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قياسات موقعية لنفاذية التربة الكلسية المستخدمة كبطانة أو غطاء لمواقع ردم النفايات الصلبة

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الخلاصة

في هذه الدراسة تم بحث ملائمة التربة الكلسية المتاحة محلياً والمستخدمة كبطانة أو غطاء لبناء مواقع ردم النفايات في الكويت. أجريت الاختبارات المعملية على عينات تربة محلية لتحديد الخواص الجيوتقنية المطلوبة لتحقيق أدنى نفاذية في الموقع. على أساس النتائج تم تشييد أربع منصات اختبار في الموقع في ظروف خاضعة للرقابة الموقعية لإجراء تجارب قياس النفاذية بواسطة

Sealed Double Ring Infiltrometer (SDRI) (سدري). تم مراقبة القياسات الحقلية من خلال تسجيل القراءات على مرحلتين: مباشرة بعد تركيب المعدات (المرحلة 1)، وبعد مرور 4 أشهر من التشييد (المرحلة 2). في نهاية المرحلة الأولي تراوحت معدلات النفاذية من 1.08×10^{-10} إلي 1.89×10^{-10} (م/ ثانية). أما في نهاية المرحلة الثانية فتراوحت معدلات النفاذية من 9.44×10^{-12} إلي 3.56×10^{-9} (م/ ثانية).

أظهرت نتائج الدراسة أن نفاذية التربة المحلية سجلت قيم نفاذية منخفضة تحت ظروف خاضعة للرقابة من عمليات الضغط الهندسي وأيضا خلصت الدراسة أن SDRIs يمكن استخدامه لقياس معدلات النفاذية وخلال فترات طويلة من الوقت للتربة الكلسية المشبعة والتي تستخدم كغطاء أو بطانة لمواقع ردم النفايات.

Insitu hydraulic conductivity tests for compacted calcareous sands using Sealed Double Ring Infiltrometers (SDRI)

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ABSTRACT

This study uses the Sealed Double Ring Infiltrometers (SDRIs) to measure the infiltration rates of compacted calcareous sands in the field. Laboratory tests were conducted on the locally available soil samples to determine the geotechnical parameters that are needed to achieve the lowest hydraulic conductivity at the field. Test pads were constructed at controlled compaction conditions and in-situ hydraulic conductivity experiments were conducted by Sealed Double Ring Infiltrometer (SDRI). Field measurements were carried out by recording the SDRI readings periodically. Infiltration rates ranged between 1.89 x 10^{-12} m/s and 1.08 x 10^{-10} m/s.

The results of the study suggest that calacareous sandy soils have achieved low permeability values under controlled conditions of compaction and SDRIs can be used for prolonged periods of time to obtain the infiltration rates that represent the hydraulic conductivity characteristic of the saturated soil liners.

Keywords: Calcareous sands; compaction conditions; hydraulic conductivity; Sealed Double Ring Infiltrometers (SDRI).

INTRODUCTION

In various construction processes, soil compaction is used to support structural entities such as building foundations, roadways, walkways, and earth retaining structures etc. (McCarthy & David, 2007). Based on the project specifications, soil is compacted to ensure the required soil density or degree of compaction that must be achieved. These specifications are generally recommended by a geotechnical engineer or an engineering consultant. Soil placed as an engineering fill is compacted to a dense state to obtain satisfactory engineering properties such as shear strength, compressibility, and/or permeability. In general, the in-situ density of the soil is determined and compared to the maximum density determined by a laboratory test.

Compacted clays are generally used as hydraulic barriers in cores of earth dams, liners and covers of landfills, and liners of surface impoundments. Compacted soils are widely used for lining landfills to isolate hazardous and other waste materials from the surrounding environment. The effectiveness of compacted soils is controlled by its hydraulic conductivity, which is restricted by environmental protection agencies. The main purpose of using liners in landfills as contaminant barriers is to contain leachate and minimize its downward migration into the subsurface soils below landfills, thus eliminating groundwater contamination (Sharma & Lewis, 1994 and Tchobanoglous *et al.*, 1993). Liner systems are generally constructed from low permeability soils such as clay materials. Provision of soils for landfill liner construction is becoming increasingly difficult and uneconomic. Clay soils are rarely found in arid climate regions whereas calcareous sands are widely found (Youash, 1984). The gatch deposit is the local name for the caliche accumulation, which is characteristic in arid and semi-arid climates. Thus, utilizing the locally available gatch deposits as a barrier material or an engineering fill can be an alternative to the rarely found clay sediments in arid regions.

Laboratory tests were conducted on soil samples collected from different areas in Kuwait to determine the hydraulic conductivity and other geotechnical parameters. Field hydraulic conductivity measurements were carried out by installing SDRI on four test pads constructed under controlled compaction conditions.

Many different tests are in use both in laboratory and at site for hydraulic conductivity. While lab hydraulic conductivity tests provide valuable insight into relative properties of materials and their potential for use in liners, numerous studies have demonstrated that values obtained in the laboratory are not reliable indicators of performances of "as built" soil liners under field conditions (Sai & Anderson, 1990). A wide variety of field hydraulic conductivity methods have been published in the scientific and engineering literature. Among these insitu tests, the Sealed Double Ring Infiltrometer (SDRI) method has received the widest popularity. In addition, the SDRI test method has been used extensively for field measurement of the infiltration rate of soils, and has also been used for studies such as leaching and drainage efficiencies, seepage rates of canal or reservoir liners, lake and irrigation pond areas, and soil liners used for retention ponds and storage tanks.

Civil works in Kuwait require specific standards to evaluate the quality control of the different structures that use calcareous sands as a major source of soils. The standards should provide consultants with appropriate methods describing the characteristics of such soils, especially, the hydraulic conductivity property. The primary purpose of this study is to measure the in-situ infiltration rates of compacted calcareous sands using SDRI method. Further, the compaction conditions of calcareous soils was evaluated to get the lowest infiltration rates in the field, so that these soils can be used as barrier material in environmental projects.

LITERATURE REVIEW

The primary function of insitu permeability testing is to provide a mechanism for monitoring the quality of liner construction in the field and assessing the design criteria while the objective of this testing is to determine the saturated hydraulic conductivity of soil liners during construction and prior to in-service saturation (Fernuik & Haug, 1990). Full scale test pads are being used extensively in the design phase for evaluating effectiveness of construction procedures, and the use of field tests for evaluating insitu hydraulic conductivity of earthen liners and caps used in waste disposal facilities (Trautwein & Boutwell, 1994).

SDRI is one of the most suitable methods for evaluating hydraulic conductivity of soil liners for landfills. The SDRI measures one dimensional infiltration from which vertical hydraulic conductivity is determined. Testing times are comparatively longer but a larger volume of soil is tested, 1000 to 3000 times that typically tested in laboratory (Trautwein & Boutwell, 1994). Neupane *et al.* (2005) reported that SDRIs are often used in the field to measure infiltration rates of natural soil deposits, recompacted soil liners, and amended soils such as soil-bentonite and soil-lime mixtures. Neupane *et al* (2005) also pointed out that full-scale test pads, equipped with performance monitoring devices (eg. SDRIs) can provide surrogate information on the performance of actual liners as they mimic the construction and quality control procedures to be employed in the field. Comeau *et al* (1998), estimated the hydraulic conductivity of weakly cemented, crushed till deposits in Canada as equal to 5×10^{-10} m/s by using SDRIs. Abichou *et al* (2002) used SDRIs to determine the hydraulic conductivity of three different test pad liners with various compositions of foundry green sand, and reported that the hydraulic conductivity ranged from 7×10^{-9} to 2×10^{-10} m/s. Benson *et al.* (1999) presented an extensive database of conducting hydraulic conductivity tests on 85 test pad sites using SDRIs distributed across USA and Canada, where the hydraulic conductivity values ranged from 1×10^{-9} to 1×10^{-10} m/s.

All sets of caliche accumulation are observed in Kuwait such as powdery granular calcareous material, or sandy deposit with isolated calcareous pods, or hard calcareous deposits (Al-Sulaimi *et al*., 1982). The most important geotechnical parameter for soil liner for waste landfills is hydraulic conductivity. Most sanitary regulations require liners to have a hydraulic conductivity of either 1×10^{-9} m/s or 1×10^{-8} m/s (Trautwein & Boutwell, 1994). For liners in arid areas, Daniel and Wu (1993) recommended to use soils rich in sand and compact at a water content as dry as possible. They also indicated that liners should be compacted at a water content of $\pm$ 2% from the optimum determined from the modified compaction, and to a dry unit weight of at least 96 – 98% of the maximum value from the modified compaction, in order to meet the requirements of low hydraulic conductivity. Ismael *et al* (1986) reported that gatch has low permeability but has swelling problems, is highly susceptible to water saturation, and is particularly affected by water flowing through it.

The soil barrier layer generally is compacted under conditions that yield low saturated hydraulic conductivity, i.e., with higher compaction water content and compaction effort (Daniel, 1987). Results of earlier work conducted by Al-Yaqout & Townsend (2004) for assessing field hydraulic conductivity of in-situ gatch by Two-stage borehole method (ASTM D6391) indicated that gatch permeabilities range between 3×10^{-7} to 17×10^{-7} m/s and that in-situ gatch deposits could be considered as a secondary barrier system beneath a liner.

There have been many papers published on laboratory and field hydraulic conductivity testing methods (e.g. Sai & Anderson, 1990; Benson *et al.,* 1994a; Trautwein & Boutwell, 1994), the correlation of laboratory and field hydraulic conductivities (Benson *et al.,* 1994a), and methods of construction and construction quality assurance (e.g. Benson *et al.,* 1997; Daniel & Koerner, 1995). However, only a few studies have characterized the field performance of in-service compacted clay liners constructed using standards typical of industry (Benson & Boutwell, 1992; Benson *et al.,* 1999; Nuepane *et al.,* 2005; Albright et al., 2006, Hamdi & Srasra, 2013). Based on the advantages of all the methods, the best and the most practical available technologies for evaluating hydraulic conductivity are the large single-ring infiltrometer and the sealed double-ring infiltrometer (SDRI) (USEPA, 1991).

Bozbey & Guler (2006) investigated the feasibility of using silty soil excavated in highway construction as landfill liner material, by conducting laboratory and in-situ tests. They reported that the in-situ hydraulic conductivity values obtained with SDRIs were in the order of 1×10^{-8} and 1×10^{-7} m/s.

MATERIALS AND METHODS

In this study, laboratory tests were conducted to calculate the properties of the locally available calcareous sandy soil. The laboratory testing included: (1) Soil classification as per Unified Classification System; (2) Atterberg limits tests; (3) Compaction tests (both Standard and Modified) (ASTM D 698 & ASTM D 1557) ; (4) Direct shear tests comparable to field densities and water content; and (5) Permeability test by variable head method (ASTM D5084).

Five bulk disturbed samples of the soil were collected from three different areas in Kuwait, namely Jahra (S-1, S-2 & S-3), Amghara (S-4) and Mina Abdulla (S-5). Chemical analysis of the samples indicated that the calcareous sands consisted mainly of quartz components (SiO_2). The other components include calcite, dolomite, and gypsum. Figure 1 shows the compaction curves for the samples based on Modified Proctor test conducted in the Laboratory. Tables 1(a) and 1(b) represent the summary of the laboratory testing program for the soil samples. The maximum dry density (MDD) of the samples ranged from 1.408 to 1.881 g/cc with the Standard Proctor test, and from 1.973 to 2.032 g/cc with the Modified Proctor test.

Based on the laboratory test results, soil sample (S-5) from Mina Abdulla area was selected for the construction of four test pads for field testing. This sample consisted of clayey sand (SC), with 19.7% of fines, plasticity index of 11%, and a maximum dry density of 2.032 gm/cc (by Modified Proctor Compaction method), and the optimum water content of 9.9%. Most importantly, this sample exhibited the lowest permeability of 1.06 x 10^{-9} m/s among the five samples. Figure 2 shows the particle-size distribution curve of the soil sample used to construct the test pads.

Test Pads and SDRI Tests

Four test pads were constructed in the field in Al-Qurain area, which is located about 15 km south-east of Kuwait City and about 1.5 km from the Gulf shore line. Field hydraulic conductivity measurements were carried out by installing Sealed Double Ring Infiltrometers (SDRI) on the test pads. Each test pad is approximately 12-m long and 10-m wide. Excavation of the top layer of the site surface was carried out to construct the test pads. After leveling the base of the excavated pits, a free-draining sand layer 20 cm thick was placed to provide a known hydraulic boundary condition for the hydraulic conductivity computations. The permeability of the draining sand was measured in the lab as 1.74 x 10^{-5} m/s. The location map of Al-Qurain area and the test pad construction arrangement is shown in Figures 3(a) and 3(b).

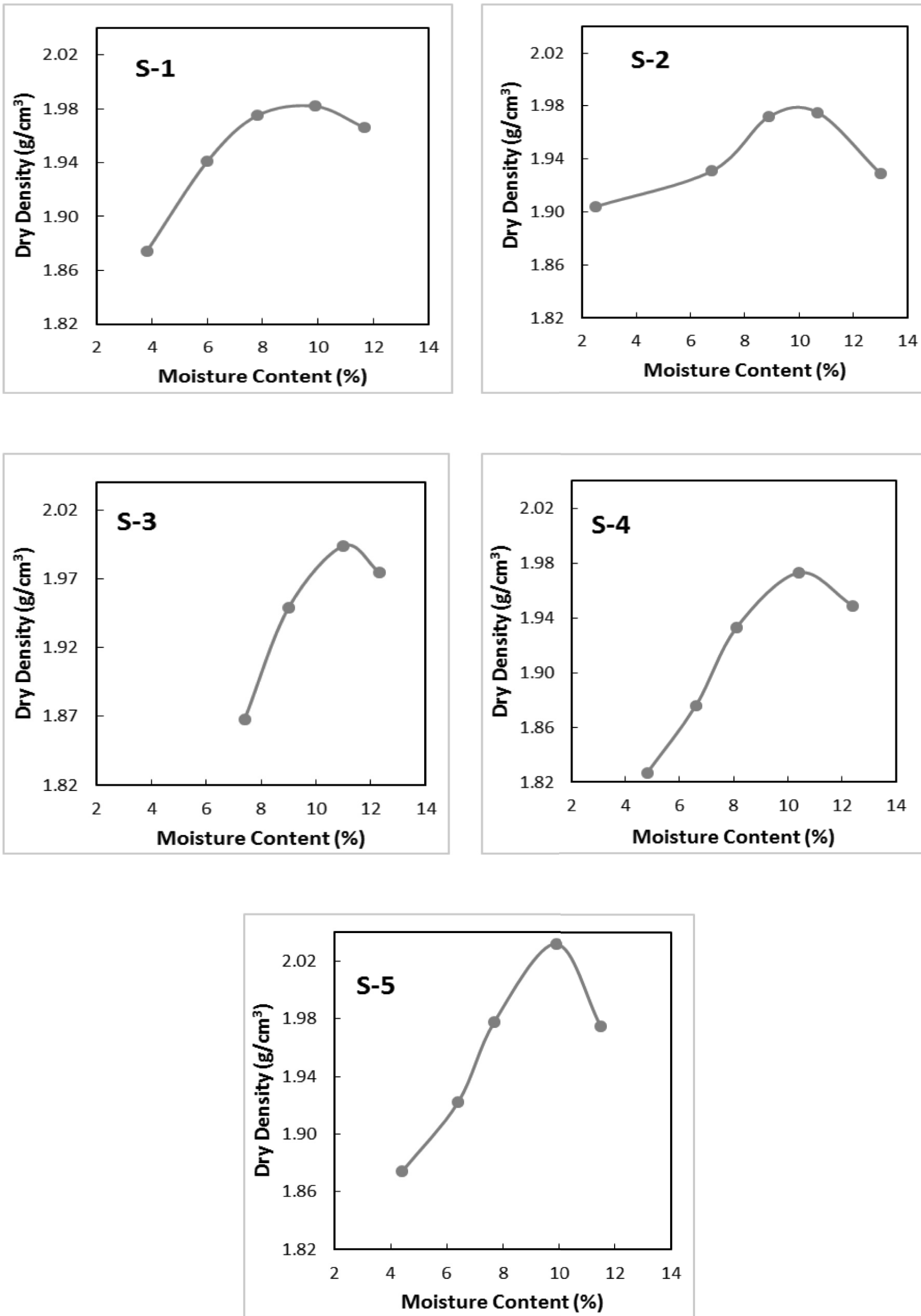

Fig. 1. Compaction curves of soil samples with Modified Proctor Test.

Table 1 (a). Summary of the properties of soil samples collected from five different sources.

Source	USCS Classification	% passing # 200 sieve	Liquid Limit	Plastic Limit	Plasticity Index	Permeability (m/s)
Al-Huwaila pit, Jahra (S-1)	SM	12.9	NP	NP	NP	1.11E-09
Al-Rashidi pit, Jahra (S-2)	SM	12.3	NP	NP	NP	1.18E-09
Rahjah Adab pit, Jahra (S-3)	SC	29.2	40	18	22	4.35E-09
Abdulla Qambar, Amghara (S-4)	SC-SM	16.3	25	19	6	1.63E-09
Shabib Al-Azmi, Mina Abdulla (S-5)	SC	19.7	32	21	11	1.06E-09

Note :– SM : silty sand; SC : Clayey sand; SC-SM : Clayey sand with silt.

Table 1 (b). Summary of the compaction and shear test results of soil samples.

Source	Proctor Test				Direct Shear Test			
	Standard Proctor		Modified Proctor		95% MDD (Standard)		95% MDD (Modified)	
	MDD (gm/cc)	OMC (%)	MDD (gm/cc)	OMC (%)	c (kPa)	Φ	c (kPa)	φ
Al-Huwaila pit, Jahra (S-1)	1.852	13.5	1.982	9.5	10	34	25	34
Al-Rashidi pit, Jahra (S-2)	1.891	12.5	1.979	9.9	21	30	26	35
Rahjah Adab pit, Jahra (S-3)	1.408	13.2	1.996	11.2	45	33	89	34
Abdulla Qambar, Amghara (S-4)	1.786	11.1	1.973	10.4	22	31	8	43
Shabib Al-Azmi, Mina Abdulla (S-5)	1.887	12	2.032	9.9	18	33	44	34

Note:- c: cohesion (kPa); φ : Angle of friction (degrees);
MDD : Maximum dry density; OMC : Optimum water content.

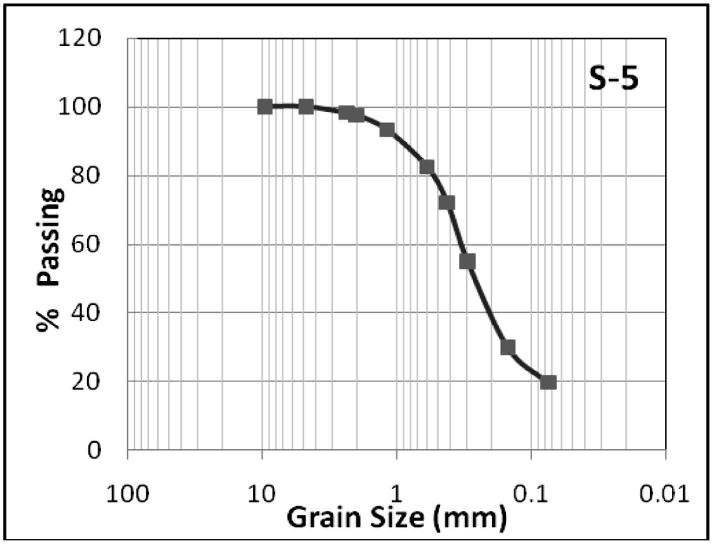

Fig. 2. Particle-size distribution curve for the soil used to construct the test pads.

Each test pad was constructed of four compacted 225 mm lifts to a thickness of 910 mm. Selected soil was placed and compacted in all the four test pads. Each lift of the test pads was compacted with a smooth wheel roller. Plastic sheet was placed on the pad walls to isolate each pad from the surrounding environment. Field measurement of water content and dry unit weight (ASTM D 2922 and D3017) was conducted using the sand cone apparatus at a rate of one test per 8 square meter per lift (i.e. 15 tests per lift). Table 2 shows the respective compaction efforts achieved and the water contents maintained for each test pad. Compaction results show that on average, the proposed compaction was achieved for the test pads, though it is slightly less than the proposed values for the test pads 3 and 4. This was due to the fact that even after increasing the number of passes, the maximum compaction achieved for some lifts inside the excavated trenches of test pads was only 98.5%. However, the low standard deviation values of the compaction efforts show that the compaction is carried out closely to uniformity. The water content evaluated for each lift of the test pads ranged between 10% below optimum and 8% above optimum. The proposed requirements of water content could not be achieved as it was difficult to maintain these percentages when the soil was compacted in the field. Moreover, achieving the degree of compaction was the main priority, which was adapted during the construction of test pads. As such, field compaction was stopped when the desired dry density was reached within the requirements, but not at the specified water content.

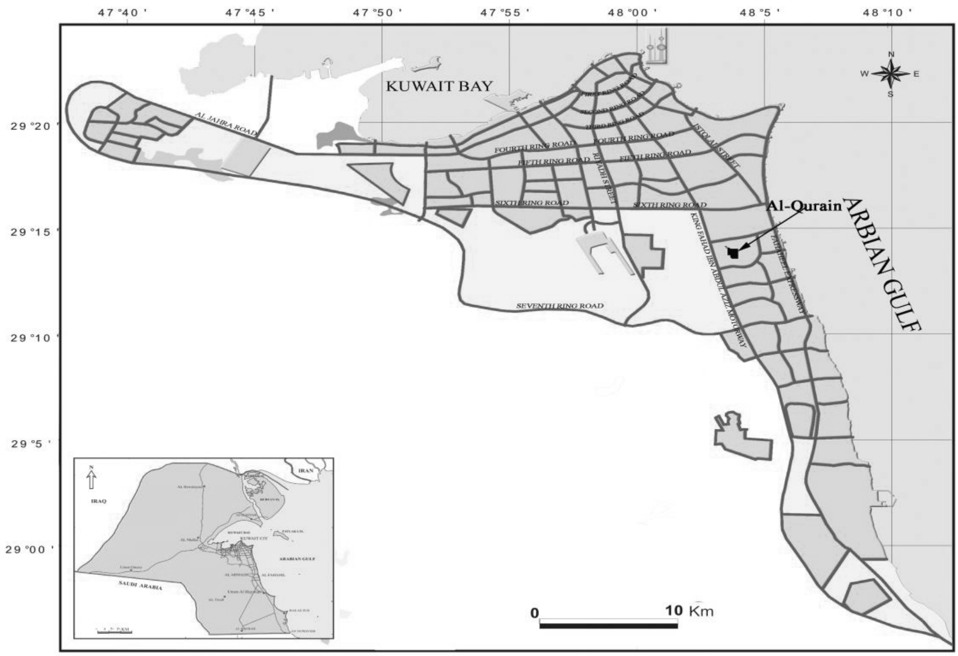

Fig. 3 (a). Location map of Al-Qurain area.

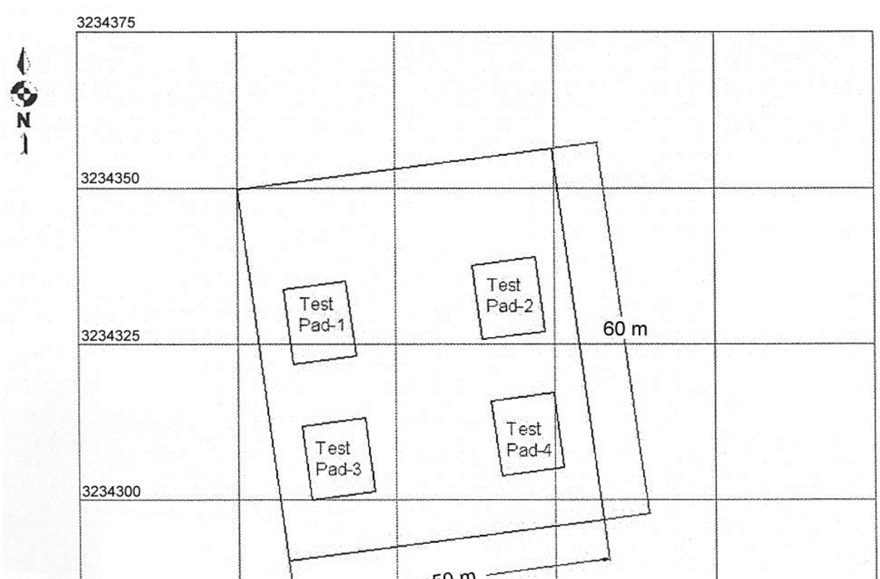

Fig. 3 (b). Typical arrangement for the construction of test pads.

Table 2. Compaction effort and water content evaluated for the test pads.

Test Pad No.	Compaction Effort Achieved				Water Content (%)			Proposed water content	Proposed Compaction
	Min.	Max.	Mean	S.D.	Min.	Max.	Mean		
1	96.5	98.5	97.29	0.608	11.1	15.1	12.84	2-3% wet of optimum	98% of SPD*
2	96.8	98.2	97.13	0.677	10.1	12.4	11.1	2-3% dry of optimum	98% of SPD*
3	95.1	97.6	96.41	0.836	9.5	14.4	10.7	2-3% wet of optimum	95% of MPD**
4	95.5	97.4	96.33	0.547	7.0	9.6	8.9	2-3% dry of optimum	95% of MPD**

S.D. = Standard Deviation; *SPD = Standard Proctor Density; **MPD = Modified Proctor Density.

SDRI devices were installed at the center of each of the four test pads. The SDRI are double ring for standard testing of soils with low infiltration rates. They are constructed of durable aluminium outer ring and a steel inner ring (Figures 4 & 5). Typical dimensions and specifications of the SDRI are given in Table 3. The inner ring is a seam welded one piece tank to prevent leaks, while the outer ring is bolted together with the aid of a rubber gasket to form a tight seal. The infiltration rings are painted to prevent rust and ensure a long life. The rings were embedded in the trenches excavated in the test area and were sealed with bentonite mud. The test consists of maintaining a constant water elevation in the rings. The inner ring is submerged and the top on the inner ring seals the water within it from the atmosphere. The volume of water added to the inner ring over time is a measure of the soil infiltration rate. The water infiltrating through the outer ring confines the flow from the inner ring to approximately one-dimensional flow in the vertical direction. After the construction of test pads and installing the SDRIs, the surfaces of the test pads were covered with sand in order to prevent desiccation, and evaporation. The outer rings of each SDRI were covered with shutters made up of plywood in order to avoid dust fall and evaporation.

Fig. 4. Set up of SDRI device in the field.

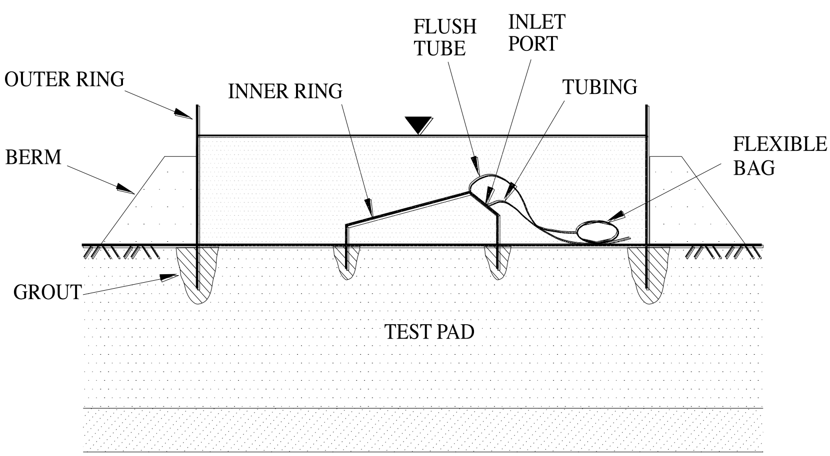

Fig. 5. A schematic diagram of the SDRI (adapted from Bozbey and Guler, 2006)

Table 3. Typical dimensions of the SDRI rings.

Dimensions	Inner Ring	Outer Ring
Size	1.5 m X 1.5 m	3.66 m X 3.66 m
Height	0.15 m	1.05 m
Depth of embedment	0.10 to 0.15m	0.35 to 0.45 m

The SDRIs were operated according to ASTM D 5093. The rate of flow was measured by connecting a flexible bag filled with a known weight of water to a port on the inner ring. Ideally, as water infiltrates into the test pad from the inner ring, an equal amount of water flows into the inner ring from the flexible bag. The flexible bag was removed and weighed after a considerable amount of flow infiltrated the test pad. The volume of water is calculated from the weight loss, and this was equal to the amount of water that infiltrated the test pad. The infiltration rate was determined from this volume of water, the area of the inner ring, and the time interval of test.

RESULTS AND DISCUSSION

Measurement of infiltration rates in the field using the SDRI were conducted in two sets. First set of tests was conducted during the months of June to September, immediately after the construction of test pads and installation of SDRI equipment. The second set of tests was conducted during the period of February to April. A gap of about 4 months was maintained between the two sets in order to allow stabilization of the test pads.

First Set

During the first set, the weight loss readings were recorded continuously, whenever there was a considerable change in volume of water in the flexible bag. This set coincided with the summer months. Early in the set, the flow rate was high and the readings were taken at every 4-5 hour intervals of time. After two weeks, the readings were recorded every day, and later, twice a week. The infiltration rates were calculated by using the measured volume of water and time taken for that measurement. The first set of measurements was continued until the flow rate became constant or the infiltration stopped. Figure 6 shows the first set of hydraulic conductivity values for the test pads. For the Test Pad-1, the infiltration rate measured was 1.08 x 10^{-8} m/s at the beginning, reducing slightly to 1.03 x 10^{-8} m/s at the end of the first week. The infiltration values gradually decreased in the subsequent weeks and stabilized at 1.89 x 10^{-10} m/s, after the 12th week. The readings were recorded up to the 15th week.

The initial infiltration rate for the Test Pad-2 was 1.38 x 10^{-8} m/s, and it gradually reduced to 1.23 x 10^{-8} m/s at the end of the first week. The infiltration gradually decreased in the subsequent weeks and became nearly constant (1.59 x 10^{-10} m/s) during the 16th week. The readings were recorded for one more week.

For the Test Pad-3, the initial infiltration rate measured was 1.39 x 10^{-8} m/s, which reduced gradually during the first week to 9.58 x 10^{-9} m/s. The infiltration values gradually decreased in the subsequent weeks and were found to be nearly constant (1.17 x 10^{-10} m/s) after the 14th week. The readings were continued for two more weeks.

For the Test Pad-4, the initial infiltration rate was measured as 1.58 x 10^{-8} m/s, and it gradually reduced to 1.35 x 10^{-8} m/s at the end of the first week. The infiltration values gradually decreased in the subsequent weeks and were nearly constant (1.08 x 10^{-10} m/s) after the 14^{th} week. The readings were recorded up to the 17^{th} week, but no change is detected.

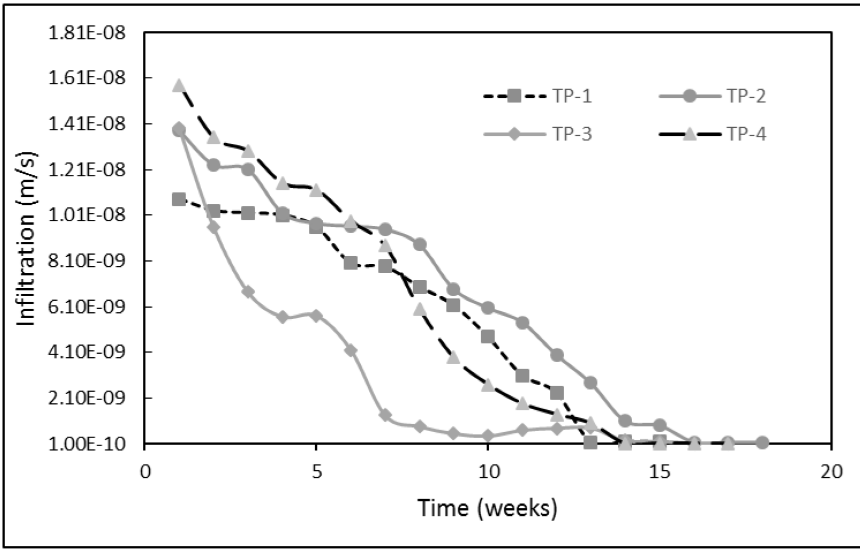

Fig. 6. Infiltration rates at Test pads during the first set of measurements.

The infiltration rates at the start of first set ranged from 1.08 x 10^{-8} m/s to 1.58 x 10^{-8} m/s. These values are higher than the permeability values (1.06 x 10^{-7} cm/s or 1.06 x 10^{-9} m/s) obtained in the laboratory for the selected gatch soil. The variation in the infiltration rates may be due to the compaction conditions of the test pads (Table 4). Though the permeability values obtained in the field are close to those obtained in the lab for the same type of soil, it indicates that reproducing the laboratory conditions in the field is difficult due to larger scale of application.

The infiltration was virtually stopped or undetected after 14 weeks for Test Pads 3 and 4, whereas the infiltration for Test Pad 1 and 2 remained constant after 13 and 16 weeks, respectively. The infiltration rates at the end of first set of measurements ranged from 1.08 x 10^{-10} m/s to 1.89 x 10^{-10} m/s, with an average of 1.33 x 10^{-10} m/s. The slight variation in the infiltration values may be due to the saturation of compacted layers of the test pads. As the layers became saturated the infiltration rates were decreased and became nearly constant. It can be observed that the infiltration values obtained after the saturation of compacted layers are less than the permeability values obtained in the lab (1.06 x 10^{-9} m/s). Thus, infiltration of compacted gatch soils decreased with time due to saturation.

Further, it was observed that the stabilization of infiltration took same time, and low values were obtained for Test Pads 3 and 4, in comparison to the test pads 1 and 2. This might be due to the fact that the Test Pads 3 and 4 were constructed with a compaction with respect to modified Proctor Test, whereas the Test Pads 1 and 2 were compacted with respect to Standard Proctor Test. As shown in Figure 7, the infiltration rates reduced with the increase in compaction effort.

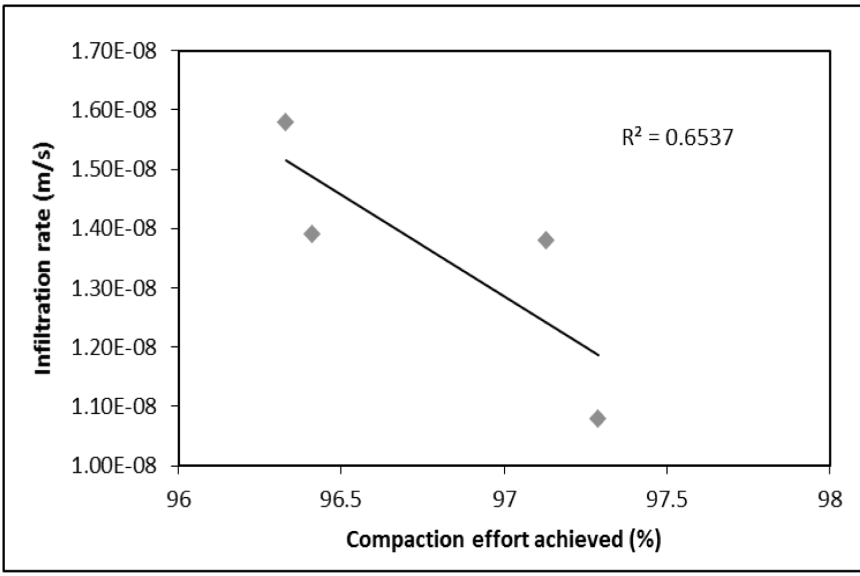

Fig. 7. Relation between compaction effort and infltration rate during the 1st set.

Second Set

The infiltration readings were taken again after a gap of about four months (approximately eight months after the construction of test pads) and were continued for about 11 weeks to observe the infiltration rates. This set coincided with the late winter months of the year (February to April). In the interim, water levels in the outer rings were checked periodically and were maintained at a constant elevation. Test Pads 3 and 4 showed good results as the infiltration rates became constant within five to six weeks. But for the Test Pads 1 and 2, rates fluctuated recording high values that may be attributed to the desiccation cracks developed in the test pads and to the climatic exposure. Figure 8 shows the infiltration rates obtained during the second set for the four test pads. During the second set, the infiltration rate for Test Pad-1 was 3.83×10^{-9} m/s at the beginning and fluctuated before stabilizing to a rate of 3.56×10^{-9} m/s after 8 weeks. For Test Pad-2, the infiltration rate recorded at the beginning was 3.00×10^{-9} m/s, and fluctuating values were recorded before obtaining stabilized values of 1.34×10^{-9} m/s after 8 weeks. The infiltration rates at the beginning were 8.97×10^{-11} m/s and 1.26 x 10^{-10} m/s for Test Pad–3 and Test Pad-4, respectively. The infiltration rate reduced to 3.18 x 10^{-11} m/s for Test Pad-3, and remained constant after the 6th week. At the same time, the infiltration reduced to as low as 9.44 x 10^{-12} m/s at the end of 8 weeks for Test Pad-4, and no infiltration was noticed after that.

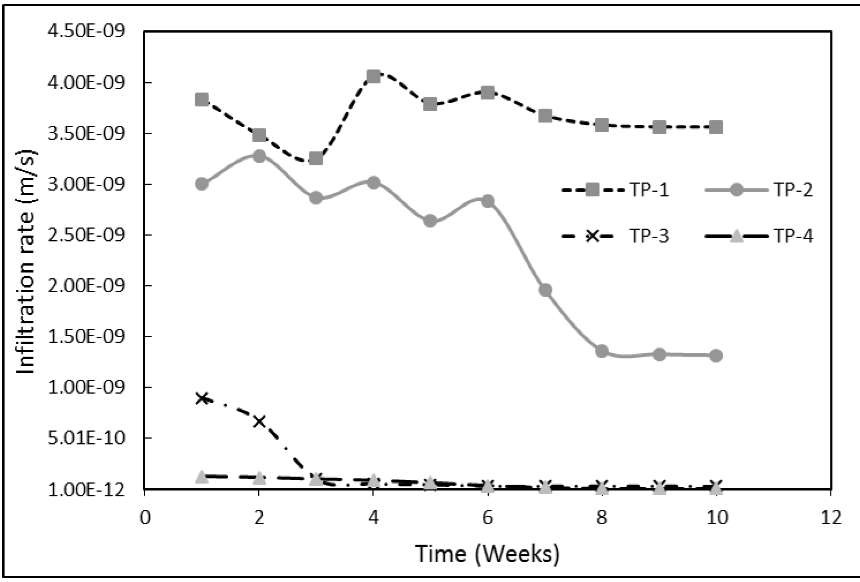

Fig. 8. Infiltration rates at Test pads during the second set of readings.

Table 4. A comparison of Infiltration rates during the two sets and compaction efforts.

Test Pad Number	First Set		Second Set		Compaction Effort (%)
	Initial Infiltration rate (m/s)	Closing Infiltration rate (m/s)	Initial Infiltration rate (m/s)	Closing Infiltration rate (m/s)	
TP-1	1.08 x 10^{-8}	1.89 x 10^{-10}	3.83 x 10^{-9}	3.56 x 10^{-9}	97.29
TP-2	1.38 x 10^{-8}	1.59 x 10^{-10}	3.00 x 10^{-9}	1.34 x 10^{-9}	97.13
TP-3	1.39 x 10^{-8}	1.17 x 10^{-10}	8.97 x 10^{-11}	3.18 x 10^{-11}	96.41
TP-4	1.58 x 10^{-8}	1.08 x 10^{-10}	1.26 x 10^{-10}	9.44 x 10^{-12}	96.33

The results show that calcareous soils with low permeability can be used as liners with consistent compaction efforts. The low infiltration rates observed after several weeks (longer period of time) confirms the fact that SDRIs can be used for longer periods to obtain infiltration rates that will approximate the characteristic saturated hydraulic conductivity of the soil after stabilization. The low infiltration rates obtained for the Test pads 3 & 4 indicate that soil liners compacted to values higher than 96% of Modified Proctor Test gave better results in controlling the seepage than the Test Pads

1 & 2, which were compacted to Standard Proctor Test. Further, test pads compacted to dry of optimum moisture contents indicated very low infiltration rates compared to the test pads compacted to wet of optimum moisture content. This is in accordance with the recommendations made by Daniel and Wu (1993). The results also show that infiltration rates as low as 1 x 10^{-11} m/s (as in the case of Test Pad-4 during second set) can be obtained with the SDRI equipment. However, not detecting infiltration below 1 x 10^{-11} m/s (the value obtained in this study is 0.94 x10^{-11} m/s) might be due to the limitation of flexible bag arrangement of SDRI tests. Nuepane *et al.* (2005) stated that flow volume measurements for very low hydraulic conductivities (< 1.0 x 10^{-11} m/s) requires special consideration of SDRI other than the flexible bag arrangement. Further, the results indicate that the SDRI equipment can be allowed to progress for a long period of time in order to assess the saturated hydraulic conductivity of the liners.

CONCLUSIONS

Four test pads, each of size 12 m X 10 m, were constructed with the locally available calcareous soils at controlled compaction conditions at Al-Qurain site, Kuwait, to estimate the hydraulic conductivity by installing SDRI equipment. Field test results were carried out by recording the SDRI readings in two sets. The first set of tests was conducted immediately after the installation of the SDRI equipment.

The initial infiltration rates during the first set ranged from 1.08 x 10^{-8} m/s to 1.58 x 10^{-8} m/s. At the end of the first set, the infiltration rates ranged between 1.08 x 10^{-10} m/s to 1.89 x 10^{-10} m/s. Though, the permeability values obtained in the field are close to those obtained in the laboratory for the same type of soil, it indicates that reproducing the laboratory conditions in the field is difficult due to larger scale of application.

During the second set, the initial infiltration rates ranged from 8.97 x 10^{-11} m/s to 3.83 x 10^{-9} m/s, and ranged from 9.44 x 10^{-12} to 3.56 x 10^{-9} m/s at the end, respectively. The results show that calcareous sandy soils with low permeability can be used as liners with consistent compaction efforts. The infiltration rates observed for several weeks confirms the fact that the soil becomes saturated and the infiltration rate will approximate the characteristic saturated hydraulic conductivity of the soil. The low infiltration rates obtained for the Test pads 3 & 4 indicate that soil liners compacted to values higher than 96% of Modified Proctor Test gave better results in controlling the seepage than the Test Pads 1 & 2, which were compacted to Standard Proctor Test. Further, test pads compacted to dry of optimum moisture contents indicated very low infiltration rates compared to the test pads compacted to wet of optimum moisture content. The results indicate that the SDRI equipment can be allowed to progress for a long period of time in order to assess the saturated hydraulic conductivity of the liners or covers.

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