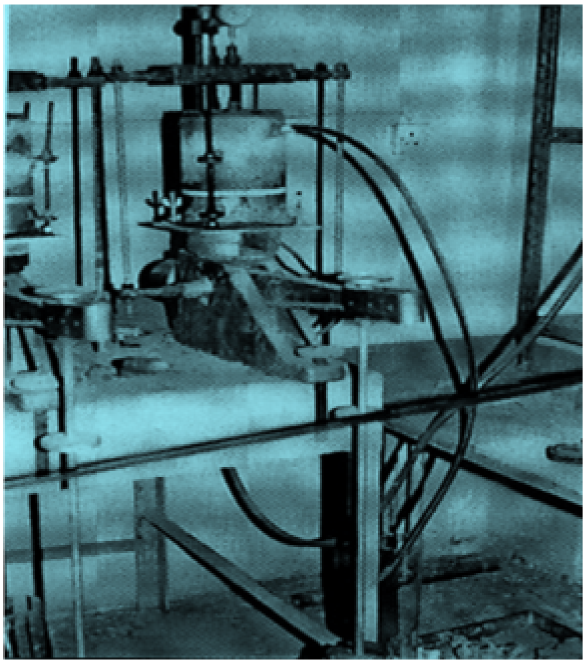


Plate (2) Modified oedometer with cell under test

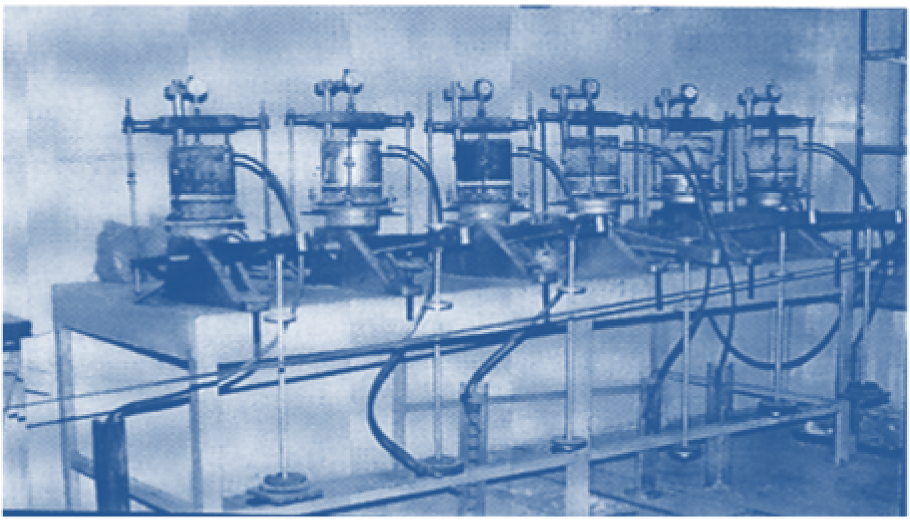


Plate (3) Modified oedometers with cells under test