SETTLEMENT AND CHARACTERISTICS OF WASTE AT A MUNICIPAL SOLID WASTE LANDFILL IN MELBOURNE

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ABSTRACT

This paper presents the findings of a settlement investigation conducted at a municipal solid waste landfill in Melbourne. As part of the study, data related to the characteristics of the landfill in terms of its waste composition, moisture content, density/porosity, daily covers, and biodegradation were also collected. The settlement data were fitted to an empirical (Sowers) model to determine long-term secondary settlement parameters related to the known landfill characteristics. They were then compared to values reported in the literature.

INTRODUCTION

Compared with soils, the settlement mechanisms in municipal solid waste (MSW) landfills are complex (Sowers 1973, Edil et al. 1990, Wall and Zeiss, 1995). The waste fill has an inherent heterogeneity and anisotropic material properties that are more difficult to characterise than soils. These include compaction/density, daily cover, moisture content, composition, and biodegradation. The variations in these properties together with the unsaturated nature of most landfills have imposed certain limitations on the use of classical soil mechanics approaches to predict landfill settlements. Settlement prediction based on monitoring and observational procedures thus becomes a viable tool. While the literature has reported some field settlement observations, few studies attempted also to relate them to the above important associated landfill properties.

This paper presents the findings of a settlement investigation conducted at a municipal solid waste landfill in Melbourne. This investigation formed part of a larger study conducted on a fully instrumented full-scale cell at the Lyndhurst Sanitary Landfill located 35 km south-east of the city. The objective of the project was to evaluate the full-scale landfill behaviour (including settlement), enhanced biodegradation promoted by leachate recirculation, and landfill hydrology. A full description of the research project was given by Yuen (1999).

The settlement of the landfill has been monitored for about four years since final capping in January 1996. Data related to the characteristics of the landfill in terms of its waste composition, as-placed moisture content, density/porosity, and daily covers were collected. Changes in moisture content caused by infiltration and leachate recirculation were obtained based on an associated hydrological evaluation. The production of landfill gas, leachate composition, and in-situ temperature were also monitored to reflect the progress of biodegradation. The settlement data were then fitted to an empirical (Sowers) model to determine settlement parameters. This paper provides a summary of the settlement investigation and related findings.

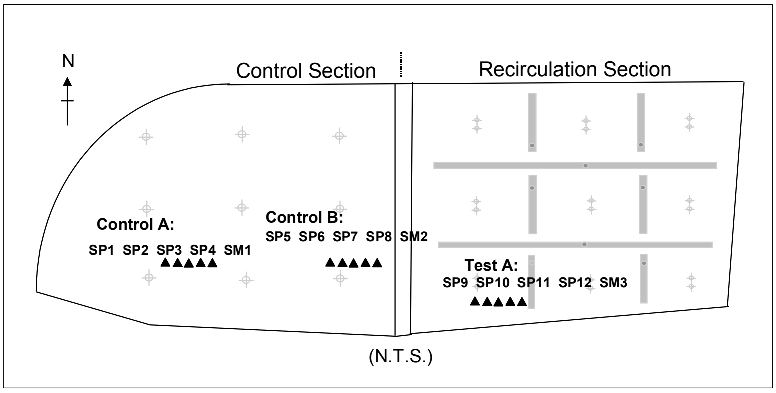

Figure 1 - Location Plan showing settlement plates

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DESCRIPTIONS OF LANDFILL

Size Of Landfill Cell

The full-scale experimental cell covers a footprint area of approximately 180m x 75m (about 1.5 hectares). The thickness of MSW fill varies from 10m to 15m according to the surface landscape. Based on survey data, the as-constructed volume is 180,365 m^3 (excluding liner and cap). Total tonnage as recorded at the weighbridge is 100,824 tonnes. In plan, the cell is divided into two sections of roughly equal area (Figure 1). The western half has been designated as the control section (i.e. dry landfilling) and the eastern half as the leachate recirculation section (i.e. wet landfilling).

Cell Design

The cell comprises a minimum 1m thick side and base liner of compacted clay with a specified hydraulic conductivity of less than 1×10^{-9} m/s.

Upon completion of filling, a 1m thick final cap was laid which was made up of a 300mm topsoil layer, a 200mm sand drainage layer, and a 500mm compacted clay layer.

The leachate collection system comprises a 300mm thick gravel drainage layer immediately above the liner, with collector pipes draining into a header pipe then into a leachate collection sump. To enable both leachate quantity and quality from the control and recirculation sections to be monitored separately, each of the two sections has its own separated collection system.

An integrated leachate recirculation system comprising sub-surface horizontal infiltration trenches and deep vertical injection wells was employed in the recirculation section with an aim to promote biodegradation.

Daily/Interim Covers

Due to licensing requirements as well as operational needs to control litter, birds and odour during filling, daily cover was used in a manner similar to other operational cells. The licence requires a 150mm layer of earth material as daily cover during waste disposal. In addition, each completed vertical lift (of 2m) should be covered by an interim cover of 300mm earth material. This requirement was applied to the experimental cell. A record of all cover material was maintained which reveals that the daily/interim cover material (in this case a clayey sandy silt) occupies about 15% of the total waste volume.

CHARACTERISTICS OF WASTE

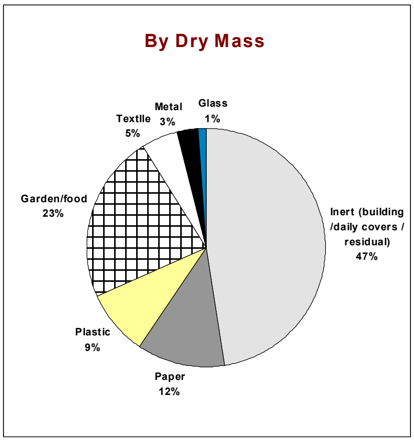


Figure 2 – Waste Composition

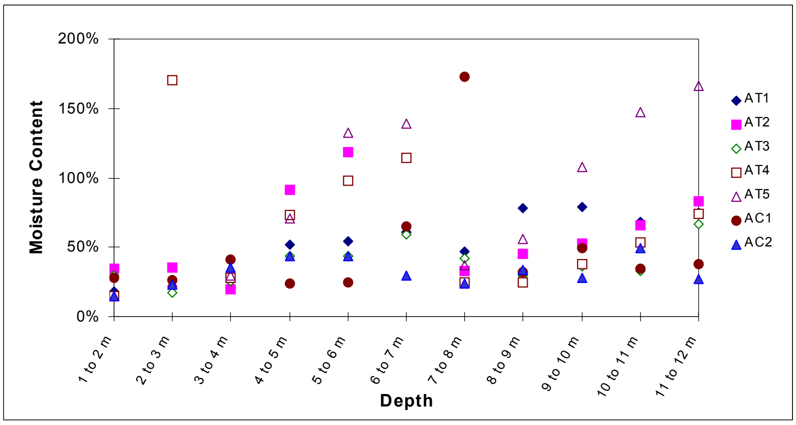


Figure 3 - Moisture Content with Depth

Waste Composition

Waste composition information was determined by collecting continuous waste samples from seven augered holes immediately after final capping. The samples were dried to determine their moisture content (described next) prior to sorting. The composition as sorted, expressed on a dry mass basis, is presented in Figure 2. It can be noted that the inert waste (including daily/interim cover soil) takes up a significant proportion due to its higher dry density than other components.

Moisture Content

The variations of moisture content (dry mass basis) with depth immediately after final capping are plotted in Figure 3. These values were determined based on the auger samples collected for the above waste composition sorting. The mean value and standard deviation of moisture content are 55% and 38% respectively.

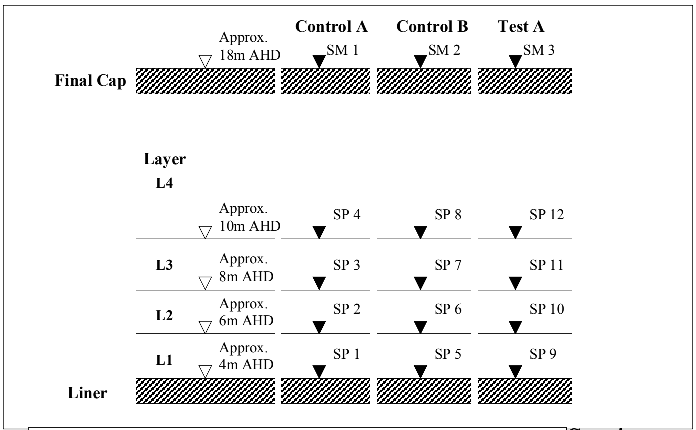
Compaction/Density/Porosity

The waste was compacted in vertical layers by a Caterpillar 826C landfill compactor with an operating mass of 32 tonnes. Based on mass and volume records, the in-situ bulk density (with daily/interim earth covers accounted) was calculated to be 0.83 tonne/m^3.

From the bulk density and the mean moisture content of 55% (above), the dry density and porosity of the MSW were also calculated: 0.54 tonne/m^3 and 0.55 respectively. The literature suggests a porosity range between 0.5 to 0.6 for MSW (e.g. Korfiatis et al., 1984; Oweis et al., 1990; Zeiss and Major, 1992). In this case 0.55 reflects that the MSW in the experimental cell is reasonably well-compacted.

MONITORING OF LANDFILL SETTLEMENT

The plan in Figure 1 shows three clusters of settlement monitoring points, two in the control section and one in the recirculation section. Each cluster is composed of a series of five settlement plates installed on top of liner at 4m AHD (Australian Hard Datum), at approximately 6m AHD, 8m AHD, 10m AHD, and on surface of final cap at 18m AHD respectively (Figure 4). Instead of just monitoring the cell surface subsidence, the settlement data collected at various levels provides additional information on subsidence behaviour along a vertical profile.



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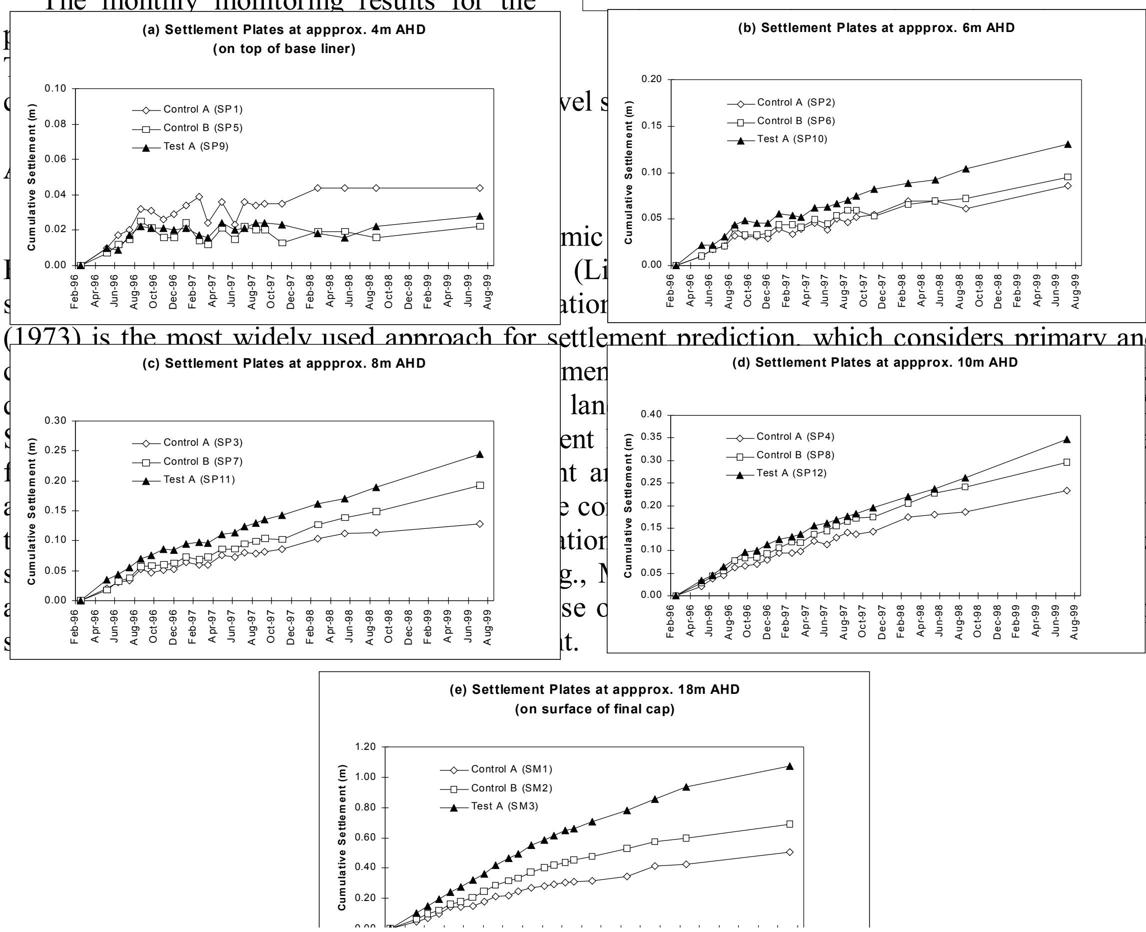

Figure 5 - Settlement Monitoring Results

$$S_s / H_p = C_{ae} \log (t / t_p) \quad (1)$$

$$C_a = C_{ae} (1 + e_p) \quad (2)$$

S_s is the secondary settlement (m),
H_p is the height of waste upon completion of primary settlement (m),
C_{ae} is the slope of the strain versus log-time curve or the secondary compression ratio,
t is the elapsed time (days),
t_p is the time for primary compression to complete (days),
C_a is the secondary compression index, and
e_p is the void ratio upon completion of primary settlement.

The use of Sowers model has a major limitation: it is sensitive to the value of t_p used which is often difficult to identify as primary and secondary settlement occurs simultaneously (Phillips et al. 1993). To investigate the sensitivity of t_p on C_{ae}, three different t_p values (30 days, 60 days and 90 days) were used. These figures were selected based on the range of primary settlement completion times as suggested in the literature (Sowers, 1973, Wall and Zeiss, 1995). In this case, the t_p of 90 days returned the best fit (Yuen 1999). Thus a 90-day period was taken empirically to be the primary settlement time in the following analysis.

Based on the monitoring data and equation (1), the secondary compression ratio, C_{ae}, for each individual layer (i.e. L1, L2, L3 L4 and overall layer as shown in Figure 4) was then determined (Table 1). For comparison, Table 2 summarises the range of C_{ae} reported in the literature. The values in Table 1 fall within the published range.

Table 1 – Results of Secondary Compression Ratio (C_{ae})

Settlement Plate Group	Layer				
	Overall	L1	L2	L3	L4
Control A	0.028	0.008	0.019	0.041	0.030
Control B	0.038	0.023	0.030	0.046	0.037
Test A	0.054	0.035	0.044	0.052	0.055

Table 2 - Reported Secondary Compression Ratio, C_{ae} (after Phillips et al., 1993)

Reference	C_{ae}	Comment	Type of Landfill
Sowers (1973)	0.075 0.025	For e_p=3 For e_p=3	Highly organic, favourable biodegradation Low biodegradation
Burlingame (1984)	0.022 0.008	3m thick 12m thick	Upper limit for old landfill, 75 kPa surcharge
Walker & Kurzeme (1984)	0.08 0.04	6m surcharge 3m surcharge	Typical upper limits for 3-15m thickness of variable age
Yen & Scanlon (1975)	0.14 0.06	<12m thick 12-30m thick	Upper limits of self-weight creep of recent refuse
Watts & Charles (1990)	0.10/0.23 0.02	12m thick	Biodegradation component of recent domestic refuse Corresponding physical creep component
Edil et al. (1990)	0.075 0.012	10-30m thick 15m thick	Upper limit, recent refuse under self-weight Upper limit, old refuse
Gifford et al. (1990)	0.020	-	Upper limit, old landfill
Walls &	0.033-0.056	0.5m dia. &	Laboratory bioreactor cell

Zeiss (1995)	0.037-0.049	1.7m thick	Laboratory dry cell

Sowers (1973) suggested that C_a is proportional to two factors: initial void ratio and favourable decomposition conditions. The secondary compression index (C_a) was then determined using Equation 2. This would require the estimate of e_p (the void ratio upon completion of primary settlement). A value of 1.22 is used here for all the settlement plates, which was based on the as-capped porosity value of 0.55 (above). While this as-capped void ratio is not exactly the same void ratio at the completion of primary settlement, any error would be small considering the relatively small magnitude of primary settlement. The results of C_a for all layers at the three different settlement plate groups are plotted in Figure 6.

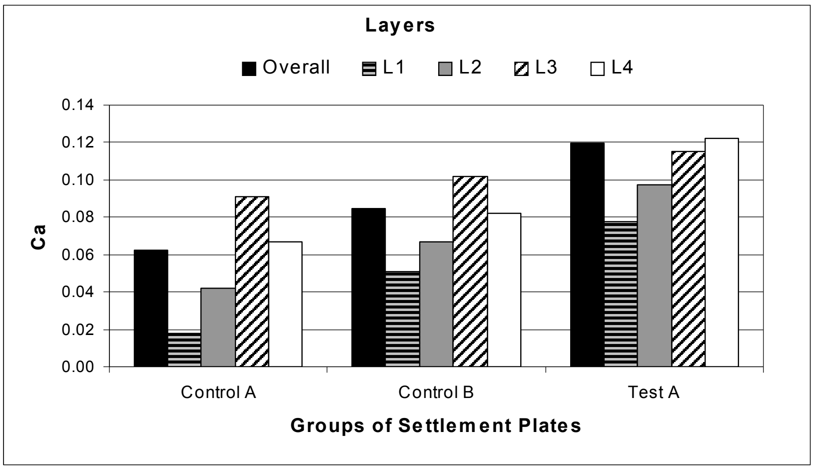

Figure 6- Secondary Compression Index (C_a)

CONCLUSIONS

Because of its simplicity, the Sowers model was used in the above analysis. It also offers the advantage that the C_{ae} values obtained can be compared with other similar published data. In this case they are within the published range. With knowledge of other associated waste characteristics, the parameters obtained can be used in predicting settlement of similar landfills with a higher degree of confidence.

Table 1 and Figure 7 suggests that while similar results were obtained from the two settlement plate groups (Control A and B) in the control section, the Test A group of plates in the recirculation section returned the highest C_{ae} and C_a. Monitoring of landfill gas, leachate quality, and in-situ temperature generally indicated a better biodegradation occurring in the leachate recirculation section (Yuen 1999). The higher settlement rate is likely to be associated with enhanced biodegradation as reported by Wall and Zeiss (1995). It can also be observed from Table 1 and Figure 7 that within each settlement plate group, there is a large variation in C_{ae} and C_a among individual layers at various depths. This implies that there is a presence of heterogeneity along the vertical profile.

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