Geosynthetic Lining System for Modern Waste Facilities – Experiences in Developing Asia

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ABSTRACT: The applications of geosynthetic liner systems are being used with increasing frequency, particularly for the environmental engineering applications in developing countries at recent years. Polyethylene geomembrane sheets have been widely accepted as a standard component of geosynthetic lining system in the waste containments for decades, which includes solid waste sanitary landfill and wastewater treatment lagoons. The paper presents the application of impervious Polyethylene geomembrane used as bottom liners and final capping systems in waste containment facilities in developing Asia. This paper discusses the characteristics and durability of polyethylene geomembrane as a lining solution to the waste containments. Successful case histories on the application of polyethylene geomembranes in bottom liner and final capping systems of modern solid waste facilities are illustrated.

1. INTRODUCTION

The U.S. Environmental Protection Agency (EPA) regulations have been promulgated for 2 categories of waste disposal: (i) Hazardous Waste – The Resource Conservation and Recovery Act (RCRA) Subtitle C [as amended by Hazardous and Solid Waste Amendments of 1984], 40CFR 264; (ii) Municipal Solid Waste - The Resource Conservation and Recovery Act (RCRA) Subtitle D, 40CFR 257 & 258. The purposes of the recommended designs are to protect human health and the environment through the isolation of waste from human. This can be accomplished through a top cover designed using polyethylene (HDPE/LLDPE) geomembrane of essentially impermeable (hydraulic conductivity of less than $1x10^{-12}$ cm/sec (Koerner, 2005), outstanding chemical resistance and high longevity, with the purpose to minimize contact between infiltrating water and waste, thus minimizing the formation of leachate. The bottom liner is design to contain any leachate, detect any leakage, provide for the prompt removal of any harmful liquids and avoid the contamination of groundwater, etc.

Many developing countries in Asia have followed the US and European experience by introducing the environmental regulations and guidelines on waste containments design in order to reduce the environment impacts and to improve the environmental quality of their nations. In 1997, China published the “Standard for Pollution Control of Landfill site for Municipal Solid Waste” (amended as GB 16889-2008 in 2008), and subsequently the corresponding technical specifications include CJJ17-2004, CJJ112-2007 and CJJ113-2007 to stipulate the construction and operations requirements of waste containment facilities (Ministry of Construction, China). The Department of Pollution Control of Thailand enacted the “Regulation and Guideline of Municipal Solid Waste Management” in 1998, which includes the design guidelines for bottom liner and final cover systems of sanitary landfill facilities.

Compacted clay liners (CCLs) were used predominantly until mid 1980’s for waste containment applications. In 1980, research at Texas A&M University, College Station, Texas, USA and in Germany found chemical reactions and subsequent degradation of CCLs. Other studies have shown that solutions of hydrocarbons can seriously affect the impermeability of clay (Brown et al., 1983; Kingsbury et al., 1985). Conventional clay liners required permeability lower than $1x10^{-7}$ cm/sec. However, when the clay soils were subjected to permeability tests with solutions of organic fluids, the permeability increases significantly and exceeding $1x10^{-7}$ cm/sec. Acidic and caustic leachates were found to disrupt clay barriers with resulting permeability increases (Anderson et al., 1983). Dissolutions of the soil-binding agents move some clay particles out of the barrier. In addition, due to cracks, fissures, weak layers, desiccations and sensitivity to the compaction control of CCL, field permeability of clay is generally higher than the permeability measured in the laboratory (Day et al., 1985).

Since its introduction, geosynthetic lining systems have been extensively adopted particularly for waste barrier and final closure applications. Composite capping system employing a geomembrane overlying compacted low permeability clay soil or geosynthetic clay liners (GCL) are generally used when infiltration to the waste mass must be held to an absolute minimum, particularly in a hazardous waste landfill. Over the past decade, less industrialized countries have begun to adopt geosynthetic barrier systems for environmental protection at landfills, either on a regulatory or voluntary basis. The use of a geosynthetic barrier in bottom liner and cover systems is rapidly becoming standard practice for both hazardous waste facilities and large municipal waste facilities in many developing countries. As geosynthetic barrier systems become more common and as records of the performance of these systems accumulate, the evidence of their effectiveness as barriers to liquid and gas transport grows. Landfill final cover is an integral component of effective management of waste within disposal facilities. As such, the cover system performs several functions of which includes limiting infiltration into waste as to minimize the creation of leachate, to control the disease vectors, odor and fires, minimize gas migration and emission, etc. In addition, proper capping of waste landfill can provide a better aesthetic appearance (Fuller, 1995).

2. HDPE GEOMEMBRANE AS WASTE BARRIER

Today, with the improvement of environmental awareness, particularly in developing countries, the protection of groundwater and surface water becomes a major consideration in the waste containment design. Geosynthetic lining systems play an important role in this mission because of their versatility, cost-effectiveness, ease of installation and good characterization of their mechanical and hydraulics properties (Bouazza et al., 2002). They also offer greater technical advantage in relation to the conventional clay liner system and hence become a value-added solution to the environmental protection.

There are various design philosophies and landfill management approaches in use today (Rowe et al., 1995). One is of passive approach, in which a cover system is required as soon as after the landfill has ceased operation, so as to minimize the generation of leachate. This approach has the advantages of minimizing both the amount of leachate that needs to be collected and treated, and the mounding of the leachate within the landfill. It also has the disadvantage of extending the contaminating lifespan, which may take a few decades to centuries. An alternative active approach is to allow as much infiltration as could practically occur. This would quickly bring the landfill to field capacity and allow the removal of a large proportion of contaminants through leachate collection system during the most effective period. The disadvantages of this approach require (i) to treat larger leachate volumes and higher cost; (ii) a higher infiltration may result in significant leachate mounding, if the leachate collection system fails. Geosynthetics play an important role in either case and provide value-added in minimizing contaminant migration into the environment to levels that have negligible impact.

Nowadays, modern municipal solid waste (MSW) landfill facilities are generally designed with a barrier system involving a composite liner system (Geomembrane/CCL or Geomembrane/GCL), which are used in combination with cover systems to accomplish waste containment, but many existing facilities are required to either be cleaned up and closed or retrofitted with pollution-reduction/prevention systems and monitored to ensure that current legal requirements are met. As shown in Figure 1, a typical composite liner system used in the modern waste disposal facilities mainly consists of three liner components, i.e. (i) bottom, (ii) side slope and (iii) cover liners (See Manassero et al., 1998).The bottom liner system is a double composite liner system, which is used in some instances for containment of municipal solid waste and is necessarily for landfill designed to contain hazardous waste with very high risk to the environment and population health.The bottom liner system includes a primary liner system that consists of a geomembrane/GCL composite liner and a secondary liner system with a geomembrane/CCL composite liner. The leachate collection system overlying the primary bottom liner system generally consists of gravel with a network of perforated pipes, while geocomposite drainage sheet is commonly adopted on the side slope. The leak detection system, located between the primary and secondary liners, can be a geosynthetic-composite drainage system.

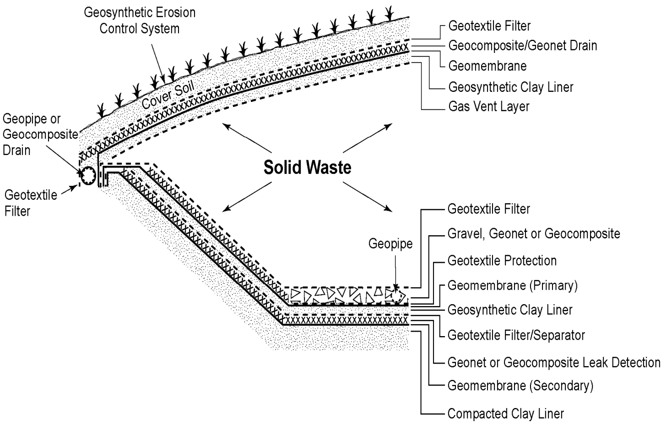


Figure 1 Cross-section of a sanitary landfill design with composite liner and cover systems

A typical barrier system of the modern municipal solid waste facilities of non-hazardous natureconsists of a leachate collection system (LCS) and a single composite liner system. The leachate collection system generally consists of a geotextile filter, a granular layer or geonet drainage system and perforated collection pipes, with the purpose to control the leachate head acting on the underlying liner, to collect and remove leachate. The composite liner system is now commonly used as standard liner system for modern landfills. It includes one or more geomembrane (commonly high density polyethylene, HDPE layer(s)) overlying a natural soil barrier, such as compacted clay liner (CCL) or geosynthetic clay liner (GCL). The application of composite liner system is to combine the advantages of two materials, i.e. geomembrane and clays, which have their respective advantages in hydraulic and physical properties, durability, etc. Generally, the geomembrane serves as the primary resistance to the advective contaminant flow and diffusion of some contaminants. The clay component (CCL or GCL) is a supplementary liner to reduce leakage through any holes or defects in the geomembranes, which could be due to poor construction quality and/or vandalism during construction or for other reasons (Rowe, 1998).

Among the plastic materials utilized for geomembranes, high density polyethylene (HDPE) geomembrane, with its superior hydraulic and mechanical properties in combination with its greater chemical resistance, thermal stability and ultra violet (UV) light degradation resistance, is the most widely used geosynthetic lining material adopted for various containment applications. HDPE geomembrane serves as an essentially impermeable barrier to stop or limit the migration of liquids and chemicals out of the containment. It is a flexible synthetic liner manufactured from polyethylene resin with a small amount of carbon black, UV stabilizers and antioxidants. There are two main manufacturing processes to produce HDPE geomembranes, namely round die co-extrusion and flat cast extrusion processes. Both processes are capable to produce smooth and textured geomembranes. By creating a roughened surface on smooth HDPE geomembrane surface through the “texturing” process, a high friction surface can be created with the purpose to enhance frictional resistance of geomembrane which can improve the interfacial stability of liner system and eventually maximize the available volume that can be contained by the geomembrane liner. The ability to line steeper slopes allows an increase in design capacity and eventually contributes to overall project cost saving and even creates higher profit from the extra storage. Typically, 7.0m wide geomembrane provides the most efficient installation which ultimately lowers the construction cost.

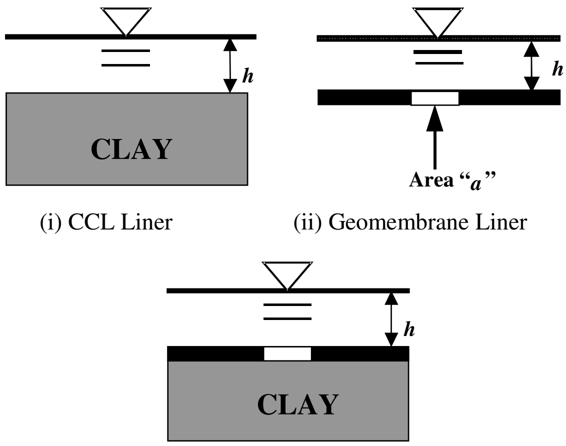
A MSW landfill is typically designed with a single composite liner, unless a specific stringent design condition and regulations required a double liner system. Hence, there is no inclusion of leakage detection system in general cases. A conventional groundwater monitoring well system therefore becomes a common practice for leakage monitoring around the facilities. Koerner (2000) reported that 24% of MSW landfills in the United States and 14% of landfills worldwide have been designed using double liner systems. The composite HDPE geomembrane liner system is used to prevent the migration of leachate towards the natural geological formation has been proved to be a cost-effective and widely accepted design in the modern sanitary landfill.

Waste containment facilities are required to have a final cover system designed to minimize infiltration and erosion, control ingress or egress of gases (e.g. egress of decomposed gases from waste or ingress of oxygen into some wastes). To maximize the capacity of the landfill and to provide solution to slope surface erosion concerns as well as the slope stability problems associated with comparatively low interface shear strength of typical cover components, an alternative cover system such as exposed geomembrane cover can be considered in order to achieve significantly steeper and higher final covers with greater storage capacity.

A typical final cover system of the sanitary landfill as shown in Figure 1 contains a composite geomembrane/CCL or geomembrane/GCL barrier layer with an overlain drainage layer that is commonly of geocomposite drainage system (geonet-geotextile composite) before filling with cover soil. Polyethylene geomembrane is commonly adopted as the primary liner for the landfill cover systemdue to its outstanding physical and mechanical properties, exceptional chemical resistance, etc. A typical passive composite liner design is aimed at limiting percolation of water into the waste, allowing minimization of the transport of contaminants from the landfill to the underground water. MSW can generate tremendous quantities of gas during its decomposition, it is therefore necessary to allow a gas collection layer with a suitable venting system to avoid air pollution and blow-outs of the barrier due to pressure buildup below the geomembranes.

3. TYPES OF LINERS AND THEIR FLOW RATES

The primary function of the bottom liner in a waste containment is a barrier to prevent the leachate from migrating into the subsoil and contaminating groundwater. It is generally required that the permeability of the liner system to be less than 1 x 10^{-9} m/sec in landfill by regulations in many countries. In general, there are three basic hydraulic barriers/liners: (i) a low hydraulic conductivity, compacted clay liner (CCL), (ii) a geomembrane liner, and (iii) a geomembrane/CCL or GCL composite liner, as shown in Figure 2.



(i) CCL Liner (ii) Geomembrane Liner

(iii) Composite Liner

Figure 2 Three basic hydraulic barriers for waste containments

Flow rate through compacted clay liners are calculated using Darcy's law as per the following expression,

$$q = k_s\, i\, A$$

Where,

q = flow rate (m^3/sec)
k_s = hydraulic conductivity of clay layer (m/sec)
i = hydraulic gradient
A =flow area of clay layer (m^2)

Geomembranes are relatively impermeable polymeric sheets that can be an excellent barrier to liquids and vapors. Thus, assumptions below are made to estimate leakage through liner:

(1) The geomembrane has one or more circular holes (defects) in the liner, which usually result from installation activities,
(2) The defects or holes are widely spaced with the leakage through each hole occurs independently from each other
(3) The pressure head above the liner is constant
(4) The subsoil under the geomembrane has very large conductivity

Giroud & Bonaparte used the equation below for estimating the flow rate through holes in the geomembrane (Giroud et al., 1995).

$$q = C_B\, a\, (2gh)^{0.5}$$

q = flow rate (m^3/sec)
C_B = flow coefficient with a value of approximately 0.6
a =area of the circular hole (m^2)
g = acceleration due to gravity, 9.81 m/sec^2
h = pressure head above the liner (m)

Industry average standard for estimating defects in an installed geomembrane assumes that approximately two to ten 100mm^2 holes per hectare exist after a geomembrane is deployed and covered with soil. The number and size of these defects can be reduced through more thorough Construction Quality Assurance (CQA) procedures, such as the use of an electric defect-detection survey on Spark-testable Conductive geomembrane after the overlying soil material has been placed. The quality of installation and the assumed size and frequency of geomembrane defects should be evaluated on a project-specific basis (Erickson et al., 2002).

Empirical modeling and field observations (Giroud et al., 1992; Giroud, 1997) resulted in the "Giroud" equation for estimating leakage through a hole in the geomembrane of a composite liner. For hydraulic head, h < 3m, and defect area, a ≤ 5x10^{-4} m^2 (25mm diameter), the empirical equation is expressed as following:

$$q = C\,[1 + 0.1(h/t)^{0.95}]\, a^{0.1}\, h^{0.9}\, k_s^{0.74}$$

Whereas, for hydraulic head, h ≥ 3m with defect area, a ≤ 5x10^{-4} m^2 (25mm diameter), the empirical equation shall be in the following form (Thiel et al., 2001).

$$q = C\,[1 + 0.1(h/t)^{0.95}]\, a^{0.1}\, h^{0.9375}\, k_s^{0.74}$$

Where:

q = rate of leakage through a defect (m^3/sec);
C = a constant related to the quality of the intimate contact between the geomembrane and its underlying clay; C=1.15 for very poor contact [17], C=0.01 for geomembrane backed GCL, and C=0.05 for geomembrane underlain by geotextile encased GCL (refer to Erickson et al., 2002)
h = head of liquid on top of the geomembrane (m);
t = thickness of soil component of the composite liner (m);
a = area of defect in geomembrane (m^2); and
k_s = hydraulic conductivity of the underlying clay (m/s).

Flow rate comparison of the three liners namely CCL, geomembrane and composite geomembrane/CCL of good ($k_{s[CCL]}$ = 10^{-7} cm/sec, geomembrane of 1 holes/ha, a=100mm^2) and poor construction quality($k_{s[CCL]}$ = 10^{-6} cm/sec, geomembrane of 10 holes/ha, a=100mm^2). Assuming CCL is of industrially accepted hydraulic conductivity (k_s = 10^{-7} cm/sec), the flow rate is 0.5m^3 per hectare per day. The flow rate of geomembrane/CCL composite liner with 0.3m hydraulic head is significantly lower, only 0.003 (m^3/ha/day). Even with poor subgrade (k_s>10^{-7} cm/s) and poor construction quality (10 holes of 100mm^2 per hectares), the flow rate is about three times less than the case of having only CCL, which still exceeds the commonly accepted conventional CCL.

Many have reported that a composite liner significantly outperforms a CCL or geomembrane alone. Therefore, HDPE geomembrane/CCL composite liners are commonly adopted in modern environmental engineering practice of waste facilities. Figure 3 shows the typical design of a composite liner system in sanitary landfills (You, 2002), in which a geomembrane liner overlying 600mm CCL with permeability of less than 10^{-7} cm/sec is served as the hydraulic barrier. A leachate collection and removal system consisting of 300mm gravel (with coefficient of permeability >1x10^{-2}cm/sec) or an equivalent geosynthetic drainage layer overlying the primary liner is used to control the hydraulic (leachate) head acting on the geomembrane liner and to collect and to remove the leachate.

4. SUCCESSFUL CASE HISTORIES

Some successful experiences on the application of polyethylene geomembranes as lining materials in waste containment facilities include large to medium scale municipal solid waste landfills in developing Asia, e.g. China, India and Thailand are presented in this section.

4.1 Bottom Liner System

A modern sanitary waste containment is typically designed with HDPE geomembrane/CCL composite liner system. Case histories on the application of HDPE geomembrane as a component of composite bottom liner system in the modern municipal sanitary landfills are presented in the following.

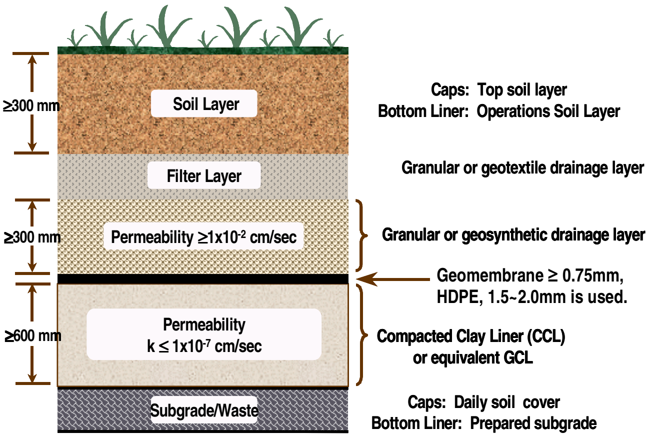


Figure 3A typical composite liner system in sanitary landfill

4.1.1 Lined Sanitary Landfill in China

This project is located in the southern China and the geological formation is generally of quaternary strata and weathering alluvium. The upper part of the strata consists of silty clay, clay and silt of the alluvium and flood deposits. A composite bottom liner system with HDPE geomembrane is designed as a barrier system to prevent the waste and leachate from contaminating the surrounding environment.

A double composite geomembrane liners system is used in this project to provide compliance with regulating authority requirements. The barrier system begins with geotextile filter immediately after the waste body. It follows with the granular materials served as primary leachate collection and removal layer, a geotextile layer overlies 1.5mm HDPE geomembrane liner, a geocomposite drainage layer for the leachate detection and removal, a secondary liner of 1.5mm HDPE geomembrane, a geotextile as cushion layer, granular drainage layer and ended with a geotextile filter layer. Figure 4 is the landfill cell after the completion of the entire liner system.

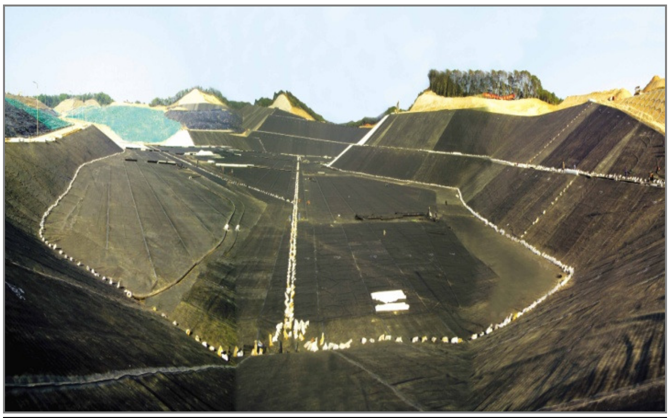


Figure 4A lined MSW landfill cell in Southern China

4.1.1 Lined Sanitary Landfill in Thailand

It is a standard regulation using HDPE geomembrane and natural CCL composite liner as the hydraulic barrier in waste containment facilities in Thailand. The site is a municipal solid waste (MSW) landfill located at the central region of Thailand. To comply with the regulations of Thailand (Thailand Pollution Control Department, 1998), a single composite liner is adopted as hydraulic barrier system in this MSW landfill. The components of the liner system from bottom-up are 600mm CCL on the subgrade, 1.5mm HDPE geomembrane as the primary liner, geotextile as protection layer and 300mm granular layer (for leachate collection and removal). Figure 5 shows the HDPE lined MSW landfill in Pathum Thani province, Thailand.

Figure 5A lined MSW landfill in Pathum Thani, Thailand

4.2 Final Landfill Capping System

The modern solid and hazardous waste landfills are typically required to be closed with a capping system in order to prevent direct contact of people and the environment with the waste, to minimize infiltration of rain water (which generates leachate) into the landfill and to prevent erosion of waste materials includes provide sufficient factor of safety for surface water drainage and slope stability, etc. Some successful case histories on the application of HDPE geomembranes as final landfill capping system are presented in the following.

4.2.1 Landfill Capping Site in Southern China

Landfill cover system is sometimes an alternative for remedial measures on old landfills constructed prior to the regulations (Carson, 1995). The landfill located at southern China is a typical example, in which the dumpsite contains 3 million tons of municipal wastes without bottom lining. After ending the 14 years operation, it was not covered and created adverse air quality and caused contamination to the environment and groundwater. The neighbors protested against the waste dumpsite as it threatened the health and aesthetic view of the vicinity. A geosynthetic capping system consisting of the following (from bottom-up) was then constructed to cover the existing site.

- 300mm thick low permeability CCL
- 1.5mm HDPE geomembrane liner
- Geosynthetics drainage product- geonet
- Geotextiles as separation and filtration layer
- 1000mm top soil / vegetation layer

The completion of final capping system has improved the air quality for the region by eliminating the odors from the open waste dumpsite and turned the disgusted dumpsite site into a friendly environment filled with green plants and grasses. Figure 6 shows an overview of the completed final capping system for the site using HDPE geomembranecovered with green vegetation.

4.2.1 Landfill Capping Site in India

This project site is an industrial waste landfill located in Western India. It is one of the largest Industrial zones in Asia having a common secured landfill for the disposal of hazardous / solid waste. When the landfill cell filled to the capacity, it was then covered with a proper designed geosynthetic capping system. The final capping system (from bottom-up) consists of :

- 300mm cover soil with 300mm gas drainage media and coarse sand layer

- Geotextiles as separation layer and 600mm thick CCL
- 50mm thick coarse sand as filtration and protection layer
- 1.5mm thick HDPE geomembrane liner and Geotextiles as protection layer
- 50mm coarse sand as filtration layer and 250mm drainage media (gravel)
- 900mm thick top soil and vegetation on agricultural soil of 100mm thick

Figure 6 A landfill final capping with vegetation in China

Figure 7 shows the overview of final capping system of the hazardous waste landfill.

Figure 7 A completed landfill capping system in Western India

5. FIELD QUALITY ASSURANCE

A proper geomembrane installation and associated construction quality assurance (CQA) is crucial to the long-term performance of lining system. A CQA plan is usually developed before construction and used during construction to guide observation, inspection, testing and documentation of all field records.

The seaming of HDPE geomembrane always requires well-trained personnel and special equipment. Prior to the welding, it is important to ensure the materials to be welded shall be wiped clean of moisture, dust and debris. During the deployment of the initial geomembrane rolls, trial welds are conducted on the same materials used on the project. The trial welds are carried out to verify that seaming conditions are properly established, and also to ensure that the equipment is functioning properly. The test welds are then subjected to destructive tests to qualify the welding and the equipment used before commencing the field seaming works.

Thermal wedge welding is the primary method used for the field seaming of HDPE geomembrane by qualified and experienced welders. The extrusion welding technique is adopted only for non-linear seams, patches, pipe penetrations or areas that wedge welder is impractical. After the seaming works, a series of installation quality assurance tests, inclusive of non-destructive and destructive weld testing, are carried out to ensure the weld quality at site is in full compliance with the engineer's requirements and/or the equivalent recognized testing standards. Typically, non-destructive seam tests include spark testing, air-pressure and vacuum-box tests. Hot wedge welder creates a double-track weld, leaving an air channel in between these two weld tracks which can then be used to non-destructively air pressure test the integrity of the seam. As shown in Figure 8, when the seam is completed, both ends of the air channel are sealed off and the seam is pressure-tested to determine its continuity. Any non-compliant seams are patched with extrusion weld before retesting. The non-destructive vacuum-box test is used to check the continuity of welded seams, repairs and patches where it is not practical to conduct air pressure test.

Destructive seam tests are used to evaluate bonded seam strength, which involves cutting out a section of the seam and tested until failure. Test strips are cut from the section and tested on site. The destructive samples are tested for shear-strength and peel-strength values, carried out in accordance to ASTM D6392. The sampling frequency is conducted as per recommendation of GRI-GM19, in which is, on average, one test location per 500 linear feet of seam for the entire project and can be reduced as per engineer's decision at site depending on the weld quality. GRI White Paper #3 provides a guide that allows a decrease in the amount of destructive seam sampling for good seams (Koerner et al., 2003). The destructive shear test involves application of a tensile stress from the edge of one sheet, through the weld to the edge of the adjoining sheet. For the peel test, the overlapping portions of the sheet are pulled in opposite directions to observe weld separation behavior.

Figure 8 Non-destructive air pressure test is in progress at site

6. CONCLUSION

The use of geomembrane and composite liners at the landfill bottom liner and final capping systems in developing countries increased rapidly in these recent years. The outstanding performance of the composite liners such as geomembrane/CCL and geomembrane/GCL has proven it a high performing and recommended barrier system for the modern waste landfill facilities. Flexible polyethylene geomembrane with its durability, low permeability characteristics and outstanding performance in various aspects has therefore become a widely accepted component of the barrier system to achieve the final protection of the environment. This paper presented the successful applications of polyethylene geomembranes in the bottom liner and final capping systems of the modern sanitary waste landfills in developing Asia countries. Polyethylene geomembrane, particularly HDPE is commonly selected as a standard component of waste barrier system and has been successfully deployed with acceptable leak-proofing performance in waste containments at different regions. It is also a cost-effective lining component for environmental engineering applications which include solid waste and wastewater facilities. Polyethylene geomembranes have a proven track record in these types of applications for more than three decades.

A proper geomembrane installation with associated construction quality assurance is always crucial to the long term performance of lining systems. To ensure the sealing integrity of geomembrane installation, a series of the quality assurance and quality control program as well as the final monitoring and field leak detection are usually required in order to serve as verification during and after construction works. Past experiences show that key design and performance issues must be evaluated on a project-by-project basis, which for geomembrane liner includes both material manufacturing quality and construction quality.

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