Quarterly Journal of Engineering Geology, **25**, 371–376. 0481-2085/92 $03.50 © 1992 The Geological Society

Clay linings to landfill sites

E. J. Murray,[1] D. W. Rix[1] & R. D. Humphrey[2]

[1] Murray Rix Partnership, 5A Regent Court, Hinckley, Leicestershire LE10 0AD, UK
[2] Lincs Lab, Lincolnshire County Council, St Georges Lane, Riseholme, Lincoln LN2 2LQ, UK

Abstract

Seepage of leachate or the migration of noxious gases from landfill sites can pollute the ground and groundwater to a considerable distance from the source of the problem. Current trends and legislation dictate that future practice at waste disposal sites will be to provide a lining capable of eliminating or minimizing the migration of contaminants. Geotechnical considerations in the design and construction of low-permeability clay linings are addressed and laboratory test results for a range of clay types are presented in support of the arguments. The use of the moisture condition value (MCV) test in the selection of acceptable materials and the control of earthworks operations is discussed. A permeability requirement of no greater than 10^{-9} m/s for the clay lining dictates the upper limit to the acceptable MCV range while the shear strength dictates the lower limit.

Introduction

Significant changes are underway in the control of waste disposal operations, changes that are aimed at protecting the environment surrounding landfill depositories by controlling leachate and landfill gas emissions to a far greater extent than in the past. To achieve this, suitably designed containment structures and strict site control of construction and landfill operations will be required. In recognition of the need to prevent contamination of the ground and groundwater, the proposed EC Landfill Directive and the National Rivers Authority Groundwater Protection Policy along with the Water Act 1989 and the Environmental Protection Act 1990 have been introduced to reduce this risk of uncontrolled waste disposal.

Decomposition of contained wastes results in the production of various potentially troublesome gases along with a leachate comprising both chemical and biological pollutants. A common method of controlling these byproducts is to deposit the waste in cells constructed using an impermeable synthetic lining and/or a low-permeability clay lining so that the pollutants are contained. Guidance on containment methods may be obtained from NAWDC Codes of Practice for Landfill (1989) and D.O.E. Waste Management Paper 26 (1990). There are, however, a number of recorded instances of contamination emanating from landfill sites where controlled placement and construction of selected lining materials has taken place. These incidents highlight the inherent difficulties of pollution control in such operations.

Clay linings

Figure 1 is a diagrammatic representation of a landfill cell comprising a clay lining and capping. Excavations specifically to form such cells are less common than the adoption of existing excavations such as redundant quarries, clay pits and sand and gravel extraction areas. Clay linings and cappings to such excavations can fail in a number of ways and in general need to be designed and constructed to withstand or mitigate the

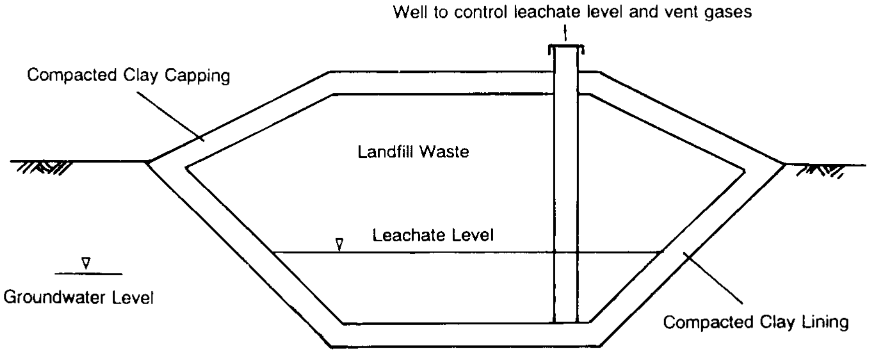

FIG. 1. Typical landfill cell.

following potential problems during and subsequent to construction.

During construction and prior to landfill placement:

(a) instability due to slippage of the natural ground and the clay lining;
(b) uplift of the clay lining due to excess hydrostatic pressures;
(c) shrinkage cracking in dry weather.

During and following landfill placement:

(d) deterioration of the lining as a result of chemical attack by leachate;
(e) excessive shear strains due to unacceptable large ground movements or landfill settlements;
(f) permeation of leachate or gas due to inadequate lining thickness or unacceptably high lining permeability;
(g) shrinkage cracks in capping allowing ingress of water and uncontrolled escape of gases.

There is a need for a detailed appraisal of individual sites including a 'desk study' and a ground investigation (BS 5930: 1981 and DOE 1990). The appraisal should include a study of local geomorphological, hydrological, geological and hydrogeological conditions. A carefully designed testing regime, particularly for the proposed clay lining, is also required in an engineered approach to landfill containment. The following concentrates on the testing, acceptability and selection of materials to form a clay lining and discusses their emplacement and performance requirements.

Use of the moisture condition test

The mositure condition value (MCV) test (Parsons & Boden 1979) provides a rapid means of determining the acceptability of clay soils which, coupled with a maximum air voids requirement to monitor the degree of compaction, may be used to assess the adequacy of the completed lining.

Cobbe & Threadgold (1988) discuss the use of the MCV test in general earthworks. As shown in Fig. 2 the degree of compaction achieved during the MCV test generally lies between that achieved by the 4.5 kg rammer and the 2.5 kg rammer methods of BS 1377: 1990. As limiting permeability is an overriding requirement of a clay lining, there is a need to ensure a uniform, homogeneous lining with worst case and not average conditions dictating adequacy. The required thoroughness of compaction will necessitate detailed site monitoring and compaction probably in excess of normal earthworks levels. However, the degree of compaction achieved in a laboratory 4.5 kg rammer test is unlikely to be realized within a clay lining. Equally the need to obtain a homogeneous, low-permeability lining would normally necessitate compaction in excess of that obtained using a 2.5 kg rammer. Densities obtained using the MCV test are thus considered more likely to represent desirable site compaction levels. Verification should always be obtained by conducting on-site trials. These may highlight the need for modifications to proposals based on laboratory testing alone.

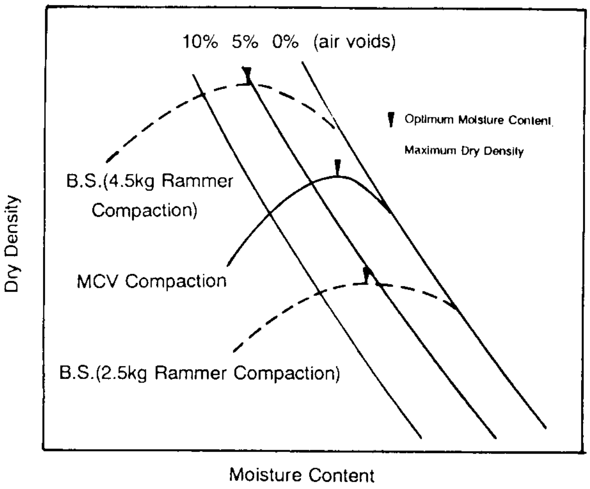

FIG. 2. Typical compaction curves.

The MCV test is based on compacting a soil sample until no further change in density occurs, whereas the B.S. 2.5 kg and 4.5 kg compaction tests are based on applying a given amount of compactive effort to a soil sample. Nevertheless the general forms of the BS compaction curves and the MCV compaction curve are similar. The explanation lies in the fact that wet of the optimum the resistance to compaction in the MCV test is dictated by the reduction of air voids to close to zero; whereas dry of the optimum the energy exerted in any single blow during compaction is insufficient to overcome frictional resistance and does not result in significant remoulding and increase in density. Experience suggests that more consistent results are obtained using the MCV test than the BS compaction tests. The MCV test is therefore recommended for use in the design and construction control of clay linings.

Figure 4 (a) shows six MCV compaction series for clays of low to high plasticity (CL to CH) as detailed in Fig. 3. The soils examined comprise Quaternary Glacial Tills and Fen Deposits considered for use at landfill sites within Lincolnshire. The clays have plasticity indices between 12% and 36% and clay contents between 5% and 50%.

The results displayed in Fig. 4 (b) show that as the plasticity of the clay reduces, there is an increase in the achievable degree of compaction or dry density.

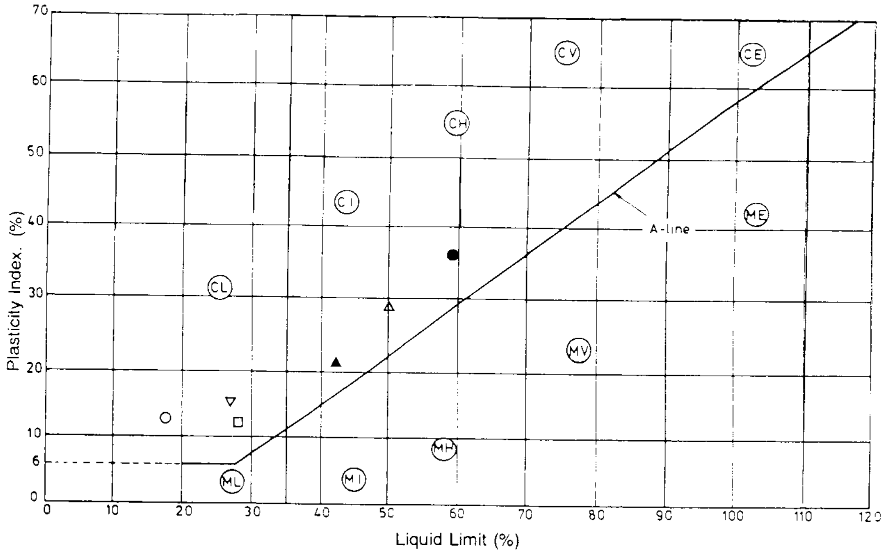

FIG. 3. Plasticity chart for clays of Fig. 4.

Figures 5 (a) and (b) show results for four series of tests on a low plasticity clay (I_p of 15% and a clay content of 26%). These results indicate an increase in MCV with decrease in moisture content until the optimum is reached. Thereafter, for further reductions in moisture content the MCV is essentially constant. The increase in MCV is matched by an increase in remoulded shear strength as shown in Fig. 6. There is evidence to suggest that clays of different plasticity exhibit similar compaction characteristics.

Permeability requirements

In most earthworks it is the strength and degree of compaction that are the controlling parameters but in the construction of a clay lining to a landfill site a low-permeability requirement presents an additional burden on the selection and emplacement of suitable materials. The maximum allowable permeability is usually taken as being 10^{-9} m/s (e.g. National Rivers Authority 1989). This value is generally accepted as the dividing line between the permeabilities of natural clays and silts (e.g. Somerville 1986). The permeability of a remoulded clay is, however, influenced by many factors, the main ones being its plasticity, density, moisture content during compaction and the method of compaction. It is these influences which need to be investigated and test results are reported herein for a wide range of clays considered for use as lining material.

Samples for permeability testing can be readily obtained from material compacted into the MCV mould. Figures 4 (c) and (d) and Fig. 5 (c) present permeability results for 100 mm diameter samples, tested by falling and constant head methods (Head 1985) in the triaxial cell.

Figures 4 (c) and (d) present the results of permeability tests at optimum moisture contents as determined during MCV compaction tests. The results show an increase in permeability with decrease in optimum moisture content and plasticity even though there is an increase in dry density. This permeability increase is marked for plasticity indices below 12% to 15% which suggests that clays with plasticity indices below about 12% may be unsuitable if a permeability of less than 10^{-9} m/s is to be achieved. This corresponds closely with the National Rivers Authority (1989) requirement that proposed lining material should have a clay content of greater than 10%.

Figures 5 (a) to (c) present results for four compaction series on a clay with a plasticity index of 15%. These results again show an increase in permeability with decrease in compaction moisture content even though there is an increase in dry density of the clay. This is consistent with the results reported by Needham (1991) and others. At around the optimum moisture content there is a more rapid increase in permeability reflecting the lack of remoulding of the clay at moisture contents below the optimum value and the possible presence of preferential seepage paths. Obviously greater compactive effort at these relatively low moisture contents would produce a greater degree

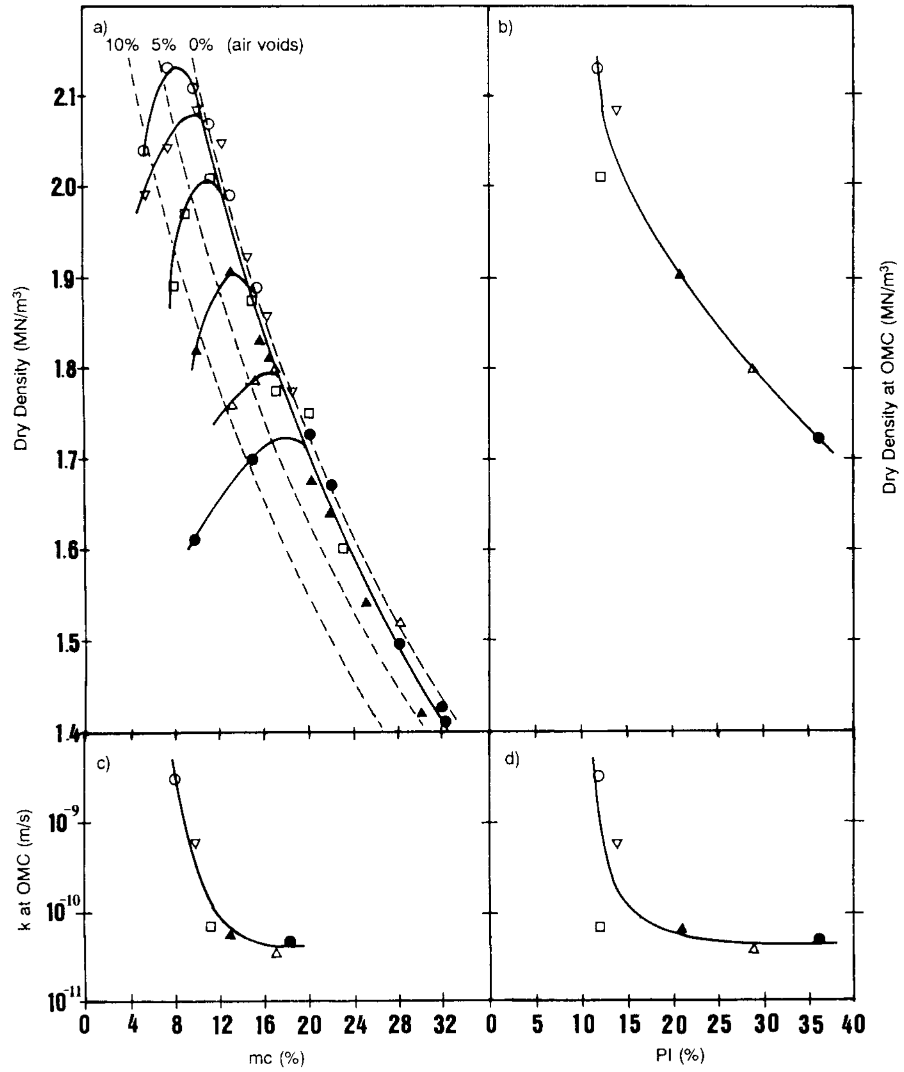

FIG. 4. MCV compaction results for different clays: (a) MCV compaction curves; (b) maximum dry density against plasticity index; (c) permeability at optimum moisture content; (d) permeability at optimum moisture content against plasticity index.

of compaction and a reduction in permeability but as discussed previously this may not be readily achievable on site. Observations during laboratory compaction operations on the drier samples suggest the presence of discontinuities which are also likely to exist during in situ emplacement of the fill. The lower limit to moisture content in selecting a suitability criterion should therefore be greater than the optimum moisture content as determined from the MCV compaction series.

Control of construction

In drawing up a specification for the construction of a clay lining, the permeability requirement should override other considerations. A performance specification may therefore be favoured. However, whether a performance or method specification is adopted, it is impractical to control the earthworks by the permeability requirement directly because of the time

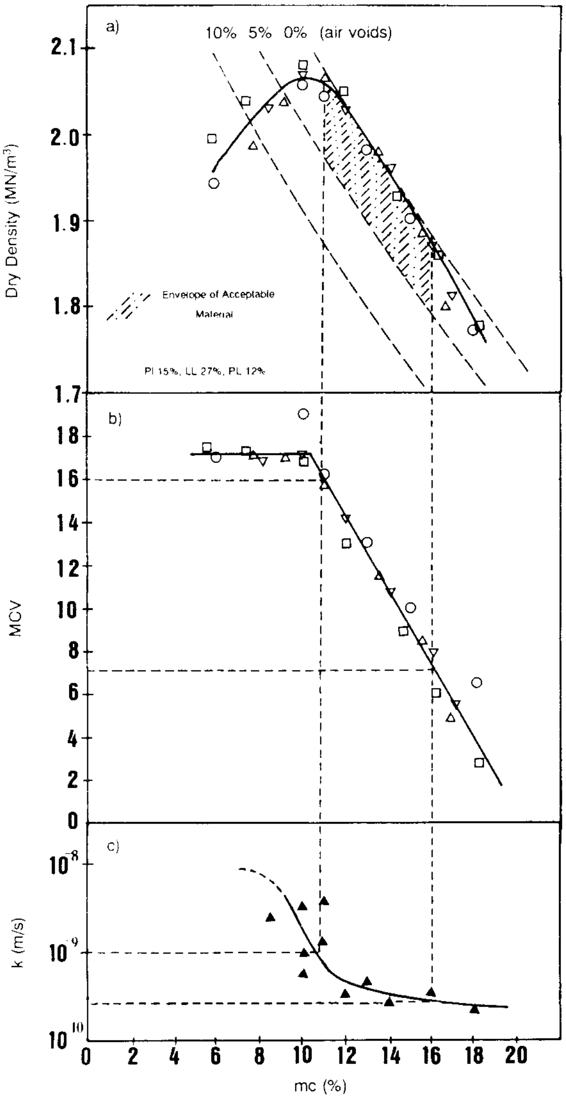

FIG. 5. MCV compaction results for low plasticity clay: (a) dry density against moisture content; (b) MCV against moisture content; (c) permeability against moisture content.

necessary to carry out such tests. For this reason it may be appropriate to relate the permeability to other soil parameters such as MCV (or moisture content) and density and use these to control acceptability and compaction. Nevertheless, this should not be taken as precluding the need for further permeability testing on the compacted lining material as an assurance that the control criteria are adequate.

For a clay of suitable plasticity, test results suggest that the lower limit for the moisture content should be dictated by the permeability requirement and should be greater than the optimum moisture content achieved in the MCV compaction series. The upper limit to the moisture content should be controlled by the shear strength of the clay because although the permeability requirement may be met, handling, compaction and trafficking become more difficult. This, in conjunction with stability considerations, makes a minimum shear strength requirement essential. Typically an undrained shear strength (C_u) of no less than 40 to 50 kN/m^2 is required in earthworks. Figure 6 presents results of hand shear vane strength tests carried out during the MCV tests reported in Fig. 5. It can be seen that for a strength of 50 kN/m^2 an MCV of 7 would be required. Thus in order to achieve a permeability of less than 10^{-9} m/s and to satisfy the emplacement requirements it may be considered appropriate to ensure the clay of Fig. 5 has an MCV between 7 and 16. Compaction trials should be undertaken to ensure the required densities are achievable using a practical layer thickness and number of passes of the selected roller. Should the density requirements not be met, the results of the trials may be used to restrict further the acceptable upper limit of MCV. A controlled compaction trial prior to the main earthworks is considered essential to alleviate potential problems in the construction stage.

The foregoing sets upper and lower bounds on material acceptability. If this is added to a compaction requirement of no more than 5% air voids the envelope of acceptable material and compaction as detailed in Fig. 5 is obtained. It would be necessary in practice to ensure that with 5% air voids the permeability requirement is still met. However, the uptake of free water by the clay forming the lining would mean a reduction in air voids and the clay complying more closely with the fully compacted state and an acceptable permeability. This would result in a corresponding softening of the lining, the consequences of which may have to be taken into account.

Consideration should also be given to the type of compaction plant to be employed on site. It is recognized that a discontinuity often exists between clay layers compacted using a smooth roller. Such discontinuities may well present seepage paths. For this reason it would be considered appropriate to adopt tamping or possibly grid rollers in the construction of clay linings. These rollers knead and remould the soil providing a more homogeneous material, reducing the risk of major discontinuities and thus potential seepage paths remaining.

Conclusions

1. Clay linings can provide sound seals to landfill sites but careful control and monitoring needs to be undertaken, not only during construction but subsequently during landfill placement.

2. A detailed ground investigation is a prerequisite to the development of any landfill site. All proposed landfill sites require the ground and groundwater conditions to be determined and the findings to be incorporated into a carefully engineered approach.

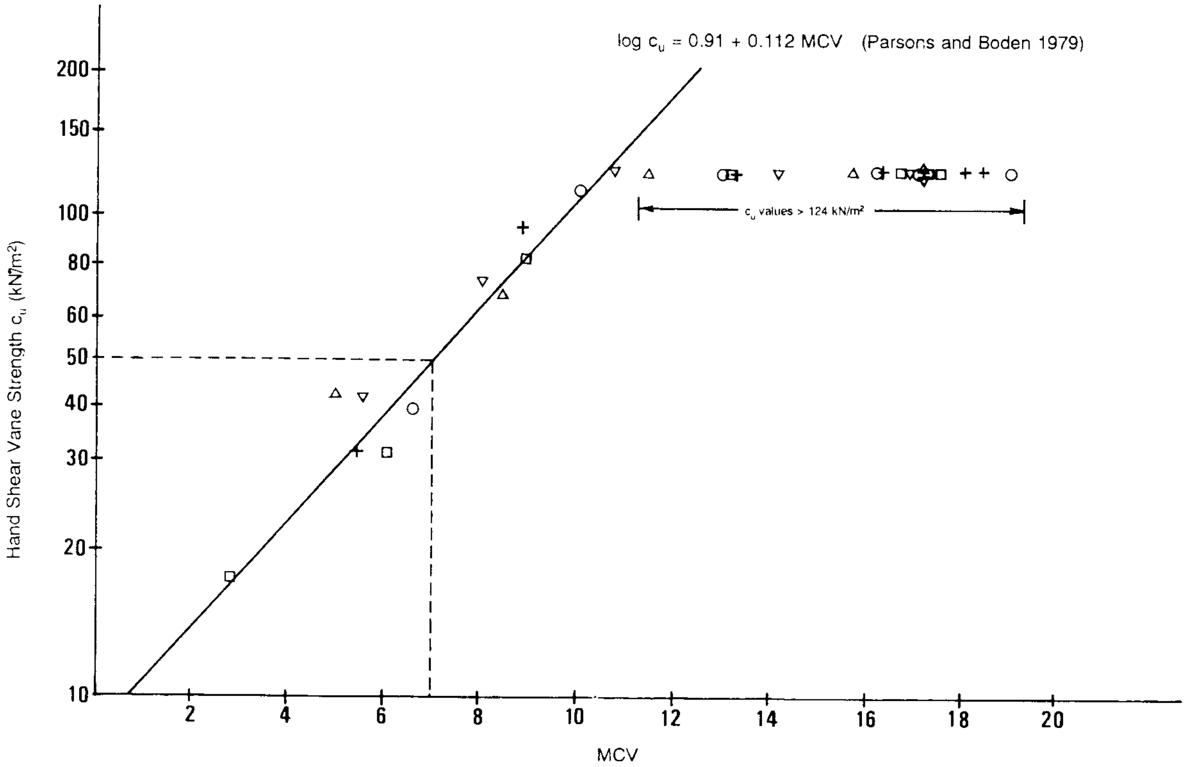

FIG. 6. Hand shear vane strength against MCV for clay of Fig. 5.

3. The selection of a suitable lining material requires extensive soil testing and on-site compaction trials. The acceptability of the material and the earthworks should be controlled by a maximum allowable permeability. Although this will require permeability determinations during construction of the lining, earthworks operations may generally be controlled by MCV and air voids determinations if adequate testing for acceptability has been carried out beforehand. The use of the Moisture Condition Value test has been described as both a control on material acceptability and as an indicator of the degree of compaction achievable on site.

4. Clays for use in linings should generally have a plasticity index of greater than 12% and a clay content of no less than 10%.

5. The lower limit to moisture content should be greater than the optimum value as obtained in MCV compaction series and is controlled by the maximum permeability requirement of 10^{-9} m/s. This dictates the upper limit to the acceptable MCV range.

6. The upper limit of the moisture content is controlled by the strength of the clay and its handling, trafficability and compaction requirements. This dictates the lower limit to the acceptable MCV range.

References

BRITISH STANDARDS INSTITUTION 1981. *Code of Practice for Site Investigation: BS 5930.*

— 1990. *Methods of Tests for Soils for Civil Engineering Purposes, Code of Practice: BS 1377, Part 5.*

COBBE, M. I. & THREADGOLD, L. 1988. Compaction control by the Moisture Condition Test—a new approach. *Journal of the Institution of Highways and Transportation*, Dec., 13–18.

DEPARTMENT OF THE ENVIRONMENT 1990. Landfilling wastes. *Waste Management Paper No. 26*. A Technical Memorandum for the Disposal of Wastes on Landfill Sites, HMSO.

HEAD, K. H. 1985. Effective Stress Tests. *Manual of Soil Laboratory Testing Vol. 3*. Pentech, Chichester.

NATIONAL RIVERS AUTHORITY NORTH WEST REGION 1989. *Earthworks to Landfill Sites.*

NAWDC Landfill Committee, August 1989. *Codes of Practice for Landfill.*

NEEDHAM, A. 1991. Clay liners—the answer lies in the clay. *Surveyor Special Supplement to Wastexpo International '91.* 18 & 19 Sept, Cannock, Staffs., 11–13.

PARSONS, A. W. & BODEN, J. B. 1979. The Moisture Condition Test and its potential application in earthworks. *Transport and Road Research Laboratory Supplementary Report 522.*

SOMERVILLE, S. H. 1986. Control of groundwater for temporary works. *CIRIA Report 113.*

Received 2 April 1992; revised typescript accepted 1 October 1992