Interface shear strength of composite landfill liner

Saravanan Mariappan
Nexus EC Sdn. Bhd., Kuala Lumpur, Malaysia .

Interface Shear Strength of Composite Landfill Liner

Masashi Kamon[1], Faisal Hj Ali[2], Takeshi Katsumi[3] , Tomoyuki Akai[4],Toru Inui[5] , and Mariappan Saravanan[6]

[1]Professor, Graduate School of Global Environmental Studies, Kyoto University, Kyoto, Japan.
[2]Professor, Department of Civil Engineering, University Malaya, Kuala Lumpur, Malaysia.
[3]Associate Professor, Graduate School of Global Environmental Studies, Kyoto University, Kyoto, Japan.
[4]Senior Research Scientist, Technology Research Institute of Osaka Prefecture, Osaka, Japan
[5]Research Associate, Graduate School of Global Environmental Studies, Kyoto University, Kyoto, Japan.
[6] Graduate Student, Graduate School of Global Environmental Studies, Kyoto University, Kyoto, Japan.

ABSTRACT:

Many engineers and researchers used various methods of parameter evaluation to evaluate the interface shear strength of composite liner in landfills. However there is no specific testing methodology and apparatus adopted till today. The current testing procedures are based on ASTM testing guideline and basic fundamental engineering testing philosophies. This paper discusses the interface tests conducted for composite liner system of interface shear strength between soil and soil, 2) geomembrane and soil, 3) geosynthetic / compacted clay liners and soil, 4) geomembrane and geotextile, 5) geotextile and soil, 6) geotextile and geosynthetic / compacted clay liners, 7) geomembrane and geosynthetic / compacted clay liners. Large scale shear box apparatus is proposed to be used for the tests with adopted modification.

Keywords ; Interface, Shear Strength, Land Fill Liner System, Modified Large Scale Shear Box, Internal Shear Strength.

1 INTRODUCTION

In Japan the material flow is about 2100 million tones annually. This consumption of resources generates waste of 600 million tones, which consist of 400 million tons of industrial waste and 50 million tons of municipal waste. Out of this 220 million tons are recycled and reused, 324 million tons are pre-treated waste for disposal and recycling. 56 million tons are used for landfill in Japan in year 2000. United State however product 300 million tons of solid waste per year. Up to 75% or 225 million tons of the solid waste continues to be land filled in spite of vigorous effort aimed for waste reduction, recycling and reuse (Qian et al., 2002).

As in the case of Malaysia the volume of waste generation increased as a result of industrialization and population growth of 2.5 % per annum which generates 0.7 kg / day per capita waste. Solid waste collection in Malaysia stands at 15,000 tons daily as estimated by Ministry of Housing and Local Government (MHLG). This generates about 5 million tons of solid in 1994. By the year 2010, the collection is estimated to reach 9 million tons.

It is estimated that at least 5 % of the Malaysian population (approximately 1 million people) are living within 1 km radius from closed landfills and existing dumpsite. The recorded 300 to 400 dumpsites located around the country have severe social and health implications to the Malaysian population (Salim et al., 2003)

The estimated life spend of landfill site in Japan is about 6 to 7 years of operational. It is becoming impossible to build new sites in Japan cause of the syndrome of “Not In My Back Yard”. The cost of new site in Tokyo could come up to 500 million US dollors. The running cost of existing landfill site in Tokyo is at 300 USD / m^3 or 250 USD / tons

The vast range of toxic material, constitute of Municipal Solid Waste need to be disposed systematically. Modern and well constructed landfill can be characterized as an engineered structure that consists primarily of a composite liner, leachate collection and removal system, gas collection and control system and final cover.

1.1 Basic landfill design

An engineered landfill site must be geologically, hydrologically and environmentally suitable. Landfills are not an open dump site. Nuisance conditions such as smoke, odor, unsightliness, insect, rodent, and seagull are not present in a properly designed, operated and maintained sanitary landfill. As such landfill site need to be carefully design to envelope the waste and prevent escape of leachate into the environment. Most important requirement of a landfill site is that it does not pollute or degrade the surrounding environment.

An engineered Municipal Solid Waste landfills consist of the following (Qian et al., 2002).

i. Bottom and lateral side liners system
ii. Leachate collection and removal system
iii. Gas collection and control system
iv. Final cover system
v. Strom water management system
vi. Ground water monitoring system
vii. Gas monitoring system

During construction or design of a landfill site, the engineers required to perform detail engineering evaluation on :

i. Landfill foot print layout
ii. Subsoil grading
iii. Cell layout and filling
iv. Temporary cover selection
v. Final cover grading
vi. Final cover selection

The above are directly relate to geotechnical engineering works which involves the use of ground improvement and slope stabilization technology. Every geotechnical engineers are required to engage in the environmental engineering problems with the motto of “Think Globally, Act Locally” (Kamon 2001).

1.2 Environmental aspect of landfill

The basic environmental guidelines have contributed in developing suitable liners or hydraulic barriers for the landfill site. Early liners consisted primarily of a single liner composed of a clay layer or a synthetic polymeric membrane. During the past few decades the trend is to use composite liner systems comprising both clay and synthetic geomembranes together with interspersed drainage layers.

The following are the approximate chronology showing the introduction date for each of these approaches.

Pre – 1982	Single clay liner
1982	Single geomembrane liner
1983	Double geomembrane liner
1984	Single composite liner
1985	Double composite liner with primary and secondary leachate collection system

Double composite liners with both primary and secondary leachate collection system have been widely adopted in solid waste landfills in the United States. This type of liner system is mandated by Federal and State regulations for hazardous waste, in United States. Figure 1, shows the typical details of double composite liner system.

Progressively many other countries have impost their own guidelines in bottom composite liners system. Figure 2 shows the various type of bottom lining system used in many countries.

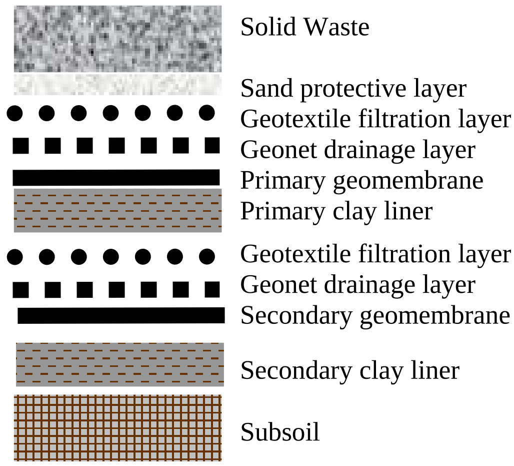


Figure 1 : Double Composite Liner System

1.3 Geotechnical engineering aspect of landfill

Geotechnical aspects of landfill involves the assessment of engineering properties of landfill components and design a stable landfill site against any mode of failure and avoid contamination to environment.

Some recent landfill failures have indicated failures taking place along low friction angle zone between subsoil and geosynthetic or geosynthetic layers, clay liners, landfill cover slopes in static state or under seismic condition. This has lead to various researches to be carried on the shear strength and interface properties of subsoils, clay liners, geosynthetic and waste material.

Most of the researches suggest the importance of geotechnical design in a landfill to prevent failures cause by low interface coefficient. The weakest interface identified, is generally lower between woven geotextile component of composite clay liner and the adjacent materials (Daniel et al., 1998). As the interface shear strength are dependent on many factors such as product type, hydration, shearing conditions and the specification of the equipment used to perform the tests (Triplett et al., 2001).

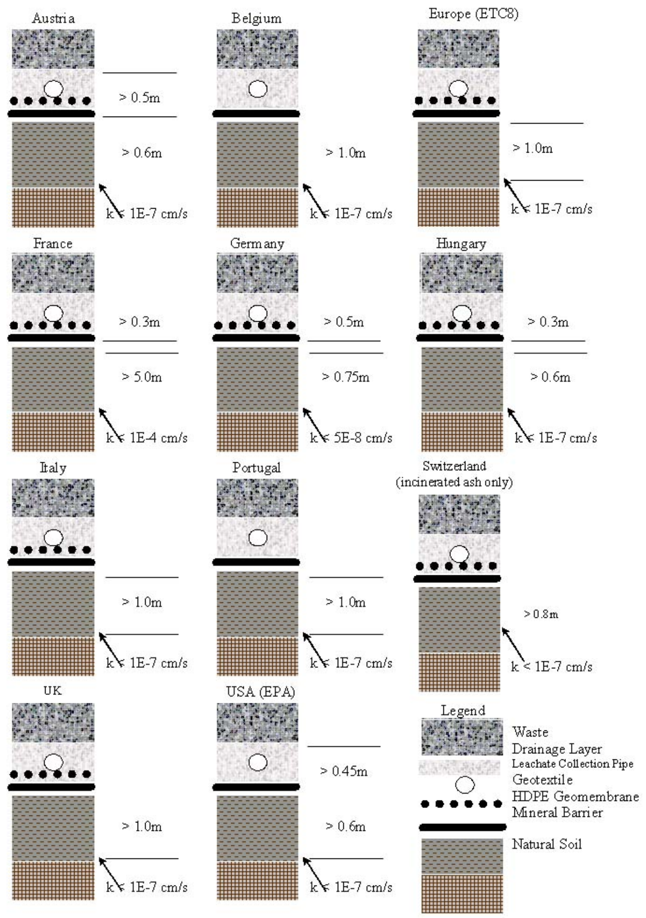


Figure 2 : Bottom lining systems used in many countries (Kamon, 2001)

Engineers are required to be careful in not designing slope that exceeds the safe slope angle for the clay liners or their respective interface within the system. For example, an infinite slope consisting of cohesionless interfaces with no seepage, the factor of safety (F) is (Daniel et al., 1998) :

$$F = \tan \phi \quad / \tan \beta$$

Where ϕ = angle of internal friction;
β = slope angle

During progressive failure in native soil, the peak strength of the MSW would be mobilized at a time when the shear strength of the native soil had declined to a value significantly below peak.

This condition takes place cause by stain incompatibility between native soil and MSW. Similar condition is also applied for geosynthetic interface and foundation soils because of their strain incompatibility with the adjacent materials in stability analysis (Eid et al., 2000). Strain incompatibility could suggest the use of residual shear strength in stability analysis instate of peak shear strength.

2 PROPOSED RESEARCH OUTLOOK

The above discussion calls for detail and compressive study of landfill stability on the following :

1. Study landfill liner component, their internal shear strength and external interface properties
2. Liner geosynthetic material and physical properties.
3. The effect of normal stress on liner system and its influence on interface properties
4. Study the compacted clay liner (CCL) internal shear strength and external interface properties with geomembrane and geosynthetic clay liners
5. Study the interface property of compacted clay liners (CCL) and geosynthetic clay liner (GCL) with native soils
6. Study the interface property between CCL, GCL, non woven geotextile and geomembrane.
7. Study the suitable configuration of composite liner system which could improve the liner stability without neglecting the hydraulic conductivity requirement
8. Conduct detail stability analysis study of various configurations of landfill liner from laboratory study data by adopting limit equilibrium method.
9. Prepare a manual for landfill stability design and installation guide for landfill liner and cover soil to improve overall stability of landfill site by providing sufficient strain compatibility within the component members

2.1 Proposed landfill liner configuration for testing

The list of testing conducted will dependent on the configuration and the material used for landfill liner system, adopted for the research.

Following Figure 3 shows the sample configuration proposed for research

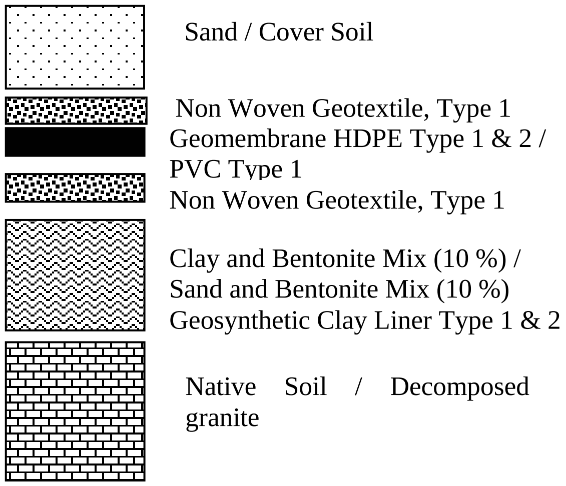
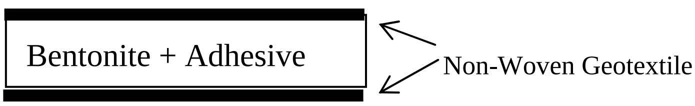


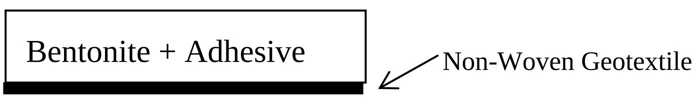
Figure 3 : Proposed Detail of Landfill Liner Configuration for Research

<u>Proposed material details are as follows :</u>

i. Sand
ii. One type of Non Woven Geotextile
iii. Geomembrane
   a. HDPE Geomembrane
      - Type 1 – Smooth non textured
      - Type 2 – Textured membrane
   b. PVC Geomembrane - Smooth non textured
iv. Clay Liners
   a. Clay and Bentonite Mix (10 %)
   b. Sand and Bentonite Mix (10 %)
   c. Geosynthetic Clay Liner (GCL)
      - GCL Type 1 – Adhesive-bond clay to upper and lower non woven geotextile



      - GCL Type 2 – Adhesive-bond clay to geomembrane



v. Native Soil type - Decomposed granite soil

Textured and non textured geomembrane is proposed for the study to validate the interface properties due to plowing. The measured friction coefficient for smooth particles is relatively low and plowing is not an important contributor. Whereas rougher and more angular particles have relatively larger frictional coefficients and plowing is important even at low normal loads. (Dove et al., 1999).

Modified large scale shear box is proposed to be used to study the interface properties. The shearing machine is required to have maximum normal load of 350 kPa and shearing speed of 1 mm/min with maximum shearing displacement between 50mm to 100mm. Each interface configuration test are proposed at be tested for normal loads of 100, 200 and 350 kPa to obtain the interface properties.

3 TESTING APPARATUS DESIGN GUIDE

The modified large scale shear box for the interface shear strength evaluation for landfill liner system was developed based on the guideline of

i. American Standard – ASTM D3080 – 98 – Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions.
ii. American Standard – ASTM D5321 – 02 – Standard Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method.
iii. American Standard – ASTM D6243 – 98 – Standard Test Method for Determining the Internal and Interface Shear Resistance of Geosynthetic Clay Liner by the Direct Shear Method.

As per the above guideline and testing requirement the apparatus design is subdivided into three categories, namely

i. Soil and soil internal and interface testing apparatus to perform test on
   - Interface shear strength between native soil and compacted clay liner
   - Internal shear strength of native soil and compacted clay liner
ii. Geosynthetic and geosynthetic internal and interface testing apparatus to perform test on
   - Internal shear strength evaluation of geosynthetic clay liners
   - Geomembrane and geotextile
   - Geotextile and geosynthetic clay liners
   - Geomembrane and geosynthetic clay liners

iii. Geosynthetic and soil interface testing apparatus to perform test on
- Geomembrane and native soil / compacted clay liner
- Geosynthetic clay liners and native soil
- Geotextile and native soil / compacted clay liner

All the above specified experiment are required to be conducted under both saturated and at optimum moisture content. Hence the equipment should meet the necessary guideline on sample saturation procedure. Following are the design guide adopted to modify the large scale shear box

i. Shear Box Design Guide
   a. The shear box size shall have a minimum size of 300mm x 300mm or 15 times the d_{85} of the coarse soil sample used, or 5 times the maximum opening size (in plan) of the geosynthetic to be tested. The adopted shear box size is 250mm x 530mm for top box and 350mm x 610mm for bottom box.
   b. The shear box height shall have a minimum height of 50mm or 6 times the maximum particle size of the coarse soil used. The adopted box height ranges between 85mm to 100mm.
   c. Test failure is defined as shear stress at 15 % to 20 % of relative lateral displacement. The shear box is designed to have maximum displacement of 80mm which is 15 % of 530mm of shear box length.
   d. The top and bottom box opening shall be ½ of d_{85} or 1mm.

ii. Geosynthetic Clay Liner Hydration Process Guide (Patrick J. Fox, 1998)
   a. Determine the received geosynthetic clay liner water content as whole
   b. Add sufficient water in shallow pan and allow the geosynthetic clay liner for 2 days hydration with 1 kPa normal aerial load.
   c. Determine water content of geosynthetic clay liner as whole before and after shearing process.

iii. Shearing Process Guide
   a. The shearing machine is required to have a range of displacement rate of 0.025mm/min to 6.35mm/min however the proposed testing procedure will adopt a displacement rate of 1mm/min due to machine constrains.
   b. The normal loading plate shall have 0.2 to 0.5mm lesser dimension than the inner box dimension.
   c. The load cell or proving ring shall have an accuracy of 2.5N the record or monitor the shearing forces.
   d. Horizontal displacement measuring device shall have an accuracy of 0.02mm with maximum displacement of 120 ~ 150mm.
   e. LVDT – Linear Variable Differential Transformer is proposed to be use to measure displacements.

The above listed is the summary of interface and internal shear strength requirement base on the guideline in , ASTM D3080-98, ASTM D5321-02 and ASTM D6343-98. With such stringent guide and testing complexity, much attention was required to modify the conventional shear box to meet the standard guideline. Figure 4 below shows the modified design shear box.

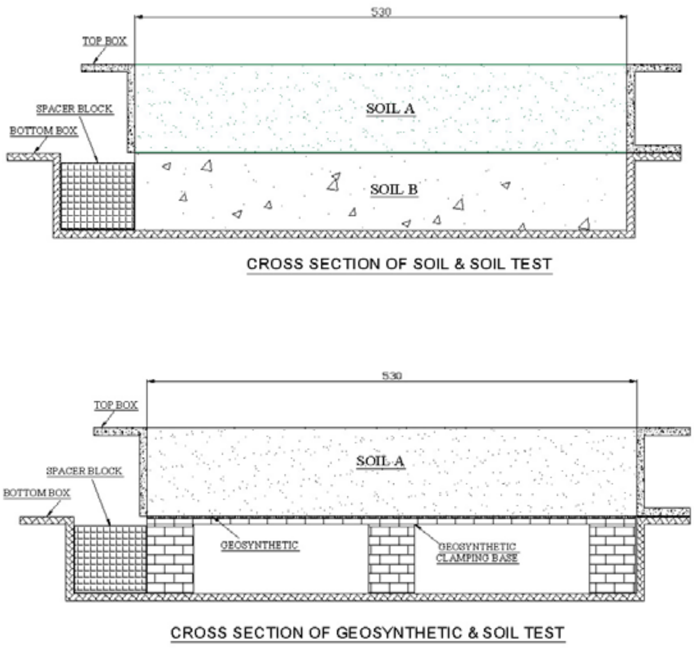


Figure 4 : Shows the apparatus proposed to be used for interface testing

4 CONCLUSION

Based on the testing requirement as per the guide line of ASTM the designed apparatus is shown in figure 4. It shows the schematic diagram of modified shear box proposed to be used to conduct interface test for :

i. soil and soil interface testing
ii. geosynthetic and geosynthetic internal and interface testing
iii. geosynthetic and soil interface testing

The summarize design guide reflects the maximum and minimum testing requirement based on the said ASTM standards.

The design equipment is expected to perform as required and obtained much reliable data. The method of data interpretation will also be investigated as the proposed testing covers both saturated and at optimum moisture condition.

REFERENCES

ASTM D3080–98 “Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions”. Annual Book of ASTM Standards, Vol 04.08. pp. 347 – 352.

ASTM D5321–02 “Standard Test Method for Determining the Coefficient of Soil and Geosynthetic or Geosynthetic and Geosynthetic Friction by the Direct Shear Method”. Annual Book of ASTM Standards, Vol 04.13. pp. 123-129.

ASTM D6243–98 “Standard Test Method for Determining the Internal and Interface Shear Resistance of Geosynthetic Clay Liner by the Direct Shear Method”. Annual Book of ASTM Standards, Vol 04.13. pp. 287-293.

Daniel D. E., Koerner R. M., Bonaparte R., Landreth R. E., Carson D. A. and Scranton H. B. (July 1998) “Slope Stability Of Geosynthetic Clay Liner test Plots”, Journal of Geotechnical and Geoenvironmental Engineering, pp. 628-637.

Dove J. E. and Frost J. D., P.E., (July 1999) “Peak Friction Behavior of Smooth Geomembrane-Particle Interfaces”, Journal of Geotechnical and Geoenvironmental Engineering, pp. 544-555.

Eid H. T., Stark T. D., Evans W. D., and Sherry P. E. (May 2000) “Municipal Solid Waste Slope Failure. I Waste and Foundation Soil Properties”, Journal of Geotechnical and Geoenvironmental Engineering, pp. 397-407.

Fox P. J., Rowland M. G., and Scheithe J. R., (October 1998) “Internal Shear Strength of Three Goesynthetic Clay Liners”, Journal of Geotechnical and Geoenvironmental Engineering, pp. 933-944.

Gilbert R. B., Wright S. G., and Liedtke E. (Dec 1998) “Uncertainty in Back Analysis of Slopes : Kettleman Hills Case History”, Journal of Geotechnical and Geoenvironmental Engineering, pp. 1167-1176.

Kamon, M. (1989) “Definition of Environmental Geotechnology” Proc. 2nd ICSMFE, Rio de Janeiro, 5: pp. 3126-3130.

Kamon, M. and Jang, Y. S. (2001) “Solution Scenarios of Geo-Environmental Problems”, Eleventh Asian Regional Conference on Soil Mechanics and Geotechnical Engineering”. S. W. Hong et al., Swets & Zeitlinger, Lisse, pp. 833-852.

Kamon, M. and Katsumi, T. (2001): Clay liners for waste landfill, Clay Science for Engineering”, K. Adachi and M. Fukue, eds., Balkema, Rotterdam, pp. 29-45.

Koerner, R. M. and Soong, T. (2000b). “Stability assessment of ten large landfill failures”, Advances in Transportation and Geoenvironment Systems Using Geosynthetics, Geotechnical Special Publication No. 103, J.G. Zornberg and B.R. Christopher (Eds.), ASCE, pp. 1-38.

Ling H. I. and Leshchinsky D., (February 1997) “Seismic Stability And Permanent Displacement of Landfill Cover Systems”, Journal of Geotechnical and Geoenvironmental Engineering, pp. 113-122.

Qian X., Koerner R. M. and Gray D. H., (2002), “Geotechnical Aspects of Landfill Design and Construction”, Prentice Hall.

Qian X., Koerner R. M. and Gray D. H., (June 2003) “Translational Failure Analysis of Landfills”, Journal of Geotechnical and Geoenvironmental Engineering, pp. 506-519.

Salim M. R., Sohaili J. and Hashim N., (2003) “Development of a Recycling Framework for Sustainable Municipal Solid Waste Management”, Proceedings of Comprehensive Seminar on Construction and Creation of Sustainable Society based on the Zero-Discharge Concept”. December 15~17, 2003, Kyoto, Japan. pp. R130.

Stark T. D., Eid H. T., Evans W. D. and Sherry P. E. (May 2000) “Municipal Solid Waste Slope Failure. II Stability Analyses”, Journal of Geotechnical and Geoenvironmental Engineering, pp. 408-419.

Triplett E. J. and Fox P. J. (June 2001) “Shear Strength of HDPE Geomembrane / Geosynthetic Clay Liner Interfaces”, Journal of Geotechnical and Geoenvironmental Engineering, pp. 543-552.