International Journal of GEOMATE, Sept., 2016, Vol. 11, Issue 25, pp.2410-2415
Geotec., Const. Mat. & Env., ISSN: 2186-2982(Print), 2186-2990(Online), Japan

INVESTIGATION OF THE HYDRAULIC EFFICIENCY OF SAND - NATURAL EXPANSIVE CLAY MIXTURES

Abdullah A. Shaker[1] and Tamer Y. Elkady [1 2]

[1] Abdullah Bugshan Research Chair in Expansive Soils Civil Engineering Department, College of Engineering, King Saud University, Riyadh, Saudi Arabia

[2] Soil Mechanics and Foundation Research Laboratory, Faculty of Engineering, Cairo University, Giza, Egypt

ABSTRACT: The aim of this study is to evaluate the hydraulic performance of a sand-natural expansive clay mixture in comparison with sand-bentonite mixture. Natural expansive clay used in this study was obtained from Al-Qatif region, Saudi Arabia. The saturated hydraulic conductivity was evaluated for different mixtures of sand-Al Qatif clay with clay contents ranging from 10% to 60% clay. Similarly, the saturated hydraulic conductivity of sand-bentonite mixtures with different bentonite contents (0%, 5%, 10% and 20%) was also evaluated. All hydraulic conductivity tests were performed under different confining pressures. Test results revealed that sand-Al-Qatif clay mixtures can perform adequately as a hydraulic barrier; however, with Al-Qatif clay contents greater than that used for sand-bentonite mixtures. This is attributed to difference between clay mineralogy between Al-Qatif clay and bentonite. In addition a quantitative approach is proposed to assess the hydraulic conductivity of sand-Al-Qatif clay mixtures in comparison to that for sand-bentonite mixtures. Finally, soil fabric of mixtures was examined using scanning electron microscope (SEM) technique to observe differences in fabric between sand-Al-Qatif clay and sand-bentonite mixtures.

Keywords: Expansive clay, Hydraulic conductivity, Sand, Mixture, Barrier

1. INTRODUCTION

The rapid growth of oil industry in the eastern region of Saudi Arabia generates enormous quantities of hazardous wastes. In order to avoid the ground water contamination with these hazardous wastes provision of proper hydraulic barriers is of utmost importance. These barriers are usually constructed using sand-clay mixtures. Current practices employ construction of hydraulic barriers using mixture of high plastic expansive clay with sand. Bentonite is commonly used in these mixtures because of its high swelling potential that provide better sealing characteristics with small clay content [8].

The call for utilizing local resources is always well received as it provides an alternative to costly imported foreign materials. Several researchers investigated the use of natural clays as a hydraulic barrier. "Reference [13] investigated the use of Oman shale in liners". "Reference [12] investigated the use of some type of shale in waste disposal landfills in Nigeria". "Reference [13] studied the permeability of clay liners of some geological formations and different depositional basins in Turkey".

General specifications of hydraulic barriers can vary from one project to another. Some tolerance on the amount of water to be allowed to pass can be considered. "References [9] and [15] suggested specifications for liner material in which the coefficient of hydraulic conductivity (cm/s) was put as ($10^{-6} < k < 10^{-8}$)".

The aim of this paper is to investigate the efficiency of a mixture of sand-Al Qatif (natural) expansive clay as a hydraulic barrier. The main efficiency criteria considered in this study is hydraulic conductivity. Test parameters considered in this study included clay content (10%, 20%, 30%, 40% and 60% by dry weight of sand and confining pressure (50, 100, 200 and 400 kPa). The relative performance of the proposed sand-Al-Qatif clay mixture with respect to sand bentonite mixtures with bentonite contents ranging from 5% to 20% by dry weight of sand was evaluated. In addition, SEM technique was used to examine the different fabrics emerged for sand-Al-Qatif clay and sand-bentonite mixtures at different clay contents.

2. MATERIALS

The sand used in this study was locally processed sand which is typically used in concrete construction in Saudi Arabia. The grain size distribution of sand is presented in Fig. 1 and its specific gravity is 2.66. Values corresponding to coefficients of uniformity and curvature are C_u = 1.737 and C_c=1.078; respectively.

The natural expansive clay used in this study was sampled from the town of Al-Qatif. Al-Qatif, which is a historic, coastal oasis region located on the western shoreline of the Arabian Gulf in the Eastern Province of Saudi Arabia. Geotechnical and mineralogical characterization of this expansive clay was documented by [1], [2] and [10]. This expansive clay is considered highly expansive in nature due to the presence of high smectite mineral content [7]. Soil samples were obtained from a test pit excavated to a depth of about three meters. Samples were transferred to laboratory for complete geotechnical, chemical and mineralogical characterization. Tables 1 and 2 summarize the Geotechnical and chemical properties of Al-Qatif clay, respectively. Figure 2 shows the X-Ray diffraction X-Ray diffraction (XRD) intensity diagram. From this figure (Fig. 2), it is apparent that the main swelling clay minerals are montmorillonite and attapulgite (palygorskite).

The bentonite used in this study was sodium type obtained by a local supplier. Bentonite is commercially used as drilling mud for boring activities in Saudi Arabia. Tables 1 and 2 summarize the geotechnical and chemical characteristics of bentonite, respectively. The mineralogical analysis of bentonite using XRD technique indicated that the main clay mineral is montmorillonite minerals along with quartz, feldspar and hematite minerals as shown in Fig. 3.

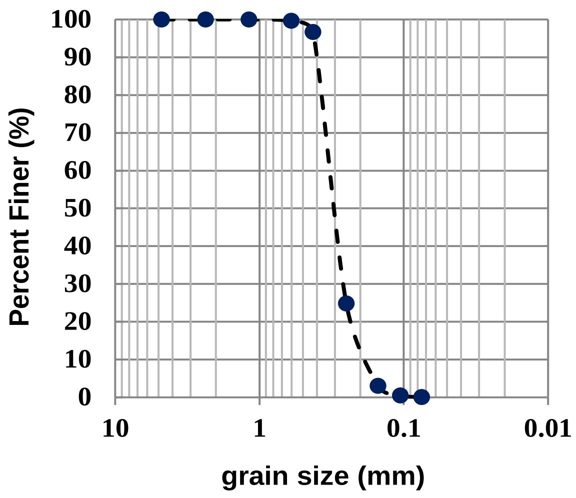
Table 1 Geotechnical characteristics of Al-Qatif clay and bentonite

Property	Al-Qatif Clay	Bentonite
	Index parameters	
Specific gravity, G_s	2.75	2.70
Liquid limit, LL (%)	140	480
Plastic limit, PL (%)	45	50
Plasticity index, PI (%)	95	430
USCS	CH[1]	--
	Swelling Characteristics	
Swelling pressure(kN/m^2)	550-600	--
Swelling potential (%)	16-18	--

(1)CH refers to clay with high plasticity

Table 2 Chemical composition of Al-Qatif clay and bentonite

Chemical Compound	Al-Qatif Clay	Bentonite
Na_2O	0.5	0.83
MgO	4.92	3.07
Al_2O_3	15.82	14.38
SiO_2	55.86	47.25
K_2O	5.22	0.57
CaO	1.74	3.87
FeO	9.39	21.36
ZnO	---	0.92



Fie.1 Grain size distribution of sand

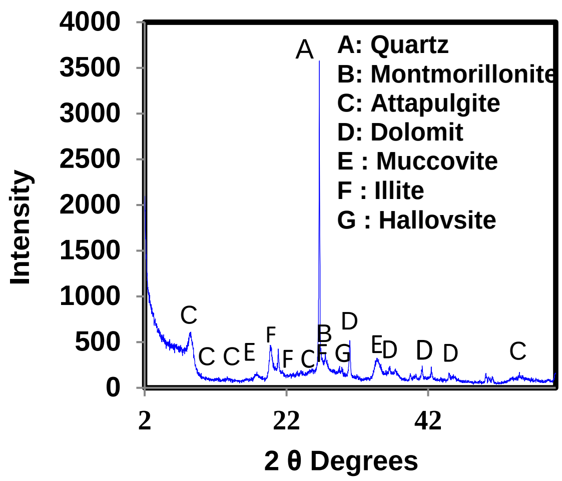


Fig.2 X-Ray diffraction of Al-Qatif clay

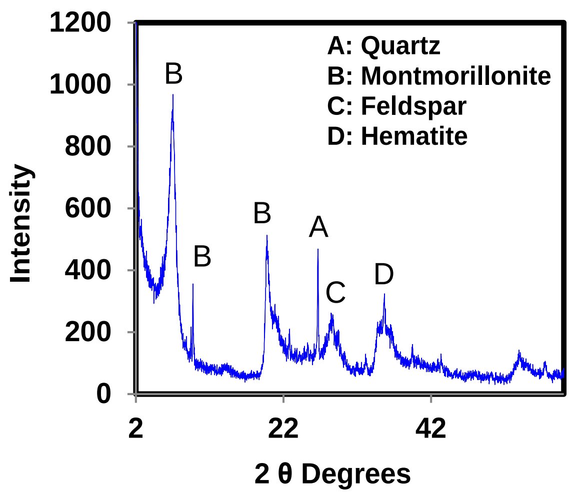


Fig.3 X-Ray diffraction of bentonite

3. TESTING METHODS

3.1 Sample Preparation of Mixtures

In this study, two types of mixtures were fabricated for the laboratory testing program. The first was sand-Al-Qatif expansive clay mixtures with clay contents of 0%, 10%, 20%, 30%, 40% and 60% by dry weight of sand. The second mixtures were sand-bentonite with bentonite contents of 0%, 5%, 10% and 20% by dry weight of sand. The sand-bentonite mixture was used to provide basis of comparison for the sand-Al-Qatif clay mixtures.

The natural expansive clay (Al-Qatif) obtained from the field was air-dried, pulverized and sieved using sieve No. 40 to form clay powder. Desired proportions of oven-dried sand and powder clay (whether Al-Qatif or bentonite) were hand mixed under dry conditions to obtain a homogenous blend. Desired water content was then added and mixed thoroughly and stored in plastic bags overnight in humid environment to allow time for the soil particles to hydrate as recommended by [4]. Test samples were statically compacted to initial molding conditions corresponding to maximum dry unit weight and optimum moisture content for each sand-clay mixture. Final dimensions of samples were 70 mm in diameter and 34 mm high for hydraulic conductivity tests.

3.2 Index Properties of Mixtures

The basic index properties of sand-Al-Qatif clay and sand-bentonite mixtures were evaluated for different clay contents. Tests performed included specific gravity tests [3] and Atterberg limits [5]. Specific gravity values are summarized in Table 3.As shown in Table 3, a notable increase in specific gravity with increase in clay content. The liquid limit, plastic limit and plasticity index values for sand-Al-Qatif clay and sand-bentonite mixtures at different clay contents, are presented in Tables 4 and 5; respectively.

Table 3 Specific gravity values for different sand-Al-Qatif clay and sand-bentonite mixtures

Clay Content (%)	Specific Gravity	Bentonite Content (%)	Specific Gravity
0	2.66	0	2.66
10	2.67	5	2.67
20	2.67	10	2.68
30	2.68	20	2.7
40	2.68		
60	2.69		

Table 4 Atterberg limits of sand-Al-Qatif clay mixtures

Clay content (%)	LL (%)	PL (%)	PI (%)
0	NA	NA	NA
10	NA	NA	NA
20	29	17.6	11.4
30	36	18.5	17.5
40	43	19.9	23.1
60	60	22.2	37.8

Table 5 Atterberg limits of sand-bentonite mixtures

Bentonite content (%)	LL (%)	PL (%)	PI (%)
0	NA	NA	NA
5	NA	NA	NA
10	36	23.6	12.4
20	62	27	35

3.3 Compaction Curves for Mixtures

The compaction curves for all sand-Al-Qatif mixtures and sand-bentonite mixtures were carried out in accordance with standard proctor compaction method [4]. Figures 4 and 5 show the variation of compaction curves as a function of clay content for sand-Al-Qatif clay and sand-bentonite mixtures; respectively. For sand-Al-Qatif clay mixtures (Fig. 4), it is apparent that as, the clay content increases, the maximum dry unit weight increases reaching a peak value between 20% and 30% clay content. However, as the clay content increased beyond this value (i.e., 25%), the maximum dry unit weight decreases with increase in clay content. Similar trend was observed for sand bentonite mixtures (Figure 5) with the peak value of maximum dry unit weight observed at 10% bentonite content. These compaction curves will be used to determine the initial molding conditions considered in this study.

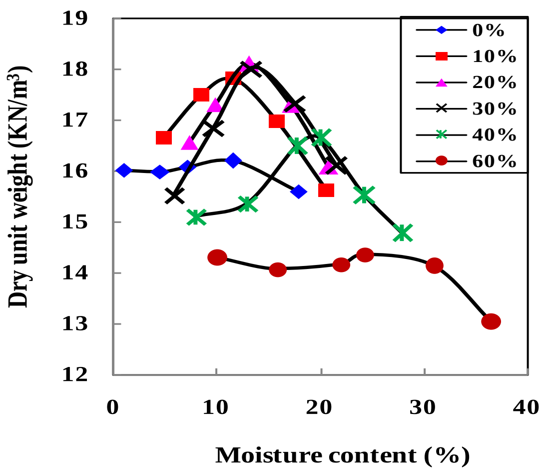


Fig.4 Compaction curves of sand-Al-Qatif clay mixtures with different clay contents

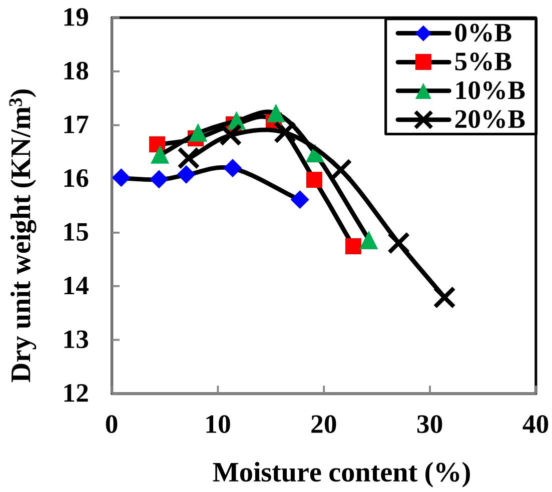


Fig.5 Compaction curves of sand-bentonite mixtures with different bentonite contents

3.4 Hydraulic Conductivity Test

The saturated hydraulic conductivities of sand-Al-Qatif clay and sand-bentonite mixtures were evaluated using flexible wall constant head permeameter. Confining pressures considered in this test series ranged from 50 to 400 kPa. Tests were performed under constant tin accordance with [6]. This procedure includes four test stages: specimens soaking, backpressure saturation, consolidation and permeation. Permeation through the test samples was conducted under a constant hydraulic gradient (i) of 30.

4. DISCUSSION AND TEST RESULTS

A comparison of hydraulic conductivities of evaluated for sand-Al-Qatif clay and sand-bentonite mixtures are presented in Fig.6. From this figure, it is observed that the hydraulic conductivity of sand-bentonite mixtures is much lower than that for sand-Al-Qatif clay mixtures. This is attributed to differences in clay mineralogy between Al-Qatif and bentonite clay. In other words, bentonite has a high swelling ability due to the presence of high percentage of montmorillonite mineral as compared to Al-Qatif clay. This swelling ability promotes the better sealing of sand voids even under low clay content.

Furthermore, it is noted that sand-bentonite mixtures with 5% bentonite content can produce a hydraulic conductivity equivalent to that of 30% Al-Qatif clay content, also the 10%, 20% bentonite content can produce a hydraulic conductivity equivalent to that of 40%, 60% Al Qatif clay content; respectively. Sand-Al-Qatif clay mixtures with clay contents greater than 40% can match the hydraulic conductivity requirements of hydraulic barrier ($K=10^{-7}$ cm/s) as shown in Fig. 6.

To quantitatively assess the hydraulic conductivity of sand-Al-Qatif clay mixtures in comparison to that for sand-bentonite mixtures, a simple index termed hydraulic conductivity performance ratio (HCPR) was proposed and is defined as follow:

$$(\text{HCPR}) = \frac{Log(K\ of\ _{\text{sand-Al\_Qatif clay}})}{Log(K\ of\ _{\text{sand-bentonite}})} \qquad (1)$$

The HCPR of sand-Al-Qatif clay mixtures are summarized in Table 6 for samples at 10% and 20% clay content. From this table, it is noted that the hydraulic conductivity performance ratio depends on confining pressure and ranges between 0.48 and 0.59.

Table 6 Hydraulic conductivity performance ratio of sand-Al-Qatif clay mixture at 10% and 20% clay content

Confining Pressure (kPa)	Performance ratio (HCPR) of mixture	
	10%	20%
50	0.57	0.48
100	0.57	0.48
200	0.56	0.5
400	0.59	0.5

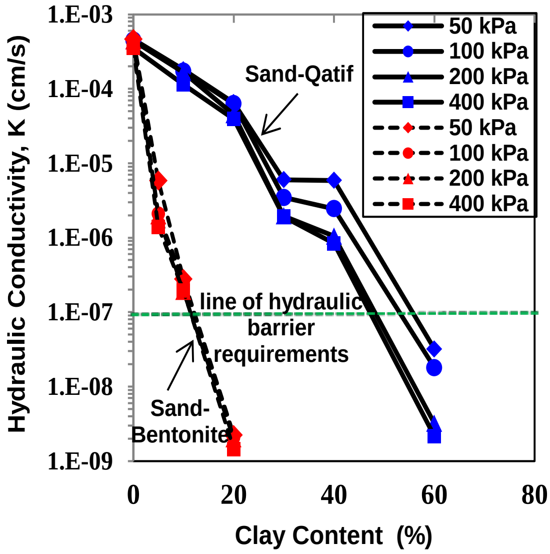


Fig.6 Variation of hydraulic conductivity of sand-Al-Qatif clay mixtures and sand-bentonite mixtures with clay content

4.1 SEM Investigation

The fabric of sand-Al-Qatif clay and sand-bentonite mixtures was observed using scanning electron microscope (SEM) technique. SEM was performed using Joel apparatus (Model JSM-6380 LA). Micrographs of SEM investigations for both mixtures at 20% clay content are shown in Figs 7 and 8 for sand-Al-Qatif clay and sand-bentonite mixtures; respectively. From these micrographs, it was observed that, for sand-Al-Qatif clay mixtures clay partially filled the void and coated the sand grains while grain-to-grain contacts are maintained which, in turn, control the behavior of the mixture. Micrographs for sand-bentonite mixture with same clay content (i.e., 20%) showed that the clay particle assemblages were observed to occupy the voids between sand grains and develop connectors between sand grains. This leads to a significant reduction in hydraulic conductivity of sand-bentonite mixtures Compared to the hydraulic conductivity of sand-Al-Qatif clay mixture at same clay content.

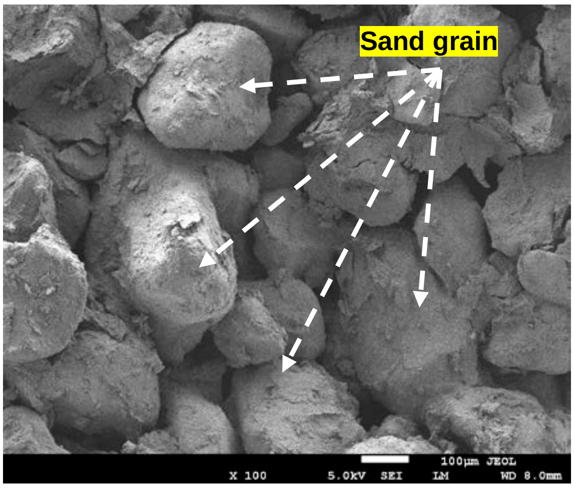


Fig.7 SEM of sand-Al-Qatif clay mixtures mixture with 20% clay content

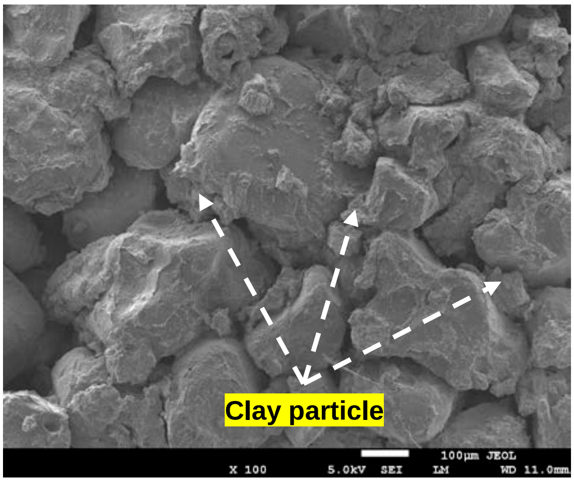


Fig.8 SEM of sand-bentonite mixtures mixture with 20% clay content

5. CONCLUSIONS

Based on this investigation, the following conclusions can be derived:

1- The clay content had a significant impact on the hydraulic conductivity of sand-Al-Qatif clay mixtures; whereas, confining pressure was observed to have a pronounced effect on K at clay contents greater than 30%.

2- The hydraulic conductivity of sand-bentonite mixtures was to be much lower than that for sand-Al-Qatif clay mixtures. This difference is attributed to the difference in clay mineralogy of Al-Qatif and bentonite clay.

3- The HCPR proposed in this study can be used as a quantitative approach to evaluate the hydraulic conductivity of sand-natural clay mixtures with respect to that of sand-bentonite mixtures. The HCPR for sand-Al-Qatif clay ranged between 0.48 and 0.59.

4- The SEM investigation for sand-Al-Qatif clay mixtures showed that the part of the clay particles reside in the voids between the sand grains at clay contents 20%. As for sand-bentonite mixtures at the same clay content observed, the gaps between sand grains are hardly visible and filled with clay causing a significant decrease in hydraulic conductivity.

5- Al-Qatif clay was found to satisfy the hydraulic conductivity requirements for liners when 40 % clay or more is used.

6. ACKNOWLEDGEMENTS

This paper was financially supported by King Saud University, Vice Deanship of Scientific Research Chairs.

7. REFERENCES

[1] Abduljauwad, S N, "Characterization and chemical treatment of Expansive clay in AlQatif.", International Journal of Rock Mechanics and Mining Sciences &Geomechanics Abstracts, Volume 29, Issue 4, July 1992, Page 226.

[2] Al-Shamrani, M.A., Mutaz,E., Puppala, A.J., and Dafalla, M.A. "Characterization of Problematic Expansive Soils from Mineralogical and Swell Characterization Studies.".American Society of Civil Engineers,Geoflorida, Florida, 2010, No.199, pp. 793-802.

[3] ASTM D854-02. “Standard test methods for specific gravity of soils.” Annual book of

ASTM standards, section 4, vol. 04.08, Soil and rock; Building stones, ASTM, PA
[4] ASTM D 698-00. “Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort.” Annual Book of ASTM Standards, Section 4, vol. 04.08, Soil and Rock; Building Stones, ASTM, PA.
[5] ASTM D4318-00. “Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.” Annual Book of ASTM Standards, Section 4, vol. 04.08, Soil and Rock; Building Stones, ASTM, PA.
[6] ASTM D5084-03. “Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter.” American Society for Testing and Materials, West Conshocken, PA.
[7] Azam. S, Influence of mineralogy on swelling and consolidation of soils in eastern Saudi Arabia. Can Geotech J, 2003, 40(5):964–975.
[8] Chapuis, R.R. “Sand-bentonite liners; Predicting permeability from laboratory tests.” Canadian Geotech. Journal, 1990, 27, 47–57.
[9] Daniel, D.E, "Geotechnical practice for waste disposal."Chapman and Hall, London, 1993.
[10] Dhowian, A.W., Ruwiah, I., AndErol, A."The Distribution and Evaluation of the Expansive Soils in Saudi Arabia."2nd Saudi Engineering Conference, KFUPM, Dhahran, Vol.4, 1985.
[11] Langdon, N.J., Al Hussaini, M.J.,Walden,P.J., and Sangha, C.M, “An assessment of permeability of clay liners: two case histories”. Geological society,London, Engineering Geology Special publications, 1996.
[12] Obrike, S.E., Osadebe, C.C., and Omoniyi, S.S, "Geotechnical analysis of two Nigerian soils for use as clay liners."Bulletin of Engineering Geology and the Environment, 2009, Volume 68, issue 3, p. 417 – 419.
[13] Rawas,A.A.,Yahiae, A.M., Abdulaziz, S.A., and Salem, A. "sand–attapulgite clay mixtures as a landfill liner."Geotechnical and Geological Engineering, 2006, 24: 1365–1383.
[14] Rowe RK, Quigley RM, Booker JR,"Clayey barrier systems for waste disposal facilities". E and FN Spon, 1995.

International Journal of GEOMATE, Sept, 2016, Vol. 11, Issue 25, pp.2410-2415.
MS No. 5134 received on July 19, 2015 and reviewed under GEOMATE publication policies.

Pertinent discussion including authors’ closure, if any, will be published in Sept. 2017 if the discussion is received by March 2017.
Corresponding Author: Abdullah A. Shaker