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Compression Characteristics of Municipal Solid Waste and Application of Geosynthetics on a Landfill in China

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ABSTRACT: A simplified method presented by authors previously is used to calculate landfill's postclosure settlement and help to choose suitable geosynthetics. A typical case in China is selected to show how the decomposition contributes to the postclosure settlement and differential settlement of landfills. The design of the cover system is discussed in more details in this paper to show some steps we want to take to resist such influence.

1 INTRODUCTION

Settlement estimation is a major concern in MSW landfill management. Settlement during filling can contribute to the increment of capacity. A large postcloure settlement, however, will lead to development of cracks of the cover system, including tearing of geosynthetics.

Biodegradation plays an important role in landfill's settlement especially the postclosure settlement. Some researchers (Sowers 1973; Morris & Woods 1990, Wall & Zeiss, 1995; Gordon et al. 1986; Edil et al. 1990) have presented different models to simulate the settlement process. Chen & Ke (2001) presented a method to calculate the contributions of organic content and decomposition rate to the compression of MSW and the increment of capacity quantitatively. On the other hand, this method could also be used to calculate landfill's postclosure settlement and help to select suitable geosynthetics. This is the main topic of this paper.

2 ORGANIC CONTENT AND DECOMPOSITION RATE OF WASTE FILLS IN CHINA

Table 1 The total volatile solid in some Chinese cities

City	Beijing	Shanghai	Tianjin	Wuhan	Guanzhou	Haierbin
n	0.407	0.388	0.521	0.175	0.284	0.268
Ic	0.521	0.539	0.365	0.776	0.65	0.696
Rc	0.072	0.073	0.115	0.049	0.066	0.036

*n is the total volatile solid content; Ic is the inorganic content and Rc is the refuse content

From table 1, the content of total volatile solids in southern and eastern developed coastal cities is higher than that in undeveloped hinterland cities. In most coastal cities, the total volatile solids content range from 28% to 60%.

Many researchers (Chen 1974; Mcgowan et al. 1988; El-Fadel et al. 1989; Young 1989) verified that the process of decomposition occurs by first-order kinetics:

$$M_c(t) = M_c(0) \cdot e^{-kt} \qquad (1)$$

In which $M_c(t)$ (kg) is the carbon mass in waste at time t; $M_c(0)$ (kg) is the initial carbon mass in waste; k the first-order rate constant.

The value of k is influenced by many factors such as temperature, water content, behavior of filling, PH value and so on. Farquhar & Rovers (1973) suggested it 0.365/year, Weng (2000) adopted 0.235/year, Suflita recorded 0.055/year-0.087/year in the New York Fresh Kills; Chen (1974) suggested it be 0.012/year-0.788/year, and this is a very wide range.

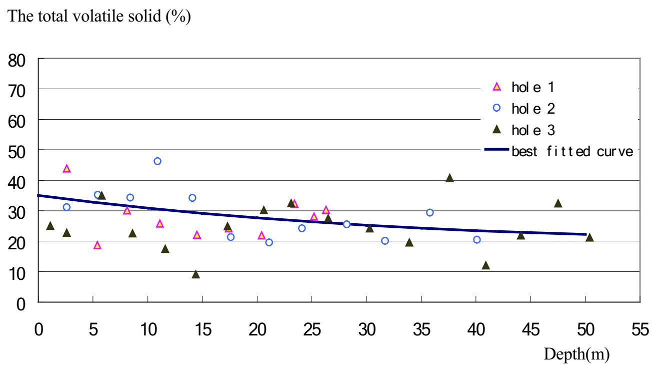


Fig.1 Variation of the total volatile solids content with Depth

In 1998, a series of in-situ and laboratory tests were conducted on Tianziling Landfill, which is located about 50km northeastern from Hangzhou. Fig 1 shows the variation of the total volatile solids with depth in that landfill. It's can be seen that the total volatile solids basically decrease with the increment of depth and this is mainly because the biodegradation of deeper waste soil. Suppose the percentile of the total volatile solids content is B_0, in which the percentile of decayable organ carbon is B_1, so $B_1 = 0.56B_0$ (Golueke, 1992). Then the variation of the percentile of the total volatile solids content B with time t in any depth can be calculated as follows:

$$B(t) = \frac{(B_0 - B_1) + B_1 e^{-kt}}{1 - B_1(1 - e^{-kt})} = \frac{(0.44 + 0.56 e^{-\frac{kz}{v}})B_0}{1 - 0.56 B_0 (1 - e^{-\frac{kz}{v}})} \qquad (2)$$

where Z (m) is depth; v (m/year) is the velocity of filling。

If define v=5m/year, B_0 = 35% (Weng, 2000) and k=0.365/year (Farquhar & Rovers, 1973), fig 1 also shows the theoretical curve of the variation of total volatile solids content with depth according to equation 2. The theoretical curve is in agreement with the average measured value, so equation 2 is satisfying to describe the variation of in situ total volatile solids content with depth.

Note: In above calculation, there are two assumptions that initial total volatile solids and the velocity of filling are all the same in the last ten years. These two assumptions may cause error to some extent, but according to the statistical records it may be accepted qualitatively.

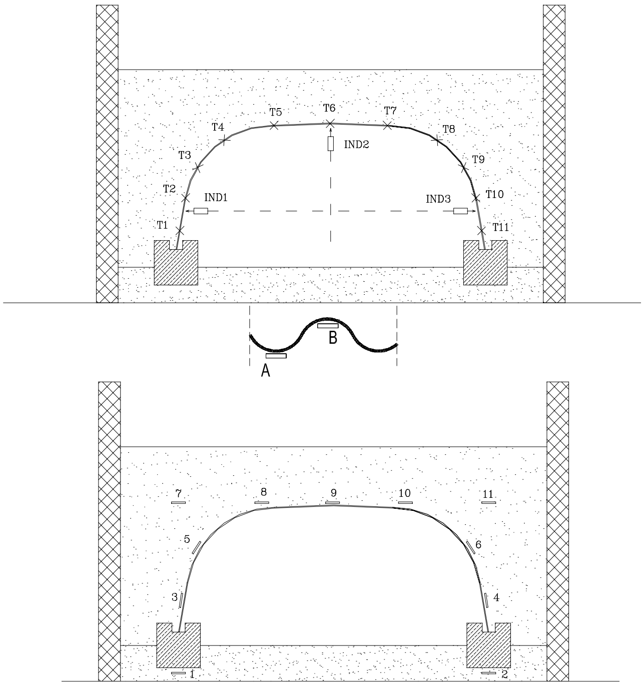


Figure 2. The test bin with the instrumented box culvert (T1–T11 – strain gages, IND1–IND3 – deformation inductors, 1–11 – earth pressure cells)

The instrumentation consists of 22 strain gages (11 locations with a strain gage in the top and bottom of the corrugation), 11 earth pressure cells and 3 deformation inductors (Fig. 2).

The geogrid used was a biaxially oriented polypropylene geogrid LBO 220 SAMP. Tensile properties of this geogrid were tested acc. to ISO 10319, GRI-GG1 and GRI-GG2 methods and as a result there was obtained the tensile strength of 7 kN/m at 2% strain and 14 kN/m at 5 % strain. The strength at peak was

Table 1. The loading program.

		Stage I	Stage II
Depth of cover [m]		0,60	0,60
Location of geogrids [m]		-	0,30
Static load	Level A – LL [kN]	870	870
	Level B – LLxDLA [kN]	1078	1078
	Level C – LLxDLAxSF [kN]	1582	1582
Fatigue load	Live load [kN]	870	870
	Number of cycles	500 000	500 000
	Frequency [Hz]	1,0	1
Maximum static load [kN]		1990	1990
Stage III			
		Load surface [m2]	Live load [kN]
Depth of cover [m]	0,6	5,0	1950
	0,3	5,0	1950
	0	5,0	1950
	0	1,5	585 – Failure load
Stage IV			
		Load surface [m2]	Live load [kN]
Height of backfill [m]	1,425		200
	0,92		200
	0,42	0,25	200
	0		200
	0		350 –Failure test

LL – live load (800 kN), DLA – dynamic load coefficient (1,26), SF – partial safety factor (1,50)

20 kN/m in both directions and the strain at yield was 11,0' machine direction and 10,0% in transverse direction.

During the test four loading stages (I, II, III, IV) were exec which differ by the loading value, depth of cover and presen geogrid. The loading program is showed at the table 1.

Static testing with load up to 1990 kN and 0,6 m cover done without and with geogrid. Dynamic testing with 500 cycles using a load of 870 kN at a frequency of 1 Hz were formed without and with geogrid. One layer of geogrid placed 0,3 m above the crown.

3. OBSERVED RESULTS FROM TESTING

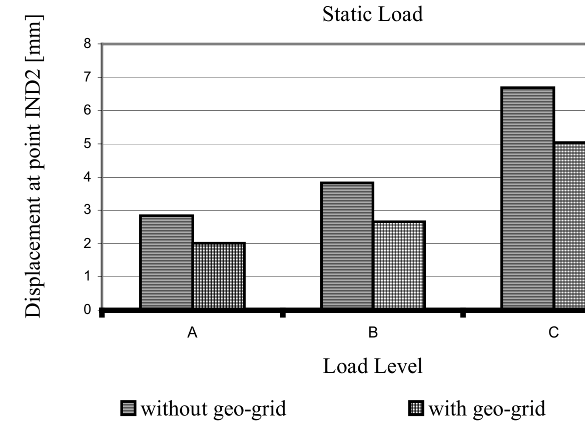


Figure 3. Deformation with static loads.

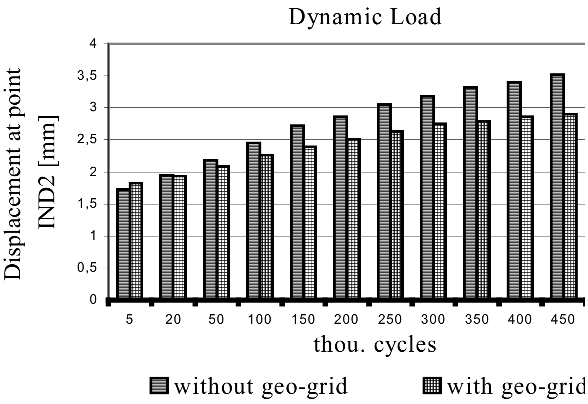


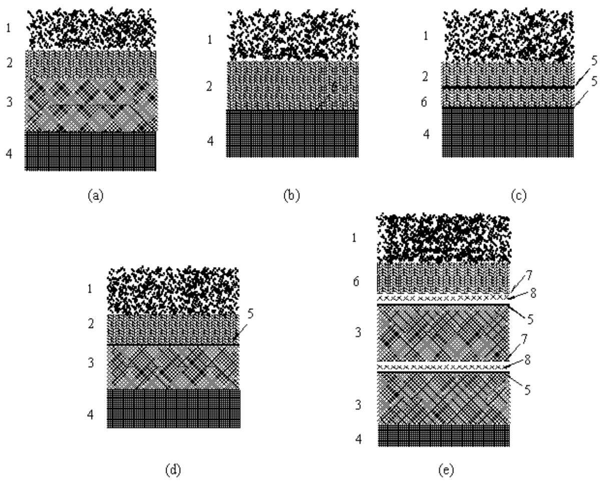
Figure 4. Deformation with dynamic loads.

The maximum deflection from static traffic load was red with 29,5 % for level A, 30,4 % for level B and 24,7 % for l C with the use of geogrid. The deflection of the crown of the culvert was reduced with 17,8 % for the dynamic load wit use of geogrid.

4. CONCLUSIONS

This instrumented full scale test of a steel box culvert under load shows clearly the potential of use of geosynthetics t crease the factors of safety and reduce the crown deflec with small cover.

settlement as well as differential settlement of this liner system will occur under the pressure of upload. So this system will not only bear high pressure as ordinary base liner, but also experience substantive deformation. And it is essential to calculate the settlement to help the design of this liner system.



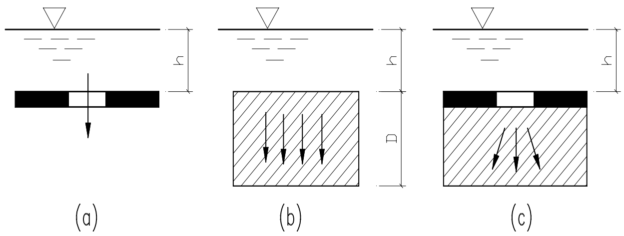
1.Solid Waste Material; 2.Granular Drainage Liner; 3 Compacted Clay; 4.Subgrade Clay Liner; 5. Geomembrane Liner; 6.Protectiive Soil Layer; 7.Barrier Layer; 8.Geonet
(a)Single Clay Liner (b)Single Geomembrane Liner (c) Double Geomembrane Liner (d)Single Composite Liner (e) Double Composite Liner
Fig.4 Cover Lining Systems Configuration

According to test results and records, the parameters for Tianziling landfill are valued as follows: e_0=5.5; γ=10kN/m^3; p_0=10 kN/m^2; E_s=150kP_a; C_{ce}=0.3, C'_{ae}=0.04; t_p =1month; n=40%; k=0.365; d_0=2.0, d_m=2.5, v=5m/year. Settlement and differential settlement of the first landfill are calculated based on above method and parameters. It can be seen from the result (fig.4) that considerable settlement and deformation will occur in the first landfill's cover system under the upload pressure and decomposition effects. The curvature of the final cover is especially high at the site vertical to the toe of the dam. This condition may lead to the tearing of geomembrane, so the anti-ooze effects of the cover system will be reduced greatlyA wide variety of materials are available to be used for landfill's barrier: natural low-permeability soil, compacted soil, geomembrane and Geosynthetic Clay Liner(GCL) Currently commonly used geomembrane materials include HDPE、PVC、CSPE and CPE etc., among which HPDE is the most prevalent one because it has good physical properties and can withstand the large stresses. In China, it is almost the only geomembrane used on landfills' lining systems. However, it also has shortcomings, for example, it is somewhat rigid and has poor puncture resistance. Since HDPE geomembranes shouldn't be folded during transport, large factory-seamed geomembrane panels are impractical. Most HDPE geomembranes seaming have to be conducted in the field. Furthermore, if HDPE geomembranes are used, their minimum thickness must be 0.6mm, which is double of PVC etc. geomembranes' thickness, since a thickness less than that may be difficult to seam. This means HDPE can hardly resist the settlements calculated above.

PVC geomembranes are used as liners for many waste containment applications in a lot of countries; however, it is not recommended to be use on MSW in China due to long-term durability concern. The merits of PVC geomembranes are that they are generally less expensive than HDPE and allow easier installation. But PVC materials' resistance to ultraviolet, ozone, sulfide and weather conditions is poor.

Due to the large settlement that will occur in refuse, cover-lining system require a more flexible geomembrane. Very low density polyethylene (VLDPE) is often used in this application since it has many of the same properties as HDPE but is more flexible and can more readily conform with underlying refuse settlements without puncturing. At the same time, low permeability clay or reinforcing geotextile is required under the liner to form composite liner to maintain its integrity or reduce leakage.

Since composite liners are comprised of a soil overlain by a geomembrane, the flow through composite liner is a combination of flow through soil and flow throw geomembrane holes. (Permeation through the geomembrane is minimal in comparison to the flow through geomembrane holes or soil in most cases.) Fig.5 illustrate the comparison of flow cases with different liner systems. Fig.5(a) is a single geomembrane liner with a defect, the flow of leachate will radiate rapidly if the refuse (or clay) under it has high permeability. Fig. (b) is a single clay liner. Though the flow rate of unit area is rather low, the overall flow is substantive because the leachate flow though all of the area. As far as the composite liner is concerned, the flow occurs first by passage of the fluid through geomembrane hole, then travels in the interface space between the geomembrane and clay liner and finally migrates downward through the clay liner as illustrated in fig.5(c). So for all liquid depths above the liner, single geomembrane liners and single clay liners have significantly greater leakage than composite liners.



(a)Rapid Flow through a Hole in Single Geomembrane
(b)Flow through Clay Liner
(c)Flow through a hole in Composite Liner
Fig.5 Flow model through Soil, Geomembrane and CL

Another factors must be taken into consideration is environmental stress cracking (ESCR), which can be defined as a rupture or crack in a polyethylene geomembrane caused by an applied stress on the geomembrane less than its tensile strength. Halse et al. (1991)list several factors that may contribute to ESCR:

1. Effects of surface wetting agents.
2. Effects of residual stress
3. Stress cracks originating from scratches or other defects
4. Stress cracks originating from irregular geometry
5. Fatigue, or cyclic, induced cracking
6. Combination of the above

The cracking occurs more readily in higher-density PEs; however, in may occur in any PE, PVC, or polyester (Bright 1993). Initiation of the cracking is usually directly over wedge welds made previously. All reported field incidents of ESCR have been in surface impoundments where geomembranes were exposed to the atmosphere and where temperature changes can mobilize tensile stresses (Halse et al. 1991). Since the occurrence of environmental stress cracking is also dependent on several pertinent polymeric properties (such as density, crystallinity, molecular orientation, molecular weight and distribution), blending and manufacturing processes can reduce the likelihood of stress cracking.

Many designers intended to select geomembranes+GCL as composite liner in foreign countries, however, considering economic factors, Geomembranes+Clay ((d) in fig. 4) is recommended in this project. In addition, designers should pay attention to following points:

1.Before madding decisions, it's essential to analyze clay's characteristics, including granule shapes, size distribution, permeability, density and shear strength etc. Clay's cost and compatibility to leachate should also be taken into consideration;

2.The friction or shear strength between soils and geosynthetics is a critical parameter since the combination of these two materials may form a weak plane on which a sliding plane may develop;

3.To minimize potential geomembrane puncture, rigorous construction regulation to protect liner should be enacted and enforced. For instance, the installation crew should wear smooth-bottomed rubber-soled shoes when working on the geomembrane; the subgrade material should be cleared of all protrusions that may damage the overlying material. The initial waste damped directed on the geomembrane should also be restricted, for example, the construction waste with reinforcing steel bar should be forbidden.;

4.VLDPE is preferred in this project to replace HDPE in the cover system of the first landfill to conform the settlements and differential settlements that will occur in that place.

5 CONCLUSIONS

A method is presented in this paper to analyze the effects that decomposition have on the landfill's settlement. It's concluded by analysis that the total volatile solids and decomposition rate of waste significantly affect the calculated landfill's settlement.

In China, the focus of concentration about liner systems layout usually is geomembrane, which is believed to be the most effective and economical; however, more attention should be paid on composite liner (Geomembranes+Clay or Geomembranes+GCL) in future.

Before madding decisions, many factors such as clay's characteristics, shear strength between soils and geosynthetics and clay's cost and compatibility to leachate should be taken into consideration.

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