Geotechnical analysis of two Nigerian soils for use as clay liners

S. E. Obrike · C. C. Osadebe · S. S. Omoniyi

Received: 21 January 2008 / Accepted: 14 November 2008 / Published online: 12 February 2009

Abstract The cretaceous Auchi shale and the Tertiary Imo shale in SW Nigeria were investigated for their suitability for use as a clay seal in waste disposal landfills. Geotechnical analyses indicated they are highly plastic inorganic clays. Although their geotechnical and chemical properties were within the range suggested by various authors for use as mineral seals, care would need to be taken with the Okada shales as they contain smectite and would be difficult to work and liable to cracking.

Keywords Clay liner · Landfill · Permeability · Waste disposal · Nigeria

Résumé Les schistes crétacés d'Auchi et les schistes tertiaires d'Imo dans le SW du Nigéria ont été étudiés pour leur aptitude à constituer des matériaux d'étanchéité sur les stockages de déchets. Les analyses géotechniques ont montré qu'il s'agit d'argiles inorganiques fortement plastiques. Bien que leurs propriétés géotechniques et chimiques les placent parmi les matériaux aptes à constituer des couches de scellement il apparaît nécessaire d'utiliser les schistes d'Okada avec prudence car ils contiennent des smectites. Leur mise en œuvre serait délicate et ils seraient susceptibles de se fissurer.

Mots clés Couverture argileuse · Remblai · Perméabilité · Stockage de déchets · Nigéria

S. E. Obrike (✉) · C. C. Osadebe
Nigerian Building and Road Research Institute,
P.M.B. 1055, Ota, Ogun State, Nigeria
e-mail: cosadebe1@yahoo.com

S. S. Omoniyi
Olabisi Onabanjo University, Ago-Owoye, Ogun State, Nigeria

Introduction

The most commonly employed waste disposal methods in developing countries are incineration and sanitary landfill. The acquisition and installation of incinerators is expensive whereas landfill sites are often available following construction work. In order to control movement of percolating water and leachate from a waste disposal site, low permeability membranes or seals are required. Daniel (1993a) divides these into artificially synthesized seals for hazardous wastes and constructed clay liners for non-hazardous waste. A third possibility is the use of a thin clay layer between two geotextiles.

The paper reports a study undertaken to identify suitable clay-rich deposits in Edo State, Southwestern Nigeria, which could be used for sanitary landfills for domestic and non-hazardous waste.

Sampling and testing

Two clay deposits were investigated: the Cretaceous Auchi shales obtained from a pit and some deep gullies 2 km from Auchi town (7°10′N, 6°20′E) and the Tertiary Imo shales obtained from a road cut and clay pit near Okada town (6°50′N, 5°20′E). The Auchi shales are dominantly dark in colour, although creamy white varieties are known north of Auchi town. The shales are fine grained, laminated and possess high plasticity when wet. The Okada shales are mottled dark to light grey and sometimes brownish in colour. They are essentially fine grained, very stiff and of high plasticity when moist.

Twenty representative soil samples were analysed, subjected to sieve analyses, classification, standard Proctor compaction and permeability tests, in accordance with

British Standard. Falling head permeability tests were carried out at maximum dry densities (MDD) of 95, 97, and 100%. The optimum moisture content was kept constant due to the difficulties of attaining 100% MDD in the field.

Results and discussion

Grain size distribution

The results of the grain size distribution curves indicated a clay content of 45% for the Auchi shale and 50% for the Okada shales. The largest grain sizes recorded (Okada shales) were <5 mm, within the range recommended by several authors (Wentz 1989; Jessberger 1994; Daniel 1993b). For the Okada shale, the sand fraction was 25% while for the Auchi shales it was 30%.

Atterberg limits

The mean values and range of Atterberg limits are given in Table 1. It can be seen that the Okada shale samples have much higher liquid limits than the Auchi shales, ranging from 142 to 148, 51 to 60%, respectively. The Okada shales have high plastic limits (76–80%) and hence a plasticity index of ca. 68%. This implies that they have a significant percentage of the clay mineral smectite. The Auchi shales have plastic limits of 28–33%, giving plasticity indices in the order of 27%.

Although many authors recommend high plasticity clays for natural liners, very high plasticity clays are difficult to handle when wet and are prone to extensive shrink/swell, forming clods separated by cracks. Parker et al. (1993) suggests such clods can be broken down if compacted with the use of sheep's foot or pad rollers and the material compacted in layers, typically less than 0.2-m in thickness. Seymour and Peacock (1994) recommended a maximum of $w_L < 90\%$ and $I_p < 65\%$ for soils to be used as liners.

Linear shrinkage tests indicated that the Okada shales had values in the order of 20% while for the Auchi shales they varied from 1 to 6%. The analyzed soils have specific gravity values of 2.51 and 2.62, just above the 2.5 minimum recommended in the Austrian Standards ONORM S 2074 (1990) and USEPA (1982).

Coefficient of permeability (*k*)

As seen in Table 2, the Okada shale samples have *k*-values in the order of 10^{-10} m/s at 95% MDD, 10^{-10} m/s at 97% MDD and 10^{-11} m/s at 100% MDD. For the Auchi shales, the values are in the order of 10^{-9} m/s at 95% MDD, 10^{-9} m/s at 97% MDD and 10^{-10} m/s at 100% MDD. For any soil to be considered suitable for use as mineral seal in a sanitary landfill, Wentz (1989), Daniel (1993a) and Seymour and Peacock (1994) recommend a *k*-value of $\leq 10^{-9}$ m/s, while Jessberger (1994) advocates $\leq 5 \times 10^{-10}$ m/s.

Compaction and liquidity index

The Auchi shales, which have a higher specific gravity and lower fines fraction than the Okada shales, have a mean optimum moisture content of 21% and mean MDD of 1.7 Mg/m^3. The Okada shale samples gave a mean optimum moisture content of 25.8% and an MDD of 1.48 Mg/m^3.

Chemical composition

The predominance of SiO_2 (55.76–47.54%), Al_2O_2 (20.6–20.68%) and H_2O in both the Okada and Auchi shales classifies them as hydrated alumino-silicates. As can be seen from Table 3, the main differences are with the iron and magnesium contents, which are much higher in the

Table 1 Geotechnical properties of analyzed samples (mean and range)

Deposit	Specific Gravity	Grain size fraction (%)				Atterberg limit (%)				Description
		Gravel	Sand	Silt	Clay	w_L	w_p	I_p	LS	
Okada shale	2.51	1	16	24	59	146 (142–148)	78 (76–80)	68 (62–72)	20 (18.5–25)	MH and OH: very highly plastic clay
Auchi shale	2.62	1	29	24	46	57 (51–60)	30 (28–33)	27 (23–29)	3 (1.2–6.18)	CH: highly plastic clay

Table 2 Mean values of maximum dry density, optimum moisture content and coefficient of permeability (*k*) values of Okada and Auchi shales (20 samples)

Deposit	MDD (Mg/m^3)	OMC (%)	*k*-values (m/s)		
			95% MDD	97% MDD	100% MDD
Okada shale	1.510	24.5	6.3×10^{-10}	3.9×10^{-10}	5.2×10^{-11}
Auchi Shale	1.705	20.4	5.6×10^{-9}	2.8×10^{-9}	9.6×10^{-10}

Table 3 Mean values of elemental composition of 20 analyzed samples

Parameters	Okada	Auchi
Oxides (%)		
SiO_2	55.76	47.24
Al_2O_2	20.60	20.64
Fe_2O_3	0.70	4.49
TiO_2	1.00	2.60
MgO	0.20	7.10
CaO	0.30	2.35
Na_2O	20	0.63
K_2O	0.30	0.90
MnO	0.02	0.07
H_2O	16.8	7.17
Heavy metals (Mg/l)		
Nickel	20.0	15.0
Cobalt	1.0	0.8
Chromium	30.0	13.0
Molybdenum	0.2	0.2
Lead	5.0	3.0

Auchi than in the Okada shales. This indicates some degree of lateralization in the Auchi shales (Emofurieta et al. 1995). The relatively higher value of Na_2O in the Okadao shale is most probably due to a significant proportion of smectite, consistent with the high Atterberg limits reported above.

Conclusions

The study indicates:

1. The Okada shales have very high plasticity, high linear shrinkage and low permeability when tested in the laboratory. In view of the likely presence of smectite, extreme care would need to be taken if these are used for clay liners, as they would be likely to experience cracking when dry. Should they be used, they would need to be compacted in thin layers and kept moist at all times.
2. The plasticity index and permeability of the Auchi shales indicate they would be suitable as a clay liner while the linear shrinkage suggests that they would not crack significantly when dry.

References

Daniel DE (1993a) Landfills and impoundments. In: Daniel DE (ed) Geotechnical practice for waste disposal. Chapman & Hall, London, pp 97–112

Daniel DE (1993b) Clay liners. In: Daniel DE (ed) Geotechnical practice for waste disposal. Chapman & Hall, London, pp 137–163

Emofurieta WO, Aladesawe AI, Ogunseiju P (1995) Secondary geochemical and mineralogical dispersion patterns associated with laterization process in Ile-Ife SW-Nigeria. J Min Geol 31(1):39–51

Jessberger HL (1994) Geotechnical design and quality control of mineral liner systems. In: Christensen TH et al (eds) Land-filling of wastes: barriers. E & F.N. Spon, London, pp 37–53

ONORM S 2074 (1990) Geotechnik in Deponiebau–Erdarbeiten Osterreichisches. Normungsinstitut, Wien

Parker RJ, Bateman S, Williams D (1993) Design and management of landfills. In: Fell R et al (eds) Geotechnical management of waste and contamination. A. a. Balkema, Rotterdam, pp 209–252

Seymour KJ, Peacock AJ (1994) Quality control of clay liners. In: Christensen TH et al (eds) Land-filling of wastes: barriers. E & F.N. Spon, London, pp 69–79

United States Environmental Protection Agency (1982) Hazardous waste management systems: permitting requirements for land disposal facilities, 126p

Wentz CA (1989) Hazardous waste management. McGraw-Hill, New York, 461 p