Continental J. Earth Sciences 4: 23 - 33, 2009

ASSESSMENT OF GEOTECHNICAL PROPERTIES OF MIGMATITE-DERIVED RESIDUAL SOIL FROM ILORIN, SOUTHWESTERN NIGERIA, AS BARRIER IN SANITARY LANDFILLS

Olusegun O. Ige
Department Of Geology And Mineral Sciences,
University Of Ilorin, P.M.B 1515, Ilorin, Nigeria
Email: Vickyige2002@Yahoo.Com

ABSTRACT
This study investigates the geotechnical properties of a migmatite - derived soil from southwestern Nigeria for its potential use as barrier in sanitary landfill. The required parameters for soils to be considered as barrier such as grain size distribution, Atterberg consistency limits, maximum dry density (MDD) and the coefficient of permeability were determined. Results obtained show that the hydraulic conductivity is lower than the suggested limit (1 x 10^{-7}cm/s) of the various waste regulatory agencies. In addition, it has adequate basic geotechnical properties, strength and the shrinkage potential upon drying. These properties suggest the potential suitability of the soil as a barrier in containment facility for disposal of waste material.

KEYWORDS: Barrier, Hydraulic conductivity, Residual soil, Unconfined shear strength

INTRODUCTION

Waste material in waste containment facilities are made isolated from the surrounding environment by providing liners barriers. The barrier is to control or restrict the migration of pollutant into the environment. Commonly use barriers are composed of natural inorganic clays or clay soils. The low hydraulic conductivity of the compacted clayey soils combined with their availability and relatively low cost make them potential materials to use as barriers in sanitary landfills for environmental protection. Since it is desirable for containment system to achieve its purpose at minimum cost; careful consideration should therefore be given to the choice of materials for the construction of the barrier. The environmental and health hazards associated with "unengineered" landfills are well known (Ige, 2003; Asiwaju-Bello and Akande, 2004; Onipede and Bolaji, 2004, and Fred and Anne, 2005). In the U.S.A, Fred and Anne (2005) asserted that 75% of unengineered landfills pollute adjacent water body with leachate. This is because deposited waste undergoes degradation through chemical reaction thereby contaminating usable surface and subsurface water supplies. In addition, the produced leachate forms complexes with the sesquioxides of lateritic soil (Orlon and Yeroschicheva, 1967) thereby weakening their in-situ geotechnical properties (Ogunsanwo and Mands, 1999).

Migmatite-derived residual soils, like other soils of basement complex origin, are widely distributed over the country. Its traditional geotechnical properties have been studied (Alao, 1983; Ogunsanwo, 1988, 1996, Adeyemi, 2002). The potential use of the soil will reduce cost of construction of sanitary landfills and encourage friendly environment. However, for soil usefulness as barrier, certain recommendations have been proposed by several previous investigators (e.g ÖNORM S 2074, 1990; Daniel, 1993; Bagchi; 1994, Benson *et al*, 1994,Benson and Trust, 1995 and Ogunsanwo, 1996). See Table 1 for the list of some of the required geotechnical parameters with the recommendations. Also minimum unconfined pressure of 200kPa (Daniel, 1993) and volumetric shrinkage upon drying of less than 4% was proposed (Daniel and Wu, 1993; Tay *et al*, 2001).

This study aims at assessing the geotechnical properties of a migmatite-derived residual soil for potential usage as barriers in landfills. The typical tests that are generally used to investigate soil proposed as barriers in landfill such as the grain size distribution, Atterberg limits compaction, unconfined compressive strength; volumetric shrinkage and hydraulic conductivity were conducted on sample of the compacted migmatite residual soil. If on the basis of these tests, the soil proves to have properties desirable for a barrier material, then it should be considered as a potentially suitable material for the isolation of waste material in sanitary landfill.

BARRIER IN SANITARY LANDFILLS

Barriers are natural clayey soils or artificial (geomembrane) impermeable materials used in sanitary landfills to prevent migration of waste leachate into groundwater body. The barrier is placed within the top sealing system to prevent percolation of run-off and precipitation into the waste column and within the bottom sealing system to prevent migration of generated leachate into the groundwater bodies (Fig. 1). Different types of seals such as clayey soils, synthetic membranes (artificially manufactured mixtures: bentonite, asphalt, cement) have been extensively studied by Bagchi (1994). The choice of residual migmatite-derived soils is emphasized in this report because of its natural occurrence and abundance at the studied locality.

MATERIALS AND METHODS

The material used for this study was migmatite-derived residual soil. The soil was obtained from the bottom of a waste disposal landfill, 2.4km along Ita-Amo/Peke road in Ilorin, Nigeria. The already excavated surface for the purpose of waste disposal prevents the interaction of humus soil, plant roots with the sampling depth and provides good access for soil sampling. The sample was collected into a plastic bag and transported to the soil laboratory of the Yaba college of Technology, Yaba, Lagos. The basic test such as specific gravity, particle size distribution and Atterberg limits of the soil were performed according to British Standard (BS 1377:1990). The data of these index properties were used to classify the soil following the Unified Soil Classification System (USCS) classification.

SAMPLE PREPARATION

The soil was air dried and crushed into small pieces. The crushed sample was then sieved through 4.75mm opening. The sieved soil was wetted with tap water (PH= 7.4) then the moistened soil was sealed in a plastic bag and stored for 3 days to allow moisture equilibration and hydration (BS 1377, 1990). The soil was later used for other geotechnical tests. The tests were conducted in duplicate for each particular soil condition to ensure the reliability of the test result. The average result of the two tests is presented in this report.

The soil was compacted with two different Proctor energies (modified and standard) which represent the commonly used energy of compaction on the field as recommended by Daniel and Benson (1990) and Daniel and Wu (1993). The hydraulic conductivity was measured using the rigid-wall permeameter under falling head condition as recommended by Head (1994). Compaction was carried out on the soils at two different energies under different water contents within the permeameter moulds. The permeant liquid was tap water and hydraulic gradient was 15. Permeation was conducted on the sample until steady condition was achieved. The volumetric shrinkage upon drying was measured by extruding compacted cylindrical specimens from the compaction mould and allowing the cylindrical specimen to dry on the laboratory table on an air-condition room (Daniel and Wu, 1993). Everyday the diameter and the height of samples were recorded with a digital caliper (accuracy 0.01). At each reading a minimum of three heights and three diameter measurements for each height at interval were recorded. The average diameter and height were used to compute volume, and the measurements were continued until the volume seized to change further. The unconfined compression test was performed in accordance with the BS 1377: 1990 procedures. The tests were performed on cylindrical specimens having a diameter and length of 50mm and 100mm respectively, which were trimmed from the larger compacted cylinders.

RESULTS AND DISCUSSION

Several limits have been proposed by various researchers with respect to the geotechnical properties of soil to be useful as barrier. Such limits are presented here along with the results obtained from this study.

Grain Size Distribution

The specific gravity of the granite residual soil is about 2.73. The particle size analysis shows that the soil contains 53% clay (<0.002mm), 70% fines (<0.075mm), 35% sand. Moreover, the results of Atterberg limits reveal the liquid limit (LL) is 68%, the plastic limit (PL) is 35% and the plasticity index (PI= LL-PL) is 33%. On the basic of these data, the migmatite residual soil is classified as CH (Inorganic clay with high plasticity) according to the USCS. Inorganic clay with high plasticity (CH) is recommended for landfill liner (Oweis and Khera, 1998).

The soil has similar properties to cohesive soils, and therefore is likely to have desirable characteristics to minimize hydraulic conductivity. The hydraulic conductivity value of the liner material is used as the principal indicator of its containment potential. Hydraulic conductivity behaviour of soil barrier is greatly influenced by the particle size distribution because the relative proportions of large and small particle sizes affect the size of voids conducting flow (Kabir and Taha, 2006). Barrier soils should have at least 30% fines (Daniel 1993b; Benson *et al*; 1994) and 15% clay (Benson *et al,* 1994) to achieve hydraulic conductivity $\leq 1\times10^{-7}$ cm/s. Thus, the migmatite-derived residual soil can be used as barrier to achieve a hydraulic conductivity $\leq 1\times10^{-7}$ cm/s, as it possesses suitable amount of clay and fine fractions. Moreover, the soil contains adequate amount of sand, which may offer notable protection from volumetric shrinkage and impart adequate strength as well.

Liquid limit is an important index property since it is correlated with various engineering properties. Soils with high liquid limit generally have low hydraulic conductivity. Benson *et al* (1994) recommended that the liquid limit of the liner material be at least 20%. However, soils with very high liquid limit have poor volume stability and high shrink-swell potentials (Kabir and Taha, 2006). Most of the specifications for soil liners proposed by various researchers or waste regulatory agencies do not generally prescribe any limit (maximum value) for their liquid limit. As long as it does not create any working problem, soils with high liquid limit are generally preferred because of their low hydraulic conductivity. Thus, the migmatite residual soil with liquid limit of about 68% appears to be promising for use as barrier.

The plasticity index is one of the most important criteria for the selection of soils as barrier in sanitary landfill construction. It is the key property in achieving low hydraulic conductivity. Literatures suggest that the plasticity index must be more than 7% (Daniel 1993; Benson *et al*; 1994; Rowe *et al,* 1995). However, extremely high plasticity soil becomes sticky when wet and then becomes difficult to work with in the field. Also high plasticity soil forms hard lumps when they are dry and are difficult to break down during compaction. The hard lumps, if not properly compacted, form zones of higher hydraulic conductivity. Moreover, a high plasticity soil tends to be more susceptible to desiccation cracking. For plasticity index value greater than 65, excessive shrinkage can be expected (Daniel, 1991). Thus, the migmatite residual soil has suitable plasticity property (PI is about 33%) to minimize hydraulic conductivity and shrinkage susceptibility as well.

The activity (PI/% clay fraction) of migmatite residual soil is about 0.62. Thus, according to Skempton's classification it is inactive clay. Inactive clayey soils are the most desirable materials for compacted soil barrier (Rowe *et al,* 1995). In order to achieve a hydraulic conductivity $\leq 1\times10^{-7}$ cm/s for the soil barrier, soil with an activity of > 0.3 has been specified (Benson *et al,* 1994, Rowe *et al,* 1995). An activity is an index of the surface activity of the clay fraction. Soils with higher activity are likely to consist of smaller particles having larger specific surface area and thicker electrical double layers (Kabir and Taha, 2006). Therefore, hydraulic conductivity should decrease with increasing activity. However, soils with higher activity are more readily affected by chemical pollutant if they are used in containment structures (Oweis and Khera, 1998).

Thus, the comparison between the index properties of migmatite-derived residual soil and the index properties as recommended by various researchers for a good barrier material shows that the investigated migmatite residual soil has suitable properties to use as barrier material.

COMPACTION PROPERTIES.

In the construction of barriers, compaction is done to achieve a soil layer of improved engineering properties. Compaction of soil results in homogenous mass that is free of large, continuous inter-clods voids; increase their density and strength, and reduce their hydraulic conductivity. Hydraulic conductivity is the key design parameter when evaluating the acceptability of a barrier material. Low hydraulic conductivity is achieved when the soil is compacted close to its maximum dry density and corresponding optimum water content for a soil under a specific compactive effort.

The compaction curves for the migmatite-derived residual soil are shown in Fig 2. The compaction curves clearly illustrate that the dry density is the function of compaction water content and compactive effort. For each compactive effort, at the dry side of optimum water content, the dry density increases with the increasing water content. This is due to the development of large water film around the particles, which tends to lubricate the particles and makes them easier to be moved about and reoriented into a denser configuration (Holtz and Kovacs, 1981). Whereas, at the wet side of optimum water content, water starts to replace soil particles in the compaction mould and since the unit weight of water is much less than the unit weight of soil, the dry density decreases with the increasing water content.

The curves (Figure 2) are single peaked and parabolic in shape, which is typical of most clayey soils (Kabir and Taha, 2006). This is expected since the liquid limit of the soil is between 30% and 70% (Lee and Suedkamp, 1972). The peaks represent the maximum dry density and corresponding optimum water content for a given compactive effort. The maximum dry density and the optimum water content obtained from these tests are given in Table 2. An increase in compactive effort increases the maximum dry density but decreases the optimum water content (Daniel, 1994). Because higher compactive effort yields a more parallel orientation to the clay particles, which gives a more dispersed structure, the particles become closer and a higher unit weight of compaction results (Das, 1998). Hence, a high compaction energy is preffered.

Hydraulic Conductivity

The relationship between hydraulic conductivity, water content and compactive effort is shown in Fig. 3. The hydraulic conductivity decreases with the increasing compactive effort because increasing compactive effort decreases the frequency of large pores and can eliminate the large pore mode (Acar and Oliveri, 1989). These changes in pore size yield lower hydraulic conductivity. The hydraulic conductivity also changes with the change of compaction water content. Soils compacted at dry of optimum water content tend to have relatively high hydraulic conductivity whereas soils compacted at wet of optimum water content tend to have lower hydraulic conductivity. Increasing water content generally results in an increased ability to breakdown clay aggregate and to eliminate inter aggregate pores (Mitchell *et al*, 1965; Benson and Daniel, 1990; Garcia-Bengochea *et al*, 1979). Moreover, increasing water content results in reorientation of clay particles and reduction in the size of inter particle pores (Lambe, 1954; Acar and Oliveri, 1989 and Benson and Trust, 1995). The hydraulic conductivity is the key parameter affecting the performance of most landfill barriers and covers (Daniel 1987, 1990 and Elsbury *et al*, 1990), thus great attention is generally focused on ensuring that low hydraulic conductivity is achieved. Therefore, it is usually preferred to compact the soil wet of optimum.

Barriers should have a hydraulic conductivity of at least 1×10^{-7} cm/s. Figure 3 shows that the two different compaction efforts caused hydraulic conductivity less than 1×10^{-7} cm/s. The minimum hydraulic conductivity and corresponding water content at various compactive efforts is represented in Table 3. In the case of each compactive effort the minimum hydraulic conductivity is obtained at water content of slightly (0.5 to 1.7%) wet of optimum water content. Generally the lowest hydraulic conductivity of clayey soil is achieved when the soil is compacted at water content slightly higher than the optimum water content (Mitchell *et al*, 1965; USEPA, 1989; Daniel and Benson 1990). This characteristic makes the soil suitableas barrier in sanitary landfill.

Volumetric shrinkage

Compacted soil barriers are subject to frequent desiccation due to evaporative water losses. Desiccation leads to the development of shrinkage. Cracks provide pathways for moisture migration into the landfill, which increases the generation of waste leachate, and ultimately increases the potential for soil and groundwater contamination. Thus, the soil barrier significantly losses its effectiveness as an impermeable barrier. Literature suggested that cracking is not likely to occur in clay barrier when compacted cylinders of the same soil undergo less than about 4% volumetric shrinkage strain upon drying (Daniel and Wu 1993; Tay *et al*, 2001)

In this study compacted cylindrical specimens were used to determine shrinkage potential of the soil. In the field, the soil shrinks under the overburden pressure. Soil shrinks simply due to water loss, which is independent of the pressure if water and soil particles are considered incompressible. Much information is not available on the relationship between overburden pressure and volumetric shrinkage of compacted soil. However, in this study, shrinkage tests were performed by allowing the specimen to dry at approximately 27˚C (the mean temperature in Nigeria) temperature to stimulate the slow rate of drying that occurs in the field (Briad *et al,* 2003). The cylindrical specimens began to shrink into smaller cylinders with volume changes occurring as the water surrounding the individual soil particles of the specimens is removed and the soil particles move closely together. During drying, the sides of the specimens were open to the atmosphere, which does not replicate the field condition. Nevertheless, the relative effects of soil type on volumetric shrinkage are supposed to be preserved. The result of volumetric shrinkage test is presented in Figure 4. Test results indicate that shrinkage strains are influenced by compaction conditions. Shrinkage increases with increasing compaction water content, but the relationship between compactive effort and shrinkage strain is less clear. At low compaction water contents, shrinkage decreases with increasing compactive effort. No clear trend is apparent at higher water contents. Similar results have been reported by other researchers (Klepe and Olson, 1985; Daniel and Wu, 1993). In this study, each of the two different compactive efforts shows little volume change behavior of less than 4%, which is typical maximum permissible limit for compacted clay soil barrier. Thus, if drying takes place, the compacted soil will undergo minimal shrinkage and desiccation cracking.

Unconfined Compressive Strength.

The result of unconfined compression test against compaction water content is shown in Figure 5. The strength of compacted soil decreases with increase of compaction water content. As the amount of water increases the electrolyte concentration is reduced, leading to an increase in diffused double layer. Expansion takes place at a distance between the clay particles as well as the distance between the aluminiosilicate unit layers increases, resulting in a reduction of both the internal friction and cohesion. Other researchers (Seed and Chan, 1959; Daniel and Wu 1993; Taha and Kabir, 2003) observed the same effect. Compactive effort has also a great influence on soil strength. At low compaction water content, unconfined compressive stress increases with increasing compactive effort. But at higher water content no clear trend is noticed: e.g at 24% compaction water content, modified Proctor effort results the lowest unconfined compressive stress among the two compactive efforts.

An isolation barrier used in waste containment system is supposed to sustain certain amount of static load exerted by the overlying waste materials. In this regard, the barrier material must have adequate strength for stability. The bearing stress act on the barrier system depends on the height of landfill and unit weight of waste. Thus, the minimum required strength of soil used for compacted soil barrier is not specified. Daniel and Wu (1993) arbitrarily selected them, to support the maximum bearing stress in a landfill. They mentioned that soil used as barrier material should have minimum unconfined compression strength of 200KPa. Test result shows (Fig.5) that the soil possesses higher strength than the recommended minimum strength of 200KPa for all the three compactive efforts.

CONCLUSIONS

The following conclusions can be drawn form the investigation of migmatite-derived residual soil:

(1) The residual soil is inorganic clay with high plasticity. Generally, this type of soil possesses desirable characteristics to minimize hydraulic conductivity, and is frequently used for the construction of compacted soil barriers.

(2) The index properties (liquid limit, plastic limit, % clay content, % fines, activity etc) of the soil satisfy the basic requirements as a liner material.

(3) It is inactive clayey soil. Thus, the soil will be less affected by waste leachate and less susceptible to shrinkage.

(4) The soil has hydraulic conductivity of equal to or less than 1×10^{-7} cm/s, when it is compacted with both modified and standard Proctor compaction efforts.

(5) Moreso, the soil has average strength in the range of 200KPa and volumetric shrinkage strain of less than 4%.

Thus, it is concluded that the migmatite-derived residual soil can be used as a suitable barrier material for isolating waste in sanitary landfills. Its potential use as isolation barrier will enhance the waste management programs in Nigeria since migmatite derived soils are locally readily available

Although the soil meets all the basic requirements as a good barrier material, it would be hard to work with due to its high plasticity. Therefore, during liner construction great attention should be focused on soil preparation. The soil should be properly blended and homogenized to achieve a mixture of relatively small clods with reasonably uniform moisture distribution.

ACKNOWLEDGEMENT
The author is very grateful to Prof. O. Ogunsanwo, Department of Geology, University of Ilorin, for reading through the draft of this paper.

REFERENCES
Acar, Y. and Oliveri,.I. (1989). Pore fluid effects on the Fabric and Hydraulic Conductivity of Laboratory Compacted Clay. Transportation Research Record, 1219, 144-159.

Alao, D. A. (1983): Geology and Engineering Properties of laterites from Ilorin, Nigeria. Journal of Engineering Geology. vol.19, 111-118.

Asiwaju-Bello, Y. A. and Akande, O. O. (2004). Urban groundwater pollution: Case study of a Disposal site in Lagos metropolis. Journal of Water Resources. 12, 22-26.

Bagchi, A. (1994). Design, Construction, and Monitoring of landfills. 2nd Edition. Wiley-Interscience Publication, New York, U. S. A, 361p

Benson, C.H., and D.E Daniel (1990). Influence of clods on Hydraulic conductivity of compacted clay. Journal of Geotechnical Engineering ASCE, Vol.116, (8), 1231-1248.

Benson, C. H. and Trust, J. M. (1995). Hydraulic Conductivity of Thirteen Compacted Clays, Clays and Clay Minerals, vol. 43, (6), 669-681.

Benson, C. H; Zhai, H. and Wang, X. (1994). Estimating Hydraulic Conductivity of clays liners. Journal of Geotechnical Engineering, vol.120, 2, 366-387.

Benson, C.H., D.E. Daniel, and G.P. Boutwell (1999). Field performance of Compacted clay Liners, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. 125, No. 5, pp 390-403.

Briad, J.L., X. Zhang, and S. Moon (2003). Shrinkage test – Water Content Method for Shrink and Swell Predictions, Journal of Geotechnical and Geoenvironmental Engineering, ASCE, vol. 129,(7), pp 590-600.

BS1377 (1990). Method of Testing soil for Civil Engineering purposes. British Standard Institute, London.

Daniel, D. E. (1987). Earthen Liners for Land Disposal Facilities. GeotechnicalPractice for Waste Disposal. vol.87, (13), (R.D Woods, Ed), New York, USA, ASCE, pp21-39.

Daniel, D. E. and Benson, C. H. (1990). Water Content – Density Criteria for Compacted soil liners Journal. of Geot. Eng. ASCE, 116, 12, 1811- 1830.

Daniel, D.E., (1990). Summary Review of Construction Quality control for Earthen Liners, in waste containment systems: Construction, Regulation, and performance, GSP, No. 26, (R. Bonaparte, Ed.), New York, ASCE, pp175-189.

Daniel, D.E., (1991). Design and Construction of RCRA/CERCLA final covers, Chapter 2: Soils used in cover systems. EPA. /625/4-91/025, US EPA,Cincinnati, Ohio.

Daniel, D.E., (1993). Clay Liners, in Geotechnical Practice for Waste Disposal, (ed. David. E Daniel) Chapman & Hall, London, UK, pp 137-163.

Daniel, D.E., Y.K, Wu (1993). Compacted Clay Liners and Covers for Arid sites, Journal of Geotechnical Engineering ASCE, vol. 119,(2), pp 223-237.

Das, B.M., (1998). Principles of Geotechnical Engineering, 4th Edition, PWS Publishing Company, USA.

Elsbury, B.R., D.E. Daniel, G.A. Srader, and D.C. Anderson (1990). Lessons learned from Compacted Clay Liner, Journal of Geotechnical Engineering, ASCE, vol. 116, (11), pp1641-1660.

Fred, L and Anne, J. (2005). Flawed technology of subtitle D. Landfill Municipal Solid Waste. Http. www.gfredlee.com.64p.

Garcia-Bengochea, I., C. Lowell, and A. Altshaeffi (1979). Pore Distribution and Permeability of Silty Clays, Journal of Geotechnical Engineering, ASCE, Vol.105, (7), pp 839-856.

Head, K.H., (1994). Manual of Soil Laboratory testing- Volume 2: Permeability, Shear Strength and Compressibility Test, Halsted Press, New York, USA.

Holtz, R.D. and W.D. Kovacs (1981). An Introduction to Geotechnical Engineering, Prentice-Hall, New Jersey.

Ige, O.O (2003). Impact of cultural and Industrial waste on surface and shallow groundwater along Asa River, Ilorin metropolis, Kwara State, Nigeria. University of Ilorin, M.Sc., thesis, unpublished, 108p.

Kleppe, J.H. and R.E. Olson (1985). Desiccation Cracking of Soil Barriers, Hydraulic Barrier in Soil and Rock, Special Technical Publication No. 874, ASTM, Philadelphia, PA, pp 263- 275.

Lambe, T.W., (1954). The Permeability of Compacted fine grained soils, Special Technical Publication, No. 163, American Society of Testing and Materials (ASTM), Philadelphia,USA, pp56-67.

Lee, D.Y. and R.J. Suedkamp (1972). Characteristics of Irregularly Shaped Compaction Curves of Soils, Highway Research Record, No. 381, pp 1-9.

Mitchell, J.K., Hooper, D., and R. Campanella, (1965). Permeability of Compacted Clay, Journal of Soil Mechanics and Foundation Division, ASCE, Vol. 91, (4), pp41-65.

Ogunsanwo, O. (1988). Basic Geotechnical Properties, Chemistry and Mineralogy of some Laterite soils from Southwestern, Nigeria. Bullettin of IAEG. 37, pp131-135.

Ogunsanwo, O. (1996). Geotechnical investigated of some soils from southwestern Nigeria for use as mineral seals in waste disposal landfills. Bulletin of I.A.E.G. 54, 119-123.

Ogunsanwo, O. and Mands. E. (1999): The role of geology in the evaluation of waste disposal sites. Journal of Mining and Geology vol. 33, 1, 83-87.

Onipede, M. A. and Bolaji, B. O. (2004). Management and disposal of industrial wastes in Nigeria. Nigerian Journal of Mechanical Engineering. 2, 1, 49-63.

ONORM S 2074 (Teil 2), (1990). Geotechnik in Deponiebau-Erdarbeiten. Osterrichisches Normungsinstitut, Wein.

Orlov, D. S and Yeroshicheva, N. L. (1967): Interaction of humic acids with the cations of some metals . Soviet Soil Science. vol. 12, 1799-1806.

Oweis, I.S., and R. P. Khera (1998). Geotechnology of waste management, 2nd Edition, PWS Publishing Company, USA.

Rowe, R.K., R.M. Quigley, and J.R. Booker (1995). Clayey barrier systems for waste disposal facilities, E & FN Spon, London, pp 404.

Seed, H.B., and C.K. Chan (1995). Structure and Strength Characteristics of Compacted Clays, Journal of Soil Mechanics and Foundation Division ASCE, vol. 85, (5) pp87-128.

Taha, M.R., and M.H. Kabir (2003). Sedimentary Residual Soil as a Hydraulic Barrier in Waste Containment Systems, In: Proceedings of the International Conference on Recent Advances in Soft Soil Engineering and Technology, 2-4 July 2003. Putrajaya, Malaysia.

Tay, Y.Y., D.I. Stewart, and T.W. Cousens (2001). Shrinkage and Desiccation Cracking in Bentonite-Sand Landfill Liners. Engineering Geology, Elsevier Science, Vol. 60, pp 263-274.

U.S. Environmental Protection Agency (1989). Requirements for Hazardous Waste Landfill Design, Construction, and Closure, Publication No. EPA-625/4-89-022, Cincinnati, Ohio.

TABLE 1: REQUIRED GEOTECHNICAL CRITERIA AND RECOMMENDATIONS FOR SOILS AS BARRIER

PARAMETERS	AUTHOR(S)	RECOMMENDATIONS
GRAIN SIZE ANALYSES	Oeltzschner (1992) Bagchi (1994) ONORMS 2074 (1990) ONORMS 2074 (1990) Daniel (1993b), Rowe et al 1995	Clay fraction <20% Largest Grain Size ≤63mm Silt/clay fraction ≥15% Largest grain size <25mm, %Gravel <30, % fine ≥30
ATTERBERG CONSISTENCY LIMITS	Daniel (1993b); Rowe et al(1995) Seymour & Peacock (1994) Oeltzschner (1992)	LL ≥30%, IP≥15% LL ≥30%, IP≥10% LL ≥30%, IP≥15% LL ≥25%, IP≥15% LL ≥30%, IP≥15% Inorganic Clay of low – medium plasticity(CL-CI) and Ac of <1.25
MOISTURE CONTENT-DENSITY RELATIONSHIPS	ÖNORMS 2074 (1990) Kabir and Taha (2006)	MDD ≥ 1.71t/m^3 MDD ≥ 1.74t/m^3
COEFFICIENT OF PERMEABILITY (*k*)	Murphy and Garwell (1998) Mark (2002) Joyce (2003) Fred and Anne (2005)	≤$1x10^{-9}$m/s ≤$1x10^{-9}$m/s ≤$1x10^{-9}$m/s ≤$1x10^{-8}$m/s ≤$1x10^{-9}$m/s

KEY: SP= Standard Proctor LL= Liquid Limit, MP= Modified Proctor IP= Index of Plasticity Ac= Activity of clay

Table 2. Maximum dry density and corresponding optimum water content.

Compactive efforts	optimum water content (w_{opt}%)	max.dry density, γ(KN/m^3)
Modified Proctor	20.7	16.33
Standard Proctor	26.2	14.51

Table 3: Minimum hydraulic conductivity and corresponding water content at various compactive efforts.

Compactive Efforts	Minimum hydraulic conductivity (cm/s)	Water content(%)at minimum hydraulic conductivity	Optimum water content (%)
Modified Proctor	2.2×10^{-8}	22.2	20.7
Standard Proctor	1.4×10^{-7}	27.9	26.2

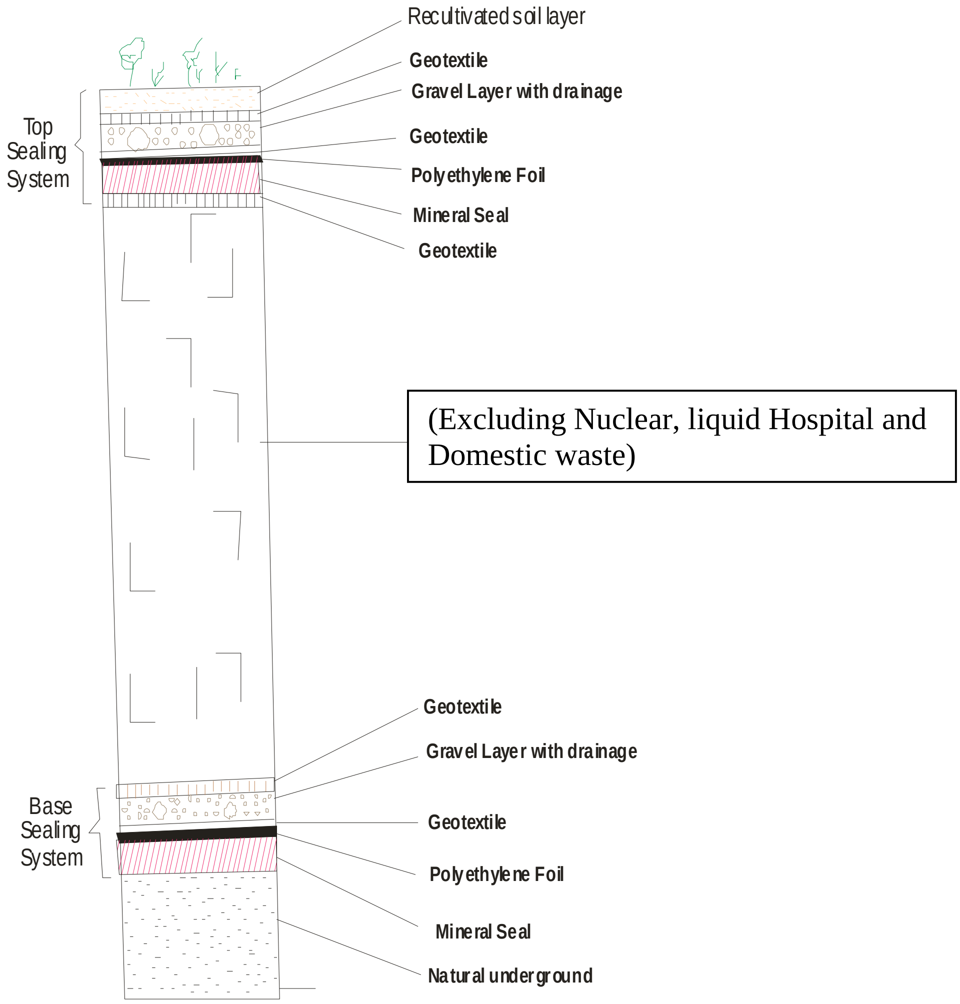

Fig.1: Section through a waste disposal sanitary landfill (Ogunsanwo, 1996).

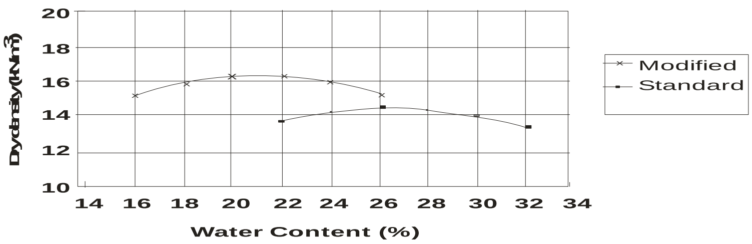

Figure 2. Compaction curves

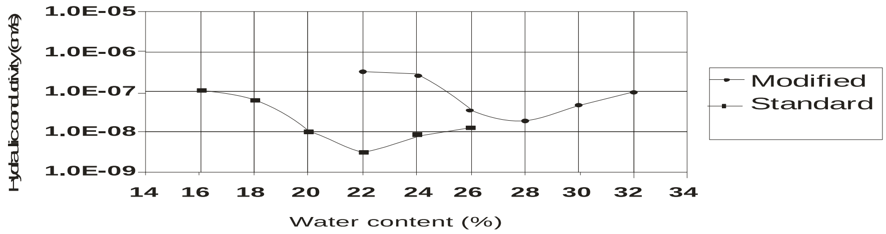

Figure 3: Hydraulic conductivity versus compaction water content

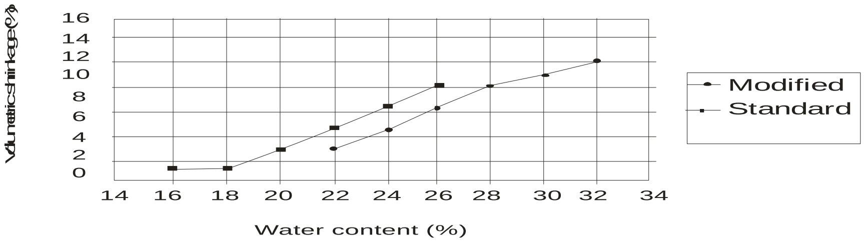

Figure 4: Volumetric shrinkage strain versus compaction water content

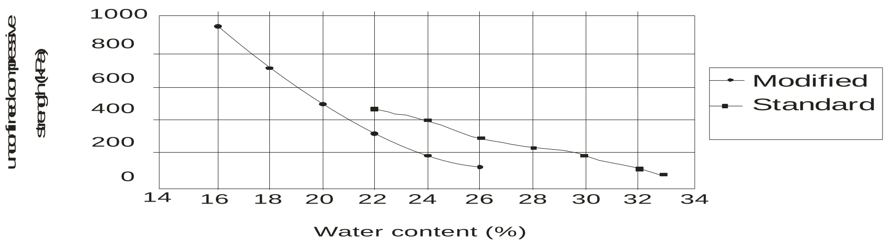

Figure 5: Unconfined compression strength versus compaction water content

Received for Publication: 23/04/09
Accepted for Publication: 27/06/09