COMBINED GEOMEMBRANE PROTECTION AND LEACHATE DRAINAGE GEOCOMPOSITE MATERIAL IN CONSTRUCTION OF LANDFILL CONTAINMENT

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ABSTRACT: In the UK, following European Legislation, the majority of engineered landfills are lined typically with 1m of compacted mineral liner overlain by 2mm of HDPE geomembrane, thick geotextile protector and then a drainage stone to handle leachate. Because of concern for the longevity of landfill containment systems, the legislation has taken a conservative approach to landfill design, requiring drainage stone layers up to 500mm thick and forcing waste management contractors to fill hard won void space with equally hard won drainage gravel. The environmental need to incorporate safety in design militates against the environmental need to maximise void space and minimise the use of a quarried or dredged stone. This paper describes the use of a carefully selected geocomposite to replace some of the drainage stone and provide a much thinner but equivalent drainage path for leachate saving on void space and drainage stone alike. It describes the very successful collaboration between key stake holders from conceptual design through testing to full trial site and describes the ongoing monitoring and testing. Early indications are that this project is successful and could pave the way for the wide spread use of basal drainage geocomposites in landfill construction.

Keywords: Geotextiles, geocomposites, landfills, field research, laboratory research, mechanical properties, design method

1 INTRODUCTION

The UK Environment Agency has always welcomed innovative development in the engineered landfill lining industry. Engineered liners have evolved from dilute and disperse to a highly sophisticated engineering solution that has European legislation at its heart. . Geocomposites have been used a leachate drainage medium for a number of years in the US, especially as side wall drainage and as secondary leak detection between double liners on the base, but rarely as a primary leachate drainage layer. In the UK geocomposites have been used extensively for landfill caps where the environmental risk levels and loadings are fairly low.

This project represents an important step forward in the use of high performance geocomposites as a leachate drainage medium in landfill containment systems. Through collaboration between Viridor Waste Management, Wardell Armstrong, GEOfabrics and the Environment Agency a series of laboratory and field trials leading to an installation has been achieved. The site identified as suitable for the full scale trial is the Pilsworth Landfill site near Bury. The site was considered typical of landfill cells in the UK and had the advantage that two cells of very similar shape were being constructed adjacent to each other, allowing one to be built in a conventional method using a primary aggregate leachate drainage blanket and the second with the geocomposite as the leachate drainage medium. This allows for direct comparisons as rainfall, waste streams and topography are effectively identical.

2 COST ANALYSIS

Apart from the environmental benefits it was important to control costs and optimize the design to achieve proper leachate control at acceptable cost. The proposal was for a 150mm stone drainage blanket as the minimum practical thickness for a stone drainage blanket to be safely placed without damaging the underlying composite or liner. The composite was to be made out of the most cost effective materials and was able to be deployed during the construction works as quickly as a standard heavy duty geotextile protector. Taking into account of the saving of void space, installation costs and the costs of the probable solution a target saving of £10 per square metre made the project an attractive proposition.

2 DESIGN OF THE GEOCOMPOSITE

The use of geocomposites in the construction of landfill containment facilities, although proposed and trialled variously in recent years, remains limited in the UK. There are, however, real benefits to be gained from their use:

- reduced consumption of primary aggregate and increased sustainability of landfill as a waste disposal option;
- increased landfill air space;
- increased ease and speed of construction;
- reduced likelihood of damage to the underlying lining system during construction;
- potential financial savings for site operators and the application of BATNEEC.

There are, however, other factors to be recognised when proposing the use of these types of materials. Design and operational issues relating to the performance of the material must be addressed and well understood; it is accepted that since their use in the UK remains innovative they are expected to withstand more detailed levels of scrutiny by the Environment Agency than traditional designs. It is with these issues in mind that a large scale trial was proposed. Advanced discussions were held with the Environment Agency and detailed design and analysis, supported by laboratory testing and field trials undertaken, together with detailed background researches into the use of geosynthetic and geocomposite products as both geomembrane protection and leachate drainage media within landfill cell containment systems (a bibliography of relevant published papers with a summary of the conclusions drawn is included at Appendix A).

Before discussing the proposed use of the geocomposite in the construction of Cell 12Ci, it is beneficial to set the background to leachate management system design at the site and provide a summary of the construction layout. The design of the leachate management system at Pilsworth Landfill site is derived from the requirements of the PPC Permit (and the hydrogeological risk assessment undertaken as part of the permit application), regulations issued by government, guidance issued by the Environment Agency and the specific geotechnical design parameters of individual cells.

Design of current leachate management systems generally follows the guidance issued in the North West Waste Regulation Officers report dated 1995. That document details various in service requirements of leachate collection systems and prescribes minimum design values to be adopted where appropriate. Additional information on the objectives of leachate management system design is provided in an Environment Agency technical paper produced in 2002. Current best practice for the use of geomembrane protection geotextiles in landfill engineering is provided by the Environment Agency in a document issued in 1999. Again, this document sets out the fundamental design requirements of protective geotextiles, prescribes specific performance requirements and details the construction quality assurance procedures to be adopted during installation.

Minimum recommended design criteria for leachate drainage systems is given in the Landfill (England and Wales) Regulations 2002, which transpose into UK law the requirements of the Landfill Directive. The regulations specify the installation of a leachate drainage blanket with a minimum thickness of 0.5 metres; however this can be reduced on the basis of an acceptable hydrogeological risk assessment. The leachate management system design for landfill cells at Pilsworth has been produced with due regard to the above guidance and regulations and is based on a hydrogeological risk assessment undertaken as part of the PPC Permit application for the site. The design comprises a protector geotextile installed above the flexible geomembrane liner, overlain by a 300 millimetre thick blanket of 10 to 20 millimetre sized drainage stone, which in turn is overlain by a network of piped collection drains and leachate extraction and monitoring chambers.

The design should take account of redundancy of the drainage blanket due to physical and biological clogging over time and demonstrates that the leachate management system design is appropriate for the proper management of leachate within the site.

The geocomposite material that was installed in Cell 12Ci is manufactured by GEOfabrics Limited of Stourton, Leeds, and comes from their Protexia product range. It consists of an extruded high density polyethylene three layer geonet core with a flat tape woven filter geotextile bonded on both sides and a needle punched, staple fibre, non woven protector geotextile on the underside. The four individual layers are heat bonded together to form the geocomposite. The geocomposite operates with the protector geotextile as the geomembrane protection layer and the geonet drainage core forming part of the leachate drainage layer (together with overlying stone drainage and piped drains). The filter geotextile acts to prevent clogging of the geonet drainage layer.

The geocomposite is installed directly on top of the geomembrane liner to replace the existing geomembrane protector geotextile and allows the thickness of the overlying stone drainage blanket to be reduced from 300 millimetres to 150 millimetres. The key design and in service requirements that have been identified in this respect are detailed below.

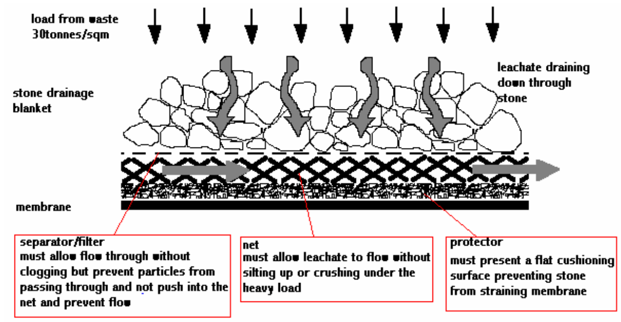

Figure 1: key components and functions of the three main elements of the geocomposite

Flow capacity

The flow capacity of the geocomposite is determined principally by the geonet drainage core element; however the protector geotextile element also has the capacity to allow through flow. It is intended that the flow capacity of the geocomposite will allow the thickness of the overlying stone drainage blanket to be reduced from 300 millimetres to 150 millimetres. Calculations have been undertaken to demonstrate the equivalency of the permeability of the geocomposite to that of a 300 millimetre thickness of 10 to 20 millimetre sized drainage stone (this is conservative with respect to the proposed 150 millimetre thickness of stone to be used). The calculations are based on transmissivity testing results obtained from laboratory testing undertaken by GEOfabrics. Details of the transmissivity testing undertaken are given in Section 3

The design transmissivity calculations include for the following factors of safety:

- Intrusion of overlying drainage stone into the geocomposite;
- Long term compressive creep of the geonet drainage core element of the geocomposite;
- Clogging of the upper geotextile filter layer;
- Geocomposite/drainage stone equivalency factor as recommended by the Environment Agency.

The calculations showed that the drainage properties of the geocomposite exceed the requirements of Environment Agency guidance for the performance of a 300 millimetre thick drainage blanket.

Physical Strength

The physical strength of the geocomposite is derived from both the protector geotextile element and the geonet core. Physical strength is required to withstand loadings imposed by the overlying waste mass. The essential components of the physical strength are compressive strength, tensile strength and puncture resistance.

Compressive Strength

The compressive strength of the geonet element of the core determines the susceptibility of the material to long term compressive creep. There are generally two types of net available in the market; 2 layer and 3 layer nets. From research work carried out in the United States it was decided to use the 3 layer net as this was considered as the most stable and had the greatest resistance to compressive creep over time. It is noted by Qian, Koerner and Gray (2002) that susceptibility of geonets to compressive creep is related to the density of the polymer used in the production of the material. A lower reduction factor for safety should be applied to higher density polymer materials. The proposed geonet element of GEOfabrics' Protexia material is produced from high density polymers; however the transmissivity calculations include a conservative factor of safety for reduction of flow capacity due to compressive creep.

Tensile Strength

Since the leachate drainage blanket covers the floor area of Cell 12Ci and to a height of 3 to 4 metres up the perimeter bunds, tensile strength is not expected to be critical to the performance of the geocomposite, it was felt that the installation process could put some temporary tensile loads into the core

Puncture Resistance and thickness

Puncture resistance and thickness are the principal design parameter for the protector geotextile. The protector geotextile element of the geocomposite has been specified based on the anticipated waste loadings and anticipated leachate drainage stone size within Cell 12Ci. Two alternative stone sources were considered 10-20mm and 20-40mm crushed angular quarry stone. The appropriate geotextile was selected by "cylinder testing" for each stone type (see section 3 Laboratory testing)

Clogging and Redundancy

There are two main aspects to be considered when addressing the redundancy issues relating to clogging:

- biological and physical clogging of the filter geotextile;
- physical clogging of the geonet core.

There is a balance to be struck between the susceptibility of the upper filter geotextile to clogging versus the ability of the core to transport fine particles away on a relatively gradient. In addition, the upper geotextile must be able to withstand the installation process and in this respect the selection of material is related to its ability to be bonded to the geonet core.

Research has shown that whilst biological clogging can build up to a high level in the base of a landfill there is a marked residual and stable flow capacity that allows adequate flow into the core for leachate drainage requirements. Experiments have shown residual flows to be approximately 50% of original unclogged materials. These experiments are likely to be conservative as they have been carried out over very small areas such as in perspex cylinders where edge effects have a dominating influence. GEOfabrics have themselves carried out long term leachate immersion tests in anaerobic conditions and found that an 8 year old sample, when tested in a permeability rig, retained 30% of its original flow capacity. The nature of the growth was largely crystalline leaving voids for flow between the coated fibres. The leachate used was from typical household landfill wastes similar to those deposited at Pilsworth.

Having researched many of the published papers, it is found that either a theoretical or non-specific route is taken to address biological clogging (see Appendix A for summary of desk study findings). The conclusion is that the theoretical ideal material would be an open geotextile (such as an open weave monofilament geotextile) which has low compressibility and has high in plane stiffness to minimise biological clogging. This, however, assumes a small filtration area and a high transportation velocity within the core (such as in a highway fin drain application) which is not the case in the fluid flow through leachate drainage systems. Authors conclude that anaerobic conditions cause least biological build up, which is likely to be the case at Pilsworth.

An optimised solution is therefore provided with the Protexia product. A flat tape woven filter has been selected as the upper filter layer, firstly to provide optimum spanning ability across the ribs of the core therefore maximising flow capacity in the core, and secondly to provide a relatively open weave at 400microns opening size, (O_{90}) 8% open area to retain silt material in order to prevent physical clogging of the core. This same flat tape woven has been used as a reinforcement layer under the core to prevent intrusion of lower protector geotextile therefore reducing physical clogging of the core and to increase potential flow rate.

The transmissivity calculations include for conservative factors of safety to allow for the effects of clogging on the geocomposite and, as previously mentioned, demonstrate that the residual flow capacity of the geocomposite exceeds the minimum criteria for a stone drainage blanket as set out in Environment Agency guidance. By placing a 150 millimetre thickness of drainage stone above the geocomposite, therefore, a reduction factor of 2 has been allowed to take account of redundancy of the geocomposite due to clogging. This is in line with the residual flow rates suggested by research (see Appendix A for summary of desk study findings).

Installation Procedures

The installation procedures (including the installation of the overlying drainage stone) were specified in order to ensure that the operations do not cause any damage to the underlying containment layers. The installation and CQA procedures are detailed below. They address, in particular, the issues associated with tracking of construction plant on the geocomposite and the correct overlapping of adjacent panels to ensure continuity of drainage and protection.

3 LABORATORY TESTING AND FIELD TRIALS

Laboratory Testing

To assist with the design process the correct combination of textiles and nets had to be established. The goal is to find the most economic solution which meets the onerous requirements of a landfill environment. Laboratory tests were undertaken as a research exercise. Two tests were used to simulate site conditions firstly the "cylinder test" undertaken in accordance with the Environment Agency document "A Methodology for Cylinder Testing of Protectors for Geomembranes", March 1998, to

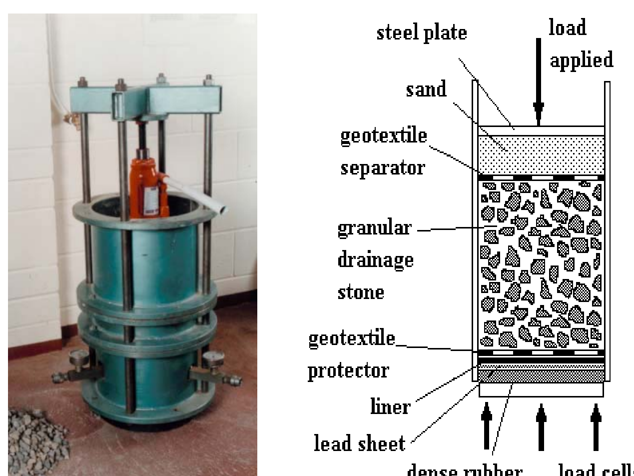

Figure 2: Photo of loaded "cylinder" test and cross section

determine the correct geotextile protector for the given net and stone combination. The second test was to establish long term in plane flow using a modified version of the transmissivity test EN ISO 12958 "Geotextiles – Determination of water flow capacity in their plane". The modification involved using the actual stone, as in the cylinder test, to simulate the actual effect of the stones on the upper filter and net. A modified version of the transmissivity test was carried out on the finished composite. Modification was to the upper platen where a sample of site stone was placed above the sample and loaded to 254kPa, hydraulic gradient of 0.1 laid on hard lower platen. The test was undertaken over a continuous 26 day period to allow for steady state conditions to be achieved.

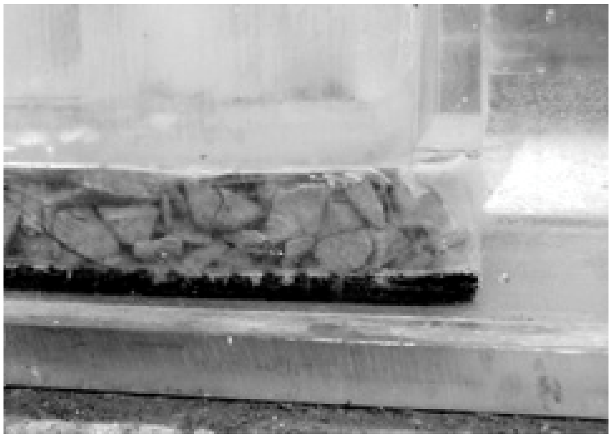

Figure 3: Photo of modified in-plane flow test using stone

A prototype 1 used a thin non woven heat bonded material, 3 layer net and protector geotextile. The combination used passed the cylinder test but flow decreased steadily over time due to ingress of the geotextile into the interstices in the net.

A second prototype was designed replacing the upper filter layer with a flat tape woven and adding a reinforcing layer under the net between it and the protector geotextile. The two tests were repeated and the flow maintained a good high level flow.

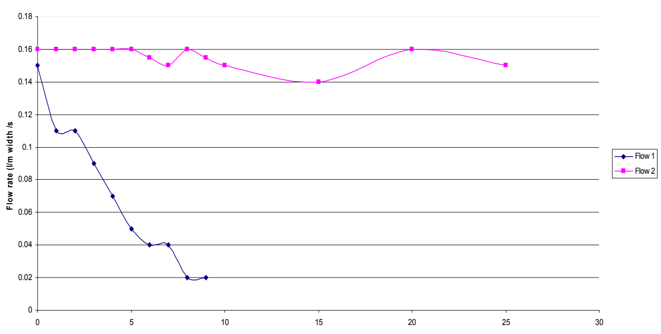

Figure 4: In plane flow results showing rejected Prototype 1 and accepted Prototype 2 with steady state flow

A second cylinder test was carried out with an alternative stone giving the contractor a choice of stone sources with a load of 65t/sqm for 100 hours using 2mm thick HDPE membrane. It was found that for the 10-20mm stone a geotextile protector with a puncture resistance of 5000N, thickness 5mm was required whilst with the 20-40mm stone a puncture resistance of 14000N, thickness 7mm was required. Additional tests proved also that the minimum strength of geotextile needed was 5000N, thickness 5mm this was limited by the effect of the net ribs on the membrane.

The final geocomposite was therefore a four component parts to the composite proposed woven filter, net core, woven reinforcement and non woven protector each component has been tested to EN (European Norm) Standards. After lamination selected tests have been carried out on the finished composite (see Section 4 for details).

Field Trials

Whilst laboratory trials had proved successful this did not prove the performance of the product during installation. A site installation trial was therefore undertaken on the Pilsworth site using all the relevant material and plant which were to be used to construct the cell. Three field trials were carried out to confirm that the installation of the geocomposite and drainage stone will be practical and that the specified protector geotextile element will perform adequately under dynamic loading with the specified drainage stone. The test pad was comprised of:

- a nominal thickness of clay (approximately 0.5 metres thick) placed and compacted using bull dozer and vibratory roller;
- installation of a 2 millimetre thick high density polyethylene geomembrane liner;
- installation of the geocomposite material above the geomembrane;
- placement of a 150 millimetre thickness of leachate drainage stone.

The field trials were undertaken under the supervision of a Wardell Armstrong, GEOfabrics and the Environment Agency. Each trial area was approximately 5 metres by 10 metres in size.

The first trial involved the use of a geocomposite with a GEOfabrics HPS 5 protector geotextile element and 10 to 20 millimetre sized drainage stone. This is the anticipated configuration for the construction of Cell 12Ci. The second used a geocomposite with a GEOfabrics HPS14 protector geotextile element and 20 to 40 millimetre sized drainage stone. A third used a geocomposite with a GEOfabrics HPS5 protector geotextile element and brick hardcore drainage layer. This trial was undertaken as an extreme worst case, utilising the geotextile protector element with the lower puncture resistance combined with a drainage blanket comprising large and irregular particles.

Figure 5: Field trials on proposed cross section

Each trial area was traversed by a 20 tonne 360º excavator directly on top of the leachate drainage blanket. Four passes and 2 slewing turns were made by the excavator across the trial pads. This was done to simulate the worst case scenario of a machine tracking directly on the stone drainage blanket during placement. It was considered that the possibility of damage to the landfill liner would be highest at this time rather than during waste compaction because during waste placement 1 metre of selected soft waste is placed onto the leachate drainage blanket to ensure that no damage is caused to the landfill lining system by the compaction plant or sharp objects within the waste.

Each trial was constructed by placing two panels of the geocomposite over the trial area with a panel join across the trial area. The panel join represents the weakest part of the installed geocomposite layer. The trials aimed to establish that the proposed overlap detail is adequate and that the panels would not become separated during stone placement or allow any stone to pass through the joins and come into direct contact with the geomembrane. Upon completion of the field trials, the geocomposite was removed and inspected to check for damage and integrity and to check the condition of the underlying geomembrane.

The results for the tests were very encouraging as the only obvious damage was in the worst case using the brick hardcore. Here scuffing of the top filter layer resulted in a 10mm hole with a few other smaller holes visible. For the proposed 10-20mm stone and the alternative 20-40mm stone there was no visible damage. Checks were made at the joints and panels within the composite were opened out and separated to observe any damage within the composite. None were observed and most importantly the liner remained completely undamaged.

4 INSTALLATION AND QUALITY ASSURANCE

A report describing the Manufacturing Quality Assurance (MQA) and the Construction Quality Assurance (CQA) plans was submitted to and accepted by the Environment Agency.

The installation of the geocomposite geomembrane protection and leachate drainage layer was supervised by an independent suitably qualified CQA Engineer provided by Wardell Armstrong. The CQA Engineer provided independent confirmation that the works were carried out in accordance with the approved installation method statement document that was approved by the Environment Agency (and any amendments approved by the Environment Agency) and any documents listed therein.

The CQA Engineer supervised the works to ensure that the testing of the geocomposite materials to be used in the works was undertaken in accordance with the details given in the installation method statement. The CQA Engineer checked all sample test results to ensure compliance with the relevant criteria. Rolls of the geocomposite were delivered to site in packaging which will protect the rolls from degradation by ultra violet light.

GEOfabrics were required to provide production test certificates for each of the geocomposite rolls delivered to site at a frequency as shown

Test/CQA Procedure	Method	Frequency
In Plane Flow Capacity (soft/hard platens)	EN ISO 12958	1/12,000m^2
Puncture Resistance	BS EN ISO 12236	1/6,000m^2

Table 1. Frequency of laboratory testing to be carried out on the geocomposite.

Samples of geocomposite were taken by the CQA Engineer upon delivery and tested at an independent laboratory in accordance with Table 1 prior to incorporation within the works.

In addition, the geocomposite manufacturer was required to provide MQA test certificates for the materials used in each of the individual layers of the geocomposite and as a minimum the following test data was included:

- Geotextile Filter/Reinforcement:

Test	**Method**
Water Flow	BS EN ISO 11058
Pore Size	BS EN ISO 12956
Tensile strength	BS EN ISO 10319

- Geonet Drain:

Test	Method
Thickness	BS EN 964-1
Tensile Strength	BS EN ISO 10319
In plane flow	EN ISO 12958 (hard platens)

- Geotextile Protector

Test	Method
Puncture Resistance	BS EN ISO 12236
Tensile Strength	BS EN ISO 10319
Cone drop	BS EN 918

Geofabrics specification for each of the above materials and the geocomposite is given in Table 2.

Test Description	Test Method	Units	Measured Value
Geotextile Filter			
Pore size	EN ISO 12956	µm	400
Water flow	BS EN ISO 11058	l/m^2/s	45
Tensile Strength md/cmd	BS EN ISO 10319	KN/m	35/30
Tensile elongation md/cmd	BS EN ISO 10319	%	30/25
Geonet Drain			
Thickness under 200kPa	BS EN 964-1	mm	5.8
Tensile strength	BS EN ISO 10319	kN/m	30
In-plane flow capacity i = 1 hard platens @ 200kPa (md)	BS EN ISO 12958	m^2/s	1.8 x 10^{-3}
Geotextile Protector			
CBR Puncture Resistance	BE EN ISO 12236	kN	5
Tensile Strength (md)	BE EN ISO 10319	kN/m	30
Geocomposite			
In-plane flow capacity i = 1 with soft/hard platens @ 200 kPa (md) *	EN ISO 12958	m^2/s	1.7 x 10^{-4}
CBR puncture resistance	BS EN ISO 12236	kN	8
Values are Typical, with the exception of Thickness, which is Nominal. Typical indicates the mean value derived from the samples taken for any one test as defined in the BS EN ISO standard – usually the mean of five samples. Nominal is a guide value.			

Platens were modified to simulate actual site conditions within the standard test. The upper platen was soft to present a surface similar to actual site conditions. The lower platen is hard, simulating the well supported HDPE geomembrane surface.

Table 2. Manufacturers Specifications.

The CQA Engineer was required to reject any rolls of geocomposite in total, or in part, for any of the following reasons:

- the geocomposite had been holed, torn or ripped or was otherwise damaged;
- the production test certificates provided by the manufacturer failed to demonstrate conformance with necessary maximum/minimum test values quoted by Geofabrics for the product;
- the samples tested in the laboratory failed to demonstrate conformance with necessary maximum/minimum values quoted by GEOfabrics for the product.

Prior to laying the geocomposite, the underlying geomembrane was inspected and any stones, debris, etc, which had the potential to damage the geomembrane was removed. The CQA Engineer supervised the geocomposite installation on a full time basis and ensured that all panels have a minimum 200 millimetre overlap. The geocomposite was permanently secured around the perimeter of the cell by running out and weighting down with leachate drainage stone.

Full details of the installation of the geocomposite were presented within the validation report for the construction of Cells 12Ci and 12Cii produced by the CQA Engineer for submission to the Environment Agency. Information relating to the geocomposite included:

- All CQA test certificates provided by the manufacturer;
- The results of all material testing undertaken including any failures and subsequent re-testing;
- As built plans of the works.

5 MONITORING AND REDUNDANCY

The project has now to be monitored over time to compare the two cells to assess the performance of the composite against the standard stone drainage blanket. In addition, long term laboratory based simulation tests can be undertaken to study likely clogging of the core and filter fabric.

As part of the design, alternative methods of removing leachate were incorporated using the assumption that the geocomposite became completely redundant.

Field Monitoring

The two cells, 12Ci with the conventional 300mm stone drainage blanket and the trial cell 12Cii with 150mm stone drainage blanket and geocomposite will be compared for performance once the cells are filled to capacity and the leachate systems are operational.

The monitoring methods are as follows:

- Weekly monitoring of leachate levels in both cells during operational phase thereafter monthly monitoring
- Draw off rates will be compared when pumping leachate down through wells. Readings from intermediate wells and from piezometers across the cells would be taken. This will give a profile of the leachate head across the site whilst pumping is taking place
- Two of the leachate monitoring chambers can be accessed by CCTV to attempt to observe local fowling of the stone and geocomposite drainage layers
- Every six months a falling head test will be carried out in the leachate extraction chamber. The leachate will be pumped out and then refilled with 1m of water and the time for the leachate to drain from the chamber will be recorded. This will give an indication of the permeability of the system.

Laboratory Monitoring

A number of samples of the finished composite as well as separate components are immersed in the leachate in the laboratory. Over time one set of samples will be removed and tested for water permeability and transmissivity. This will indicate the growth rate of biological and chemical clogging which can be used to compare with onsite results.

Redundancy

As a precaution it was agreed that whilst the stone drainage stone was being placed a number of drill pads would be placed to a depth of one metre at intervals across the site. Assuming the geocomposite became completely redundant calculations were carried out to show that if wells were drilled into the waste material to the pads then the additional pumping could handle the residual flow needed to compensate for the redundant composite.

6 CONCLUSIONS

This project has been undertaken cautiously and steadily over the last two years involving all the relevant stakeholders in the project. The result has been a well developed trial which could potentially have a large impact on the design of engineered landfills in the UK and beyond.

Early indications are that the two comparative cells are performing satisfactorily. This is an ongoing process and further reporting on this project is required. Back analysis on costs showed that taking into account the learning curve for this particular site especially with attention to speeding up of the jointing methods that the composite is a sound commercial as well as environmental proposition

GEOfabrics has had to develop new techniques for laminating woven fabrics to net core materials and these are improving with time. At present this type of composite is to be used on relatively shallow gradients of short bund slopes only as more work is required on the interface shear and peel properties of the laminated product.

7 ACKNOWLEDGEMENTS

Thanks are due to Vince Caddick at GEOfabrics for carrying out the laboratory testing; Jones Brothers (Ruthin) Ltd for their cooperation in the field trials

8 APPENDIX A.

There follows a summary of relevant conclusions and notes obtained form an extensive survey of published papers over the last 10 years mainly focused on the effects of biological and chemical clogging in geotextiles.

- Large opening size of geotextile is desirable to minimise the risk of biofilm development.
- Very low compressibility, highly porous geotextiles are preferred.
- Geotextiles with fibres with anti-bacteria attachment to be developed.

- An understanding of the type of leachate in a particular landfill is important, especially where high iron oxide content is present.
- Aeration of leachate should be minimised to reduce aerobic bacteria forming.
- Non-woven geotextiles could be compressible therefore increasing the likely biological clogging in certain types.
- Flow rate through geotextile should equal flow rate expected in the landfill
- Woven geotextiles present simpler structures than non-woven, therefore easier to differentiate.
- Woven geotextiles allow direct measurement of pore size and percentage open area (POA)
- POA governs piping/clogging process during filtration. Direct relationship between piped fines and POA.
- After one month hydraulic conductivity of a geotextile reduced by 80% in a leachate and 20% in tap water for a flat tape woven.
- Non-wovens did better in the tests. Reducing to only 50% in leachate
- An antibacterial agent should be added to the geotextile.
- Comparison of two layer and three layer nets under high compressive loads with modifications to a transmissivity test to allow for intrusion by geotextiles and cover soils: sand and clayey soil. Intrusion factors of 1.5 and 2 for clayey soils.
- Steady reduction of flows in two layer nets over long period, reaching a 95% reduction factor. Intrusion factor 20.
- Long term creep testing recommended. Suggests a period of 10,000hours testing.
- Using neoprene underestimates the intrusion due to geotextiles. Better to use real soil in test.
- Site trials suggest that composite could be very beneficial.
- Pumping trials proved that geocomposite reduced flow rates as compared with aggregate solution but still acceptable.
- Anaerobic (desirable) microbiological growth was achieved.
- Clogging in geocomposite slightly higher than that found in the aggregate.

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g) The assessment of long term hydraulic flow rate on Tenax Tendrain geocomposites. Technical Report TDD007 – 10/03 Tenax Spa. Geosynthetics division – gives suggested factors of reduction for physical clogging, biological clogging, chemical clogging, and long term creep compression.

h) Methodology for assessing the use of a geosynthetic composite as a leachate drainage media in a composite lined landfill. Ellard, H.; Hewitt, P J ; Marshall, R; Robinson, N – trials on alternative drainage cores

i) Landfill Engineering: Leachate drainage collection and extraction services R&D Technical Report P1-397/TR Pub Environment Agency. - Methodology which has informed this research proposal to cover the relevant technical areas required.

j) Determination of the allowable flow rate of a drainage geocomposite. Geosynthetic Research Institute GRI Standard – GC8 4/2001 – Equivalent methodology of assessment as used in the United States of America

k) Leachate drainage design and research. Lord St Helens Quarry Landfill Site St Helens Merseyside. Cells 2A and 2B – interim report. CL Associates 4/2001 – detailed report into use of a geocomposite on a nearby landfill site.

l) Case studies using three layer net

1) New River Regional Landfill, Union County, Florida USA – three layer composite used to replace traditional gravel and pipe. Geocomposite covers the base of the landfill and is used as the leachate collection layer above the liner and as a leak detection layer below.

2) Atlantic Waste Disposal, Waverly, VA, USA – Used as a leak detection system under high compression loads (100m deep) Tests showed that the residual flow under these very high compression loads were still 50% of original.

3) Three layer net case history reference list from 1995 onwards. Approximately 120 projects completed with 50 of these acting as primary leachate drainage in the base of landfills in the USA. Normal construction from base upwards is HDPE liner/geocomposite/200mm sand/waste. It is interesting to note that designs are being modified following damage tests to change the sand drainage layer to gravel.