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Designing geosynthetics for landfill sites

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ABSTRACT: The paper outlines the design considerations and installation practices of a variety of geosynthetic materials associated with the development of a contained municipal solid waste landfill site at Tullyvar, Aughnacloy, Northern Ireland. An assessment of the design criteria for the protection of geomembranes using geotextiles and geogrids is presented. In addition a summary of construction problems and ensuing solutions is provided. The paper concludes that consideration must be given to the design of protection measures to the lining materials and that an assessment of the temperature effects on the geosynthetics be undertaken for usage in the landfill environment.

1 INTRODUCTION

Current legislation and guidelines such as the Waste Management Paper 26B demand a high level of environmental protection in municipal solid waste (MSW) landfill sites. The objective is to protect the environment from both leachates and landfill gas.

Leachates are produced following the percolation of rainwater through the landfill mass, whereby contaminants are collected. Problems associated with leachates include contamination of groundwater and water courses. Landfill gas is generated as the landfill materials biologically degrade into predominantly methane and carbon dioxide. Problems associated with landfill gas is the migration off site to underground structures.

Due to the reasons detailed above it is necessary to develop new MSW landfill sites on a containment basis. Practice throughout Europe and USA follows the use of either natural low permeability clays or synthetic barriers. It many cases a combination of both provides a composite system.

The paper identifies specific design problems and solutions involving the protection of the geomembrane on the base, slopes and beneath an access ramp. The objective was to prevent excessive stress and strain generation for loading. Problems associated with the construction and in particular the effects of low temperatures on the geomembrane are presented.

1.1 Site Development

The construction of one of Northern Irelands first contained (MSW) landfill sites took place in a former limestone quarry situated in the west of the province. The quarry was approximately 3 ha in area and between 15m and 35m in depth.

The first phase development was jointly let by Dungannon and Omagh District Councils as a design and built Contract. The phase one earthworks included the grading of the floor to promote drainage, and preparation of the vertical faces to 35^0 slopes to facilitate lining.

The site design included groundwater and leachate collection systems which comprised both pipework and a drainage blanket. These layers were imported to avoid adverse chemical reactions which occur between limestone (calcium carbonate) and leachate.

The slope lining was a length of 26m and particular design considerations were given to their stability.

2 LINING SYSTEM

The geosynthetics used as environmental barriers include High Density Polyethylene (HDPE) geomembranes as a primary liner, and Geosynthetic Clay Liner (GCL) as a secondary liner. At Tullyvar Landfill Site, a 2mm HDPE and a GCL (Gundseal) were deployed to provide the composite lining system.

HDPE is a semi-crystalline polymer and its use as a geomembrane is widely accepted as a containment layer. The material has a very low permeability, high chemical resistance, reasonable ductility and can allow good quality seaming on construction sites. In Northern Ireland the authorities specify a 2mm thickness for all MSW sites. Research by Peggs et al, identifies stress cracking or rupture as a fundamental problem with HDPE geomembranes. Recent alternatives include the use of polypropylene fibres in geomembranes. These have a lower degree of chemical resistance but possess greater ductility. It is speculated that polypropylene has greater environmental stress cracking resistance than HDPE

GCL materials utilise both geosynthetics and natural materials to provide a low permeability layer. The liners are formed by providing a layer of sodium bentonite which is carried on or between geosynthetics. The most common type is referred to as the geotextile sandwich, whereby the bentonite is placed between two layers of geotextiles which are subsequently needle punched together. Another type includes gluing bentonite unto a thin HDPE geomembrane (Gundseal).

Modern developments sparsely utilise GCL's for the basal lining. The preferred option is a deeper bentonite enhanced soil or natural clay layer which provides additional robustness and puncture resistance. However GCL's are frequently deployed on the slopes and embankments of the sites.

2.1 Construction Quality Assurance

Given the nature and importance of providing an intact lining system construction quality assurance (CQA) is essential. During the development of Tullyvar Landfill Site an independent CQA Engineer was present. The majority of the monitoring is associated with the HDPE geomembranes. A paper by Peggs indicates the importance of full quality assurance from design through to completion stage. During the design for Tullyvar a comprehensive quality assurance (QA) plan was prepared prior to construction. At the construction stage the CQA Engineer ensured that this was complied with, and following completion a leak detection survey was carried out.

The geomembranes are delivered in rolls and hence require cutting, shaping and jointing to fit the irregular shape of the site. The joints/seams are formed using two types of welding apparatus. These are known as fusion and extrusion welders. Both welds undergo destructive and non destructive tests to ensure continuity and strength. The quality and climatic conditions are monitored to ensure the adequacy of the seam.

An important aspect of the QA monitoring is the deployment of the protection layers and over drainage to ensure that damage is not caused to the system.

3 DESIGN OF PROTECTION LAYERS

Following selection and design of the lining system careful consideration was given to its short and long term protection.

The purpose of both the GCL and HDPE is to provide an environmental containment barrier. To ensure its long term integrity it is essential to protect the HDPE from excessive strains and stresses. These may lead to tearing or stress cracking over a sustained loading period.

At Tullyvar both geotextiles and geogrids were used on the floor, slopes and beneath the access ramp to protect the geomembrane.

3.1 Geotextiles - Protection from Penetration

The landfill site at Tullyvar includes a leachate drainage layer above the lining system. This facilitates the rapid removal of leachates from the base of the site. The layer is composed of gravels and crushed stone of maximum aggregate size 28mm.

It was necessary to avoid excessive local strains being induced into the geomembrane from the penetration of the stones. In order to achieve this

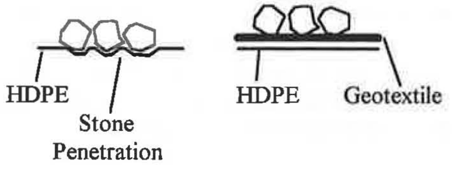


Figure 1 Protection Geotextile

Polyfelt TS800, a thick non woven needle punched geotextile was provided. The design parameters included the temporary traffic loading, the ultimate waste loading and the aggregate size. The geotextile was designed to prevent local strains in excess of 6% being induced into the liner. (See Figure 1)
A critical construction activity is the placement of the leachate drainage layer. It was important to avoid high strains from vehicle loading and hence a low load bearing tracked machine was the only vehicle permitted to traffic on the 300mm leachate drainage layer. A minimum cover of 1.0m was required for the trafficking of wheeled vehicles.

3.2 Geotextiles - Side Slopes

The site at Tullyvar was designed with 35^0 side slopes. During the design process careful consideration was given to the stability of the lining layers.

At an early stage laboratory tests were carried out at the Queens University of Belfast on a large shear box to determine the interface friction angles between the various materials.

The shear box was 300mm x 300mm and was considered of adequate size to test the variety of both natural and geosynthetic materials. To facilitate testing of the geosynthetics, a platform was prepared onto which the geomembrane and geotextile samples were attached.

The tests were undertaken at normal stresses of 75, 150, 250 and 400 kN/m^2. The strain rate varied between 0.25 and 0.5 mm/minute.

Following the tests an assessment of the probable forces is the geosynthetic layers was carried out. The slope system analysed includes the leachate (over)

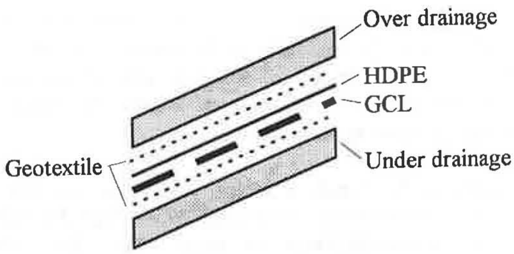


Figure 2 Slope Lining System

drainage layer, geotextile, HDPE, GCL, geotextile and under drainage. (See Figure 2)
Interpretation of the results provided the forces which would be generated in each successive layer. Initial calculations suggested that the HDPE would have to carry a significant proportion of the waste loading.

Research by Koerner et al suggested the utilisation of the low friction angles between the HDPE and the geotextiles to prevent tensile stress generation. The approach adopted was to assess the slope stability problem whilst using a mono textured HDPE, i.e. textured on one side and smooth on the other. By carefully selecting the materials a lining system structure was developed where the angles of friction increased with descending layers below the HDPE. See Figure3

The resulting scenario was that any forces which were transferred to the HDPE could then be passed to ground through the friction interface of each layer. Hence the geomembrane or the GCL did not undergo any tensile straining from the waste loading.

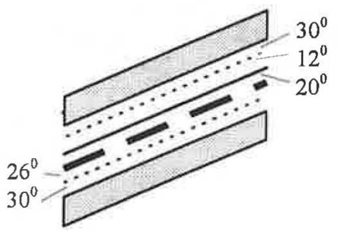


Figure 3 Slope Lining - Interface Friction Angles

The aspect of shearing stresses was considered as the loading must be passed from the upper to the lower side of the material. Calculations and comparison with manufacturers data suggested that these stresses could easily be accommodated.

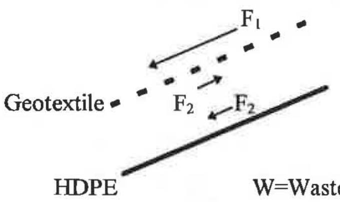
However the resulting problem with the very low friction from HDPE/Geotextile and a high friction from Geotextile/Over drainage was that the geotextile layer was required to carry a significant loading.

Figure 4 below indicates the large force which can be induced onto the geotextile and the low force which can be transferred by friction to the geomembrane. The resultant force dictated the design values for the upper geotextile.

A geotextile (Polyfelt TS800) was selected and provided a resistant strength of 24 kN/m^2. During the design of the upper load carrying geotextile it was important to assess its long term characteristics. The effect from ultra violet light, elongation and deterioration of puncture resistance was considered.

3.3 Geogrid Reinforcement

Given the particular geometry of the site a relatively large access ramp was required to traverse the vehicles down the 15m(vertical) height at a practical gradient. At the conceptual design stages of the project consideration was given to using the existing quarry ramp and lining over it. However a more favoured option was to build a new ramp over the liner system. It was considered that lining over the old ramp would provide a hard spot with the possibility of local settlement on each side. Hence excessive straining of the geomembrane.



W=Waste Load
Slope Angle=35^0

F_1 = Geotextile Loading
= Wcos35^0 tan30^0 = 30 kN/m^2

F_2 = Loading Transferred to HDPE
= Wcos35^0 tan12^0 = 18 kN/m^2

Geotextile Strength = F_1 - F_2 = 12 kN/m^2

Figure 4 Geotextile Loading

The preferred option however also provided technical difficulties in that the loading created in the dead weight of the ramp and vehicular movements would also induce significant strains into the geomembrane.

Figure 5 below presents a diagrammatic section of the access ramp into the landfill site.

An assessment was carried out to determine the loading on the liner system at various sections along the longitudinal line of the ramp. In areas of deep fill the dead weight of the material was predominant. However at shallower depths of the ramp the point loading of the vehicle wheels determined the design parameters.

The geogrid was designed on a platform basis. Calculations provided the actual strains from the loading and permissible strains that could be accommodated in the liner system. Therefore the geogrid reinforcement was detailed to carry the difference. At maximum loading points along the ramp section three layers of Tensar SS40 were deployed. The reinforcement was selected on a tensile strength of 34 kN/m^2 being attained at a strain value of 6%. The strain value related to the values which could be easily accommodated by the geomembrane.

Following installation and usage of the site for over one year, inspection has shown that the geogrid reinforcement continues to operate as designed. The long term behaviour of the material was not considered in great detail given that the ramp would be obsolete in five to six years.

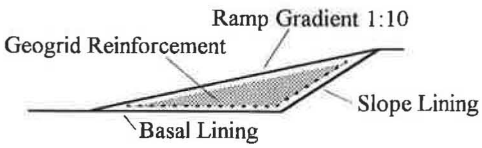


Figure 5 Access Ramp - Longitudinal Section

4 CONSTRUCTION

The construction phase of the project generated several interesting problems associated primarily which the geomembrane. This paper presents two of the significant problems which occurred during the deployment of the geomembrane on the site.

4.1 Cold Weather Welding

The lining of the site consisted of 40,000 m^2 of HDPE on the floor and slopes. Deployment of the geomembrane commenced in late summer and continued through to December. As the weather became inclement and the ambient temperatures began to drop, problems arose in the quality of the welding.

The general specification for welding of geomembranes states that welding shall not occur during temperatures lower than 5^0C. During November/December in the deep quarry environment the temperatures rarely rose above the specified temperature. Following a time lapse whereby no welding could be undertaken it was felt reasonable to instigate and develop a cold weather welding plan.

The conclusions of the work hence provided guidelines, extra precautions and testing that should be carried out during low temperature welding. An important criteria was to pre and post heat around the weld area. Research by Peggs et al suggested that the risk of stress cracking was significantly higher when seams were overheated. On site testing during cold weather welding indicated that the machines had to operate at much higher than normal temperatures to provide a satisfactory bond in the seam. In order to minimise this overheating and provide a good bond a series of tests were initiated to assess the impact of preheating the weld area. It was concluded that welding could occur at normal machine temperatures when the correct amount of preheating occurred. Post heating was to reduce the risk of excessive crystallisation of the weld area during rapid cooling of the semi crystalline polymer.

In localised welding areas were predominantly patching and repair work was undertaken, tents were deployed with internal heating systems to provide a suitable welding environment.

During the period of inclement weather additional samples were extracted from the weld area for destructive testing. The two types of test are shear and peel strength testing which were carried out using a calibrated tensiometer. However in addition to simply monitoring the strength of the weld it was important to assess the mode of failure. Research by Peggs suggests that the elongation of the geomembrane during a shear test is indicative of the weld quality in terms of stress cracking resistance. During our initial testing it was discovered that welding undertaken in sub zero temperatures with no additional precautions resulted in a brittle failure during shear testing. This would indicate a rapid failure of the bonding in the polymer and hence would be prone to stress cracking in the future.

Current testing standards require that the seams are tested at a strain rate of 50mm/minute. During testing at Tullyvar we concluded that testing at higher speeds gave inaccurate results and indicated that the weld was satisfactory when it was not.

4.2 Geomembrane Thermal Contraction

As previously mentioned in 4.0 installation of the geomembranes commenced in the late summer. During the early lining period the ambient temperatures were between 15 - 25^0C. The geomembrane was installed on the slopes to a neat fit with no compensation added to allow for contraction of the liner if the temperatures dropped. Several months later when lining was ongoing in part of the site when temperatures were 0 - 5^0C the effect of geomembrane thermal contraction became apparent.

A significant problem arose due to contraction of the geomembrane on the long slopes of the site. The problem was fortunately localised along a length of 80m - 100m. The liner contraction was visually apparent due to the trampolining at the bottom of the slopes. In several locations the liner was approximately 1.0m above the subgrade.

Upon investigation between ourselves and the installer it was concluded that a strain of 5% would be allowable to accommodate the trampolining. In areas were a strain of greater than 5% would be required to stretch the liner back to the subgrade, compensation was added to the slope to remedy the problem.

It is apparent that this was an installation problem whereby the installer had not adequately considered the thermal expansion/contraction of the material over the significant temperature fluctuations. Current design procedures and installation specification now allow for compensation material to be placed in order to avoid this problem.

It should be noted that the problem has not yet been solved. In order to provide the necessary compensation additional material is added to the slope length. However this excess material naturally gathers at the bottom of the slope and hence causes wrinkles in the liner. In order for the theory to work in a satisfactory manner the compensation must be evenly distributed along the entire slope length. The difficulty is how to maintain the even distribution of slope compensation during site operation.

5 CONCLUSIONS

Following experiences during the design and construction of Tullyvar landfill site it is concluded that the following must be considered when designing containment systems for MSW landfill sites:

1) Adequate protection measures must be included in the liner system to ensure long term integrity of the geomembrane.

The protection from stone penetration is of fundamental importance in restricting excessive strains in the geomembrane. However further research may be required to assess what level of straining is appropriate for containment layers

On long and steep slopes were several layers of geosynthetics are frequently encountered, consideration must be given to the internal slope stability of these materials. It is recommended that tests be undertaken for site specific materials. More research is required on the effects of temperature variations during the biological degradation of the waste.

2) The long term characteristics and performance of the protection geotextiles must be assessed for the landfill environment.

3) The use of geogrids are ideal as load bearing platforms to prevent excessive strains being induced into the lining system from overlying layers. Consideration must also be given to the long term degradation and relaxation of the material.

4) Installation specifications must allow for geomembrane welding during cold weather conditions. In particular quality assurance procedures should be sufficient to ensure that the seams are satisfactory. All destructive testing should be carried out on a calibrated tensiometer.

5) During the installation of geomembranes in areas were climatic fluctuation occur or when lining progresses from one season to another, careful consideration should be given to providing adequate compensation for thermal expansion/contraction.

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