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Daily Soil Cover: A Preliminary Study of its Impact on the Landfill of Municipal Solid Waste.

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Abstract: The changes in the hydro-physical properties of a municipal solid waste (MSW) fill owing to an intermediate soil layer were studied. Key parameters, including dry density, drainable porosity, and saturated hydraulic conductivity of waste samples with and without an intermediate soil layer were measured in conventional test cells under increasing overburden stresses. Ravelling of the soil grains (SG = 2.65) into the underlying waste layer, estimated to be up to 50%, appeared to increase the density of the waste fill, in effect, decreasing its permeability. The waste-only fill was more permeable than waste incorporating a soil cover; however, this reduced with increased vertical stress applied to the fills. The measured and calculated values of the saturated hydraulic conductivity of the composite layered fill differed up to a factor of 100 at low vertical stresses. The moisture routing, undertaken with a modified Hydrologic Evaluation of Landfill Performance (HELP) model, suggests that the use of daily cover soil may reduce leachate drainage, thus increasing the degree of moisture saturation in waste fills. Further, waste fills with daily cover may drain leachate for a longer time and require closer spacing of basal drains. However, appropriate use of daily cover soil was found to benefit the sustainable practice of MSW landfilling.

Key words: cover soil; municipal solid waste; saturated hydraulic conductivity; density; modified HELP model; simulation; soil mechanics

INTRODUCTION

A sustainable waste landfill requires a good understanding of the properties of the emplaced waste. For instance, adequate knowledge of the bulk hydraulic properties of waste fills is imperative for the design of efficient leachate control and recirculation systems employed to accelerate stabilisation of MSW fills [1,2]. Similarly, a prediction of landfill settlement enables estimation of the volume of waste infill, and the likely post-closure uses of the site. Such waste properties are commonly measured in purpose-built test cells [3,4], owing to the difficulty often encountered in obtaining reliable results *in situ* [5,6]. In no studies, however, has the impact of the daily cover material on the properties of waste fills been fully investigated.

Daily cover is an integral part of a landfill system, usually comprising granular materials spread thinly over the working face of an active cell at the end of each day to minimise odour and rainwater infiltration, and to prevent rodents and insect infestation, without presenting a threat to human health and the environment. The impact of daily cover on waste fills is often ignored, owing to its small volume compared to the bulk volume of the emplaced waste. In addition, fine materials similar to the cover materials are often inherent in typical solid waste streams sent to landfills. However, the daily cover soil is placed in layers embedded between successive waste layers. It is usually subjected to overburden stresses, both static and dynamic and may vary in nature from cell to cell, and from site to site. Previous field tests indicated that the characteristics of intermediate cover materials would influence moisture storage in a waste landfill [7]. It may cause hydraulic isolation of waste cells and lead to differential settlements within the waste mass. Accordingly, the influence of low permeability daily cover and compaction techniques should be considered in the design of leachate collection, and recirculation systems when using design data obtained from waste-only tests [8].

The daily cover thickness is likely to reduce from 20% to 5% of the waste layer thickness, because of assimilation [9]. This was based on visual observations during landfill operations. Owing to lack of data on the soil cover-waste layer interaction, a constant thickness of the daily cover layer was assumed in a previous hypothetical simulation of temporal settlement and

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hydraulic conductivity of a hypothetical MSW fill [10]. Obviously, a better understanding of the post-placement behaviour of daily cover in landfills will enhance behavioural modelling, and thus the design of MSW landfill facilities.

The determination of waste properties under controlled conditions in experimental cells is convenient, but demands some caution, due to the effects of sampling, scaling, and environmental conditions on measured parameters of this heterogeneous material. To minimise these, a large-scale cell, preferably 1-2m diameter could be used for such tests [11]. Other authors stated that results comparable with field values could be obtained in test cells if large representative samples of the waste fill were compacted to field density prior to testing [12]. In the short term, results comparable to field values could be obtained from measuring waste properties in smaller compression cells, if the particle sizes were scaled down to less than 20% of the diameter of the test cell [3].

The main concern regarding the use of shredded waste is the influence of the larger surface area of the small particles, especially on the biodegradation of waste. Some authors reported that the saturated hydraulic conductivity of waste in compression test cells should be monitored over an extended timescale to ensure that the gas produced by easily biodegradable fractions in the waste is expended [13]. In contrast, insignificant degradation of crude MSW particles, was noted tested over a period of six months in a large-scale compression (Pitsea) cell [8]. Also of concern is the influence of particle-particle and particle-wall friction on adequate transmission of applied stresses through waste fills in cells, especially of high height/diameter ratio. The Pitsea cell with a height-diameter ratio of 3:2 was found to transmit 90% of applied vertical stress to the base of its cell, as recorded by a load cell[4].

Various materials such as compost and mulch produced from garden waste, and compost from shredded municipal solid waste are encouraged as alternative daily cover to soil, to enhance sustainable landfilling [14]. For instance, the alternative daily covers permitted by the California Integrated waste Management Board [15]) include: (a) Ash and cement kiln dust; (b) Treated auto shredder waste; (c) Construction and demolition waste; (d) Compost; (e) Green material; (f) Contaminated sediment; (g) Sludge; (h) Shredded tires; (i) Foam products; and (j) Geosynthetic fabric

The use of these materials is governed by rules regarding particle size and surface placement. Nevertheless, soil remains the most common type of daily cover, as it is often readily available and easy to work with. Knowledge of the suitability of various soils as cover material (Table 1) enables appropriate material to be used for specific purposes; however, site mined worn soil (native soil), with fair qualities are often used in practice to minimise operational costs. In this paper, a series of tests were undertaken on model waste-fills with and without an intermediate soil layer, in a range of geometries in convectional cells under increasing vertical stresses, to determine the changes in density, drainable porosity, and saturated hydraulic conductivity of the waste columns. The implications in the use of soil as a resource was undertaken with temporal moisture simulations, based on inferred data from the cell tests, using a modified landfill model, comprising the Hydrologic Evaluation of Landfill Performance (HELP) computer model and empirical waste models.

MATERIALS AND METHODS

Equipment: Each of the three test cells used comprised a Perspex cylinder, 240mm in internal diameter, 230mm high and with 12mm wall thickness (Figure 1). The cylinder was sealed at the base by a Perspex plate, which was firmly secured to a wooden support framework. The inner wall of the cylinder was lined with a 2mm thick polythene sheet to minimise sample-wall friction during the application of vertical loads on the waste sample. Two perforated galvanised steel plates (8 mm diameter holes; 60% void area) bound the waste materials at the upper and lower faces to minimise the loss of material fines during upflow of water in the cell. The lower screen overlaid a 50mm gravel bed (10mm gravel) placed at the base of the cell. The upper screen was overlaid by 20mm polystyrene cubes, evenly spaced to provide uniform vertical stresses applied by an upper 8mm perforated Perspex platen. The platen was connected by a steel rod to the top base plate on which loads were placed.

The inlet and outlet ports were located at four levels on the cell. On the lowest level were four uniformly spaced ports connected via a manifold of plastic tubes to a constant-head overhead tank that supplied de-aired water to the cell. The next two levels, which were 50mm apart, also had four uniformly spaced ports. These were connected to standpipes through 7mm diameter plastic tubes. At the top level were two evenly spaced ports that served as exit channels for the flow of water in the cell.

Waste Materials: The waste material used in the tests was taken from the face of freshly emplaced waste at White's Pit landfill, Wimborne, Dorset, UK. The site is the largest MSW landfill in the Dorset district and is underlain predominantly by Broadstone clay of the

Poole Formation of the Palaeocene age. It consists of a restored "dilute and disperse" landfill area and an active waste containment area. Approximately 330,000 tonnes of controlled waste is currently deposited annually at the site. The food and green/garden wastes in the waste samples were already putrid prior to the start of the tests and were replaced with fresh potato and hay respectively, which have a low degradable rate. The waste particles including textile, grass, paper and cardboard, plastic, metals, potato, hay, and wood wastes were shredded to a nominal size of 20 x 5mm, which was deemed compatible with the size of the test cell. Hardcore materials (stones, clay clumps, etc.) with larger sizes were excluded from the sample owing to the size of the test cells. The intermediate soil used in the tests was obtained from the native soil stockpile, used in practice as daily cover at the site. The soil was classified as slightly clayey/silty, gravely sand (Figure 2), and it has similar particle size characteristics with the particle fines of the waste samples. The saturated hydraulic conductivity of the sand determined in the test cell was 6.35 ´ 10^{-7} m/s [17].

Test Procedure: Three different types of waste fills were simulated in the cells. These were:

- waste-only fill (Test 1)
- waste fill incorporating an intermediate soil layer whose volume is equivalent to 7.5% of the underlying waste layer (Test 2)
- waste fill incorporating an intermediate soil layer whose volume is equivalent to 10% of the underlying waste layer (Test 3)

The composition of these waste fills is recorded in Table 1.The shredded waste materials were mixed and introduced in small quantities to the cell. In Test 1, the waste material was uniformly compacted to the sample height of 110mm, and bulk density of 250 kg/m^3. In Test 2, the waste material was initially compacted to a thickness of 50mm, of density 250 kg/m^3. Then, cover soil equivalent to a nominal thickness of 3.75mm was placed on it. Finally, waste materials of density 250 kg/m^3 were placed on the soil layer to makeup a sample thickness of 110 mm. The same procedure in Test 2 was repeated in Test 3, but with a nominal thickness of the intermediate soil layer of 5mm. Three representative subsamples of waste components used in each cell were dried in the oven at 105°C for 24 hours for moisture content determination (Table 2).

Porosity and hydraulic conductivity tests were carried out consecutively on the waste fill in each cell. At the start of the tests, no load was applied to the waste sample in the cell. The de- aired water from the constant head overhead tank was passed upward in small volumes into the sample though the inlet ports to provide uniform saturation of the waste constituents. As the water moved up the cell, pockets of accumulated air in the manometer tubes were completely displaced. The water levels in the manometer tubes were allowed to level prior to each successive addition of water. Once the sample was fully saturated, it was completely drained under gravity into a measuring cylinder. The drained volume was the initial drainable porosity of the waste fill in the cell. This is often called the effective porosity in waste investigations. Permeability tests were not undertaken at this period owing to the non-confinement of the sample.

The next stage involved the application of a 45N load to the waste fill using metal weights. Full consolidation was considered to have occurred when there was less than 1% variation in sample thickness over 12 hrs. The effective porosity of the consolidated fill was measured as in the previous stage. The new depth of the fill was measured at eight evenly-spaced peripheral points, owing to uneven settlement of the waste particles. Following this, a continuous upward flow of water through the sample was established. The volumetric flow rate was calculated at regular intervals until flow equilibrium was attained. This stable condition was considered to be attained when there was less than 5% change in the measurements within a 6-hr period [18]. The saturated hydraulic conductivity of the waste in the cell was calculated using Darcy's equation:

$$k = Q / \left(A \left(\Delta H / L \right) \right) \quad (1)$$

where

k = saturated hydraulic conductivity of waste sample
Q = flow rate through the waste sample
A = cross sectional area of the waste sample
$\Delta H/L$ = hydraulic gradient in the waste sample, DH is the change in hydraulic head and L is the length of flow. L = 50 mm.

Finally, the sample was drained prior to another cycle of operation with incremental loading. The applied loads ranged from 45N to 360N. Two replicates of each waste column were tested under similar conditions.

Ravelling of the soil cover grains into the pores in the underlying waste layer was physically observed during sample placement and subsequent application of vertical loads on the waste columns. Unfortunately, the volume of the assimilated cover soil in the waste layer could not be correctly measured owing to the complex nature of ravelling and modest sophistication of experimental instrumentation. Steady flow conditions

Table 1: Suitability of general soil types as cover material [16]

Function	Clean Gravel	Clayey Silty Gravel	Clean Sand	Clayey Silty Sand	Silt	Clay
Prevents rodents from borrowing and tunnelling	G	F-G	G	P	P	P
Keep flies from emerging	P	F	P	G	G	E
Minimise moisture entering fill	P	F-G	P	G-E	G-E	E
Minimise landfill gas venting through cover	P	E	P	E	G-E	E
Provide pleasing appearance and control blowing paper	E	G	E	E	E	E
Grow vegetation	P	P	P-F	E	G-E	F-G
Be permeable for venting decomposition gas	E	P	G	P	P	P

E = excellent; G = good; F = fair; P = poor

Table 2: Classification of waste materials used in the tests

Waste material	Percent of bulk mass (%)			Gravimetric moisture content (%)
	Test 1 (No cover soil)	Test 2 (7.5%cover soil)	Test 3 (10% cover soil)	
Paper	30.59	31.94	29.92	57.87
Cardboard	4.32	5.51	5.16	11.46
Plastic	3.70	2.95	2.77	nd
Thin plastic	5.73	4.58	4.29	nd
Textile	1.82	1.45	1.36	2.32
Glass	4.29	3.42	3.21	nd
Food waste	12.48	4.37	4.10	81.48
Ferrous Metals	4.55	2.83	2.65	nd
Non Ferrous metals	1.49	1.19	1.11	nd
Combustibles	6.43	5.13	4.81	0.63
Greens/garden	16.32	9.84	9.22	9.92
Wood	0.61	0.49	0.46	10.65
Fines<10mm (including cover soil)	7.67	26.3	30.94	na
Total	100	100	100	na

nd: not determined; na: not applicable

were achieved within two days in all of the test cells. The small quantity of easily degradable materials and the unconfined nature of the cells would have minimised the accumulation of biogas, which usually destabilises steady flow in solid waste. The preferential flow (channelling) of water within the waste, and in particular, down the side of the cell wall was minimised by uniform placement and compaction of the waste particles. The applied stress was taken as the total vertical stress transmitted by the waste fabrics owing to the following factors: (a) free drainage of water in the cell; (b) negligible self-weight of the waste fill in the cells; and (c) insignificant rebound of waste particles during the tests.

RESULTS AND DISCUSSION

Results: The Reynolds numbers, calculated for the hydraulic flows during tests were less than 10. This indicated that linear laminar flow conditions existed during the permeability measurements; thereby enabling the use of Darcy's formula.

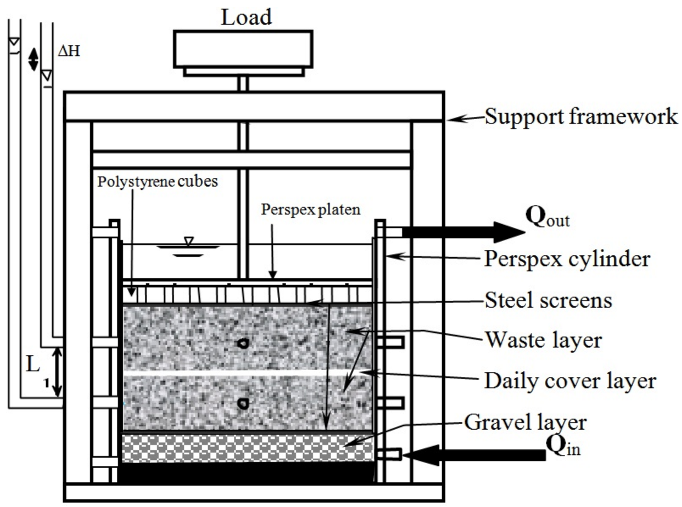

Fig. 1: Schematics of the test cell

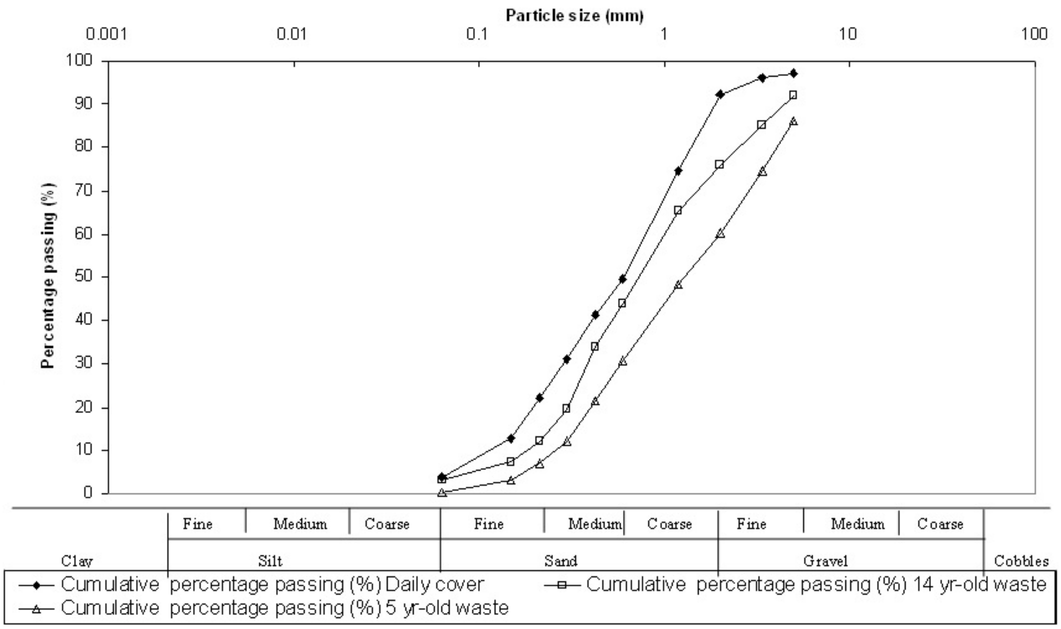

Fig. 2: Particle size distribution curves of the cover soil and fines (<10mm) in the waste samples.

The measured thickness, drainable volume, and saturated hydraulic conductivity of the waste columns at various increments of applied stress in the test cells are tabulated in Table 3. These were the mean values of test data obtained for each type of waste fill. As the waste in the cell compressed with increasing vertical stress, the thickness of the fills decreased. The maximum compression of the fills occurred in the waste-only fill (Test 1) while the waste column incorporating the thickest intermediate soil layer (Test 3) was the stiffest. This is illustrated in the plot of dry density of the waste fills at different applied stresses (Figure 3). While there was a general increase in dry density with increased overburden for the various fills, the magnitude of densification was proportional to the increased quantity of the intermediate soil at the prevailing applied stresses.

The relationship between porosity and dry density is depicted in Figure 4. It shows the drainable porosity of the fill with waste-only to be significantly lower than that of fills incorporating intermediate soil layers at the same densities. While this trend also applied to the saturated hydraulic conductivity at equal densities (Figure 5), the magnitude of the disparity was not as significant. The plot in Figure 6 probably explains the contradiction between the degree of pore space and the saturated hydraulic conductivity observed for the various fills. It shows that, at equal porosity, the saturated hydraulic conductivity is higher in the waste-only fill compared to the fills incorporating an intermediate soil layer.

Table 3: The hydro-physical properties of the waste columns at various overburden

Overburden load (N)	Thickness of sample (mm)			Drainage volume (ml)			Saturated hydraulic conductivity (m/s)		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
initial	110	110	110	2510	2495	2470	nd	nd	nd
45	96.6	100.3	101.2	1940	2070	2090	3.6×10^{-2}	1.2×10^{-3}	4.7×10^{-3}
90	87.2	88	89.1	1470	1500	1535	6.1×10^{-3}	4.0×10^{-3}	2.1×10^{-3}
135	82.3	84	84.7	1265	1295	1305	5.6×10^{-3}	3.3×10^{-3}	2.0×10^{-3}
180	75.6	78.4	79.6	960	1070	1115	2.5×10^{-3}	2.2×10^{-3}	1.4×10^{-3}
225	71.8	74.7	75.1	790	900	935	1.8×10^{-3}	1.2×10^{-3}	1.0×10^{-3}
270	66.3	70.3	70.3	635	730	735	1.4×10^{-3}	9.4×10^{-4}	7.8×10^{-4}
315	63.7	66.4	66.9	505	605	625	8.2×10^{-4}	7.0×10^{-4}	5.2×10^{-4}
360	61.4	63.8	63.9	425	495	505	6.5×10^{-4}	4.4×10^{-4}	4.0×10^{-4}

nd - not determined

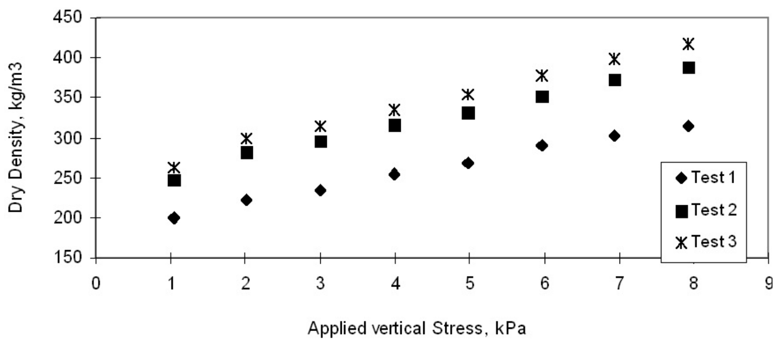

Fig. 3: The dry density of the waste fills at various applied

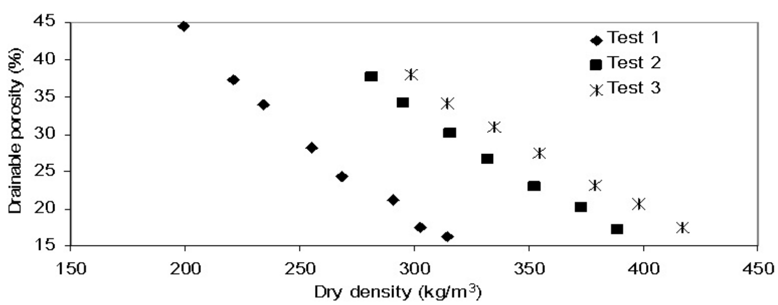

Fig. 4: Drainable porosity of the waste fills at various dry densities

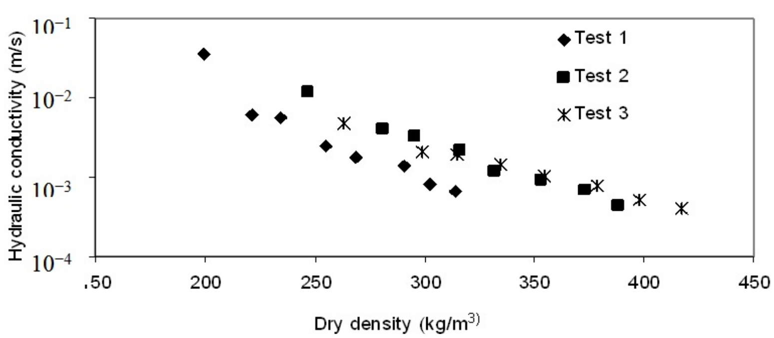

Fig. 5: Saturated hydraulic conductivity of waste fills at various dry densities.

In accordance with the degree of compressibility, which is indicative of the degree of macrospace, the lowest water drained from the cells occurred in the waste-only fill, while the largest volume drained from the fill with maximum thickness of intermediate cover, respectively. However, the saturated hydraulic conductivity of the waste-only fill was greater than the waste fills incorporating an intermediate soil layer at various applied stresses owing to the higher "through" volume of the micropores of its constituents (Figure 8).

Geotechnical engineers commonly make quick engineering judgements based on calculations using established soil models. In waste problems, there is a need to establish validity between measured data and corresponding model estimates using soil theories. Theoretical estimates of the hydraulic conductivity of waste fills incorporating an intermediate soil layer in the test cells were calculated at the various applied stresses and compared with measured values. The saturated hydraulic conductivity of the composite (waste-soil-waste) layered fill was obtained using the composite soil formula stated as follows [19]

$$K_e = \frac{T_e}{\sum_{i=1}^{n} \frac{T_i}{K_i}} \quad (2)$$

where

K_e = effective saturated hydraulic conductivity of the combined layers

T_e = effective thickness of combined layer

Ti = thickness of layer i

K_i = saturated hydraulic conductivity of layer i

In the computation, measured coefficients of permeabilities (Table 3) were used for the waste-only layer whereas the predetermined saturated hydraulic conductivity of the sand bed, 6.35 ′ 10^{-7}m/s, was used for the intermediate soil layer. As can be seen in Figure 4(a), there is no apparent change in the computed hydraulic conductivities with increasing vertical stress. The measured and calculated data differ by a factor of up to 100 at lower vertical stresses, with the variation decreasing with increasing vertical stress.

Using the test results (Table 2), the maximum ravelling volumes in waste incorporating 5% and 10% soil year are estimated at 36% and 50% respectively. Equally, it appears that the quantity of ravelling increased with increasing overburden and water flow though the sample. The exact volume of the assimilated sand grains in the waste could only be known if the magnitude of the resistance to compression of the bulk waste offered by the ravelled soil could be accurately quantified. This was not possible with the current conventional apparatus.

Implications for Computer Modelling and Design: Customarily, the primary concern regarding the use of daily cover among landfill designers and operators is its influence on the control of leachate produced in the landfill. A study that takes into account the characteristic trends of the test data was undertaken for further understanding of this issue.

Modelling: The waste data inferred from the experiments and pertinent site data were used to retroactively simulate the moisture routing at White's Pit landfill, Poole (Figure 8), using a modelling technique that includes the HELP computer model [20]. The site is an "old dilute and disperse" landfill fully described in an earlier paper [21]. The availability of complete historical data for the restored MSW landfill area of the site enabled the use of various scenarios for the moisture modelling of this study area [22]. A waste column located in tipping area G of the landfill was chosen for the elemental analysis. The simulation technique, which is proven and well documented is depicted in Figure 9. The HELP computer program is well known for simulating macro-water movement in and out of landfills, but does not take into account the temporal changes in landfill features. To accommodate this, empirical models, calibrated from site data, were incorporated with the HELP modelling process to reasonably replicate the temporal moisture volume at the landfill from inception in 1986 to 1998. These models, which account for temporal changes in the porosity, field capacity, and hydraulic conductivity of the lifts, were defined in terms of dry density to facilitate the simulation technique.

A simplified flow chart of the technique is shown in Figure 9. The emplaced refuse is divided into lifts, comprising waste layers and cover soil placed in one year, as the HELP program models yearly. Using the site data for phases of tipping, only three lifts were emplaced at the selected waste column, which is underlain by "Broadstone" clay. The waste in lift 1 (6.45m) was placed in 1986, lift 2 (8.60m) in 1987, and finally lift 3 (4.30m) in 1989. Clay capping occurred in 1990, while post-capping vegetation occurred in 1991. The irregular waste placement at the site caused difference in the density, field capacity, porosity, and hydraulic conductivity of each lift, which was considered in the simulation.

By assuming a face compaction equivalent to an overburden stress of 40kN/m^2 on fresh waste placed at the landfill, dry densities of approximately 450kg/m^3, 550kg/m^3, and 600kg/m^3 for model waste fills in Tests 1, 2, 3 respectively are estimated from the extended characteristic lines in Figure 3. The equivalent permeabilities and other hydro-geotechnical parameters

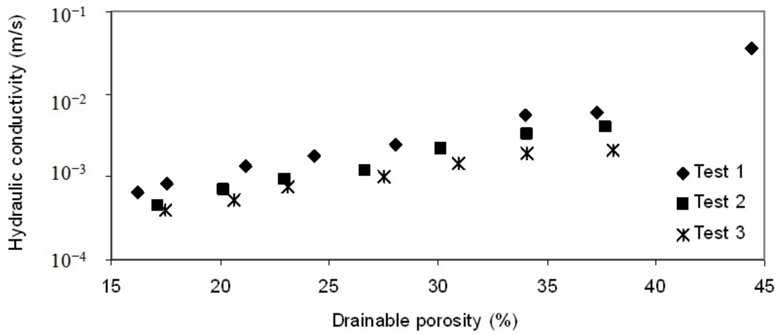

Fig. 6: Saturated hydraulic conductivity of waste fills at various drainable porosities

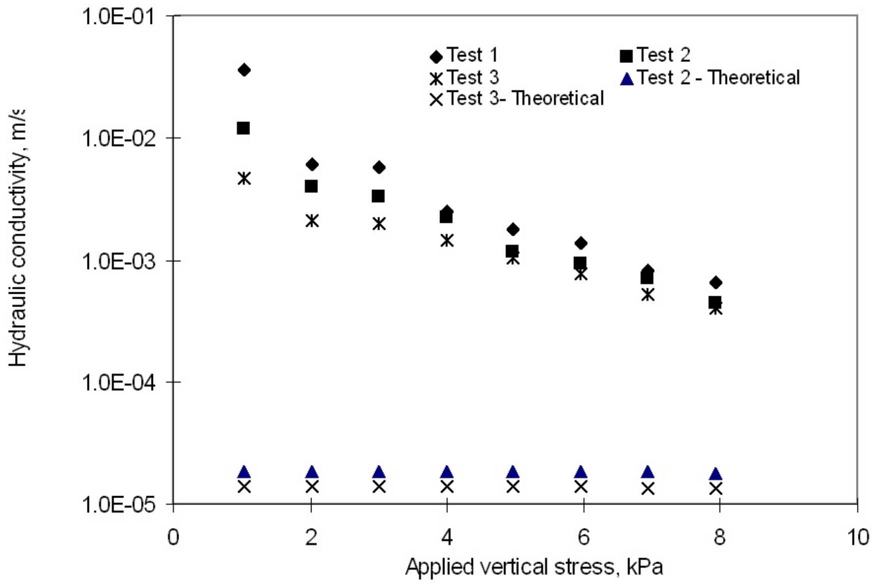

Fig. 7: Saturated hydraulic conductivity of the waste fills at various overburden stresses

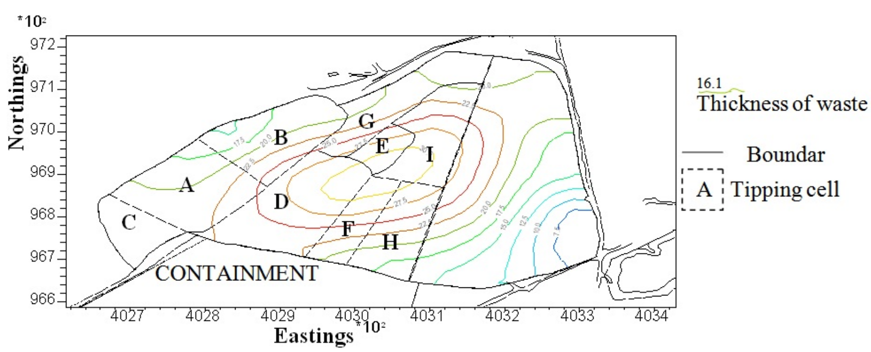

Fig. 8: The tipping areas at White's Pit landfill, Poole.

for these densities were calculated using empirical models [21,22], Each waste lift has initial volumetric moisture content of 0.1709, being the value obtained from the freshly placed waste during the site investigation.

The three scenarios described by Tests 1-3 were applied to landfilling at White's pit. The plots in Figures 10-12 show the moisture routing simulated for the hypothetical landfills representing waste-only fill, and waste fills with 7.5% and 10% of intermediate soil layers respectively at White's Pit. In each case, the moisture content of the lifts increase rapidly during the active period of waste filling, which ended in 1991. Similarly, the cumulative leachate produced and drained

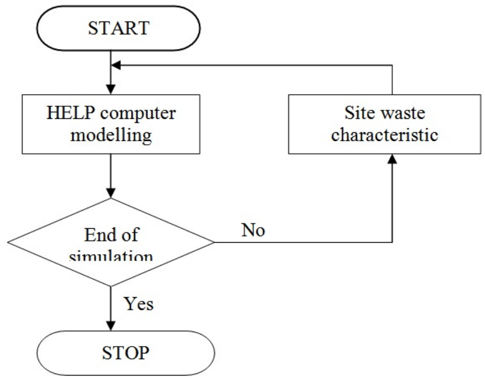

Fig. 9: A simplified flowchart of the moisture simulation

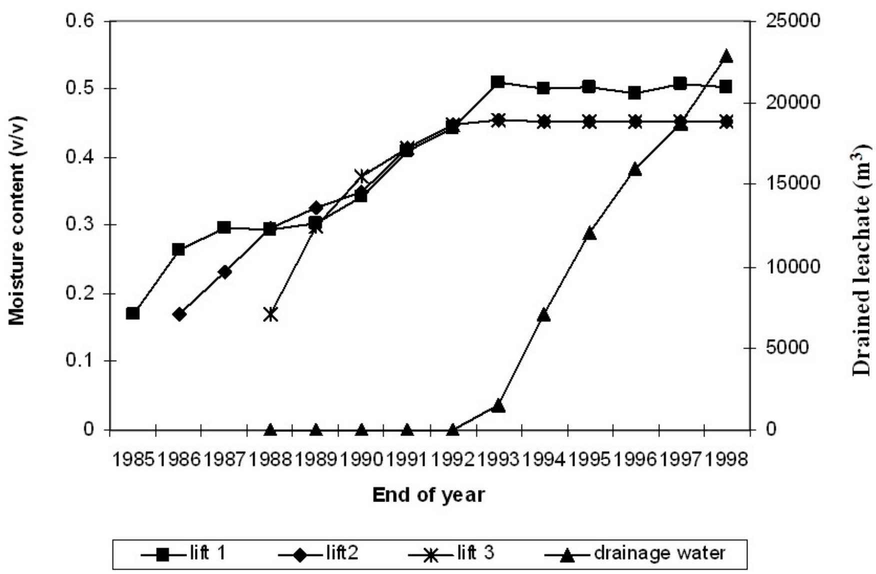

Fig. 10: Moisture stored and drained in the landfill with no daily cover.

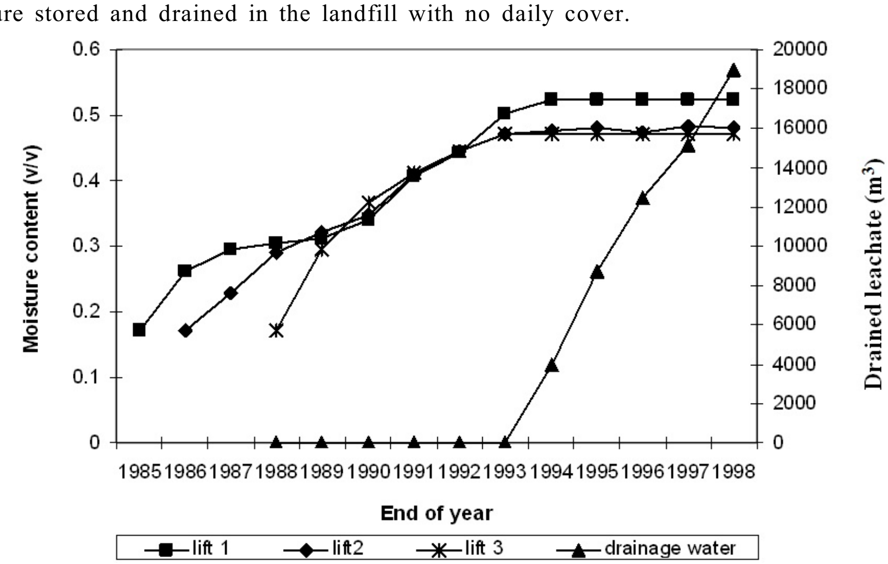

Fig. 11: Moisture stored and drained in the landfill incorporating daily cover of 7.5% initial waste layer depth.

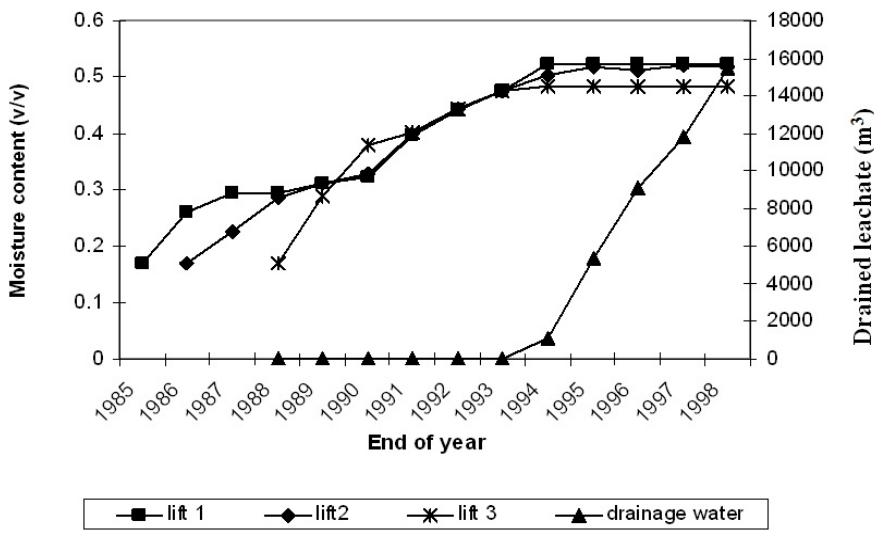

Fig. 12: Moisture stored and drained in the landfill incorporating daily cover of 10% initial waste layer depth.

from each wastefill scenario increased with time owing to the "dilute and disperse" mode of landfilling at Whites pit.

The landfill without daily cover has the highest volume of drained leachate ($23000m^3$) during the simulation period. It also has the earliest significant volume of leachate generation, which occurred in 1993. As soon as the field capacity was attained by overlying lifts 2 and 3 respectively in 1993 (Figure 10), the percolated moisture reaching the base of the landfill appeared to drain without any build-up of leachate in the basal waste lift. This indicated that the rate of lateral drainage is significantly more than any percolation through the underlying clay liner, as depicted by the undulating moisture profile of the basal lift 1 (Figure (10).

In the case of landfills with 7.5% and 10% intermediate cover soils (Figures 11 & 12), a reduced leachate volume was drained from the emplaced fills, owing to a reduced permeability. The cumulative volumes of leachate drained for these fills in 1998 were 16000 m^3 and 19000 m^3, respectively, far less than the volume drained from the waste-only fill. The relative resistance to flow (owing to the soil cover) signifies more moisture retention time in the bulk of the waste fill and also delay in the formation of leachate that reached the basal clay liner and thus the side drains

At the end of 1998, the percolated water through lift 2 and lift 3 in the landfill with 7.5% cover saturated the basal lift 1, and was just building up in lift 2 in 1998 (Figure 11). This is depicted by the equilibrium state of the volumetric water content of lift 1, and the fluctuated rising level of lift 2. Similarly, lift 1 has been saturated in landfill with 10% cover in 1998; however, the build-up of leachate in lift 2 of the fill was much higher, as the lift in this case was almost saturated (Figure 12). This further suggests that a higher moisture retentive characteristic results from a fill that has a higher density.

Application to Leachate Management: The configuration of the drains to collect percolated leachate at the base of the landfill is probably crucial in the design of an MSW landfill facility. The design of the drains is influenced by several factors including the hydraulic conductivity of the emplaced waste. The modified Dupuit-Forchheimer equation is suitable for calculating the spacing of landfill leachate drains [4]. It is described as follows:

$$L = \sqrt{\frac{\left(h_2^{\,2} - h_1^{\,2}\right) \cdot k}{P}}$$

where
2L = distance between parallel spaced drains (m)
h_2 = maximum desired leachate level above base (m)
h_1 = desired leachate level in the drain (m)
P = the recharge rate (m/s)
k = hydraulic conductivity of the refuse fill

In this scenario, the observed variations in the permeabilities of model waste fills in the test cells is used as a variable parameter in the leachate drain spacing for three hypothetical landfills. The saturated hydraulic conductivities of the model refuse fills in Test 1, Test 2 and Test 3, 1.4×10^{-3} m/s, 9.4×10^{-4} m/s and 7.8 $\times 10^{-4}$ m/s (Table 2) respectively, being obtained at an overburden of 8kPa can only be used to simulate shallow MSW landfills. For instance, if the desired leachate level in the drain is taken as 0.3m, the maximum desired leachate level above the basal liner is 0.9m, and the infiltration through a silty sand cover is 6.35 ´ 10^{-7} m/s, the calculated spacing of the leachate drains for the hypothetical landfills with a waste-only fill, and waste fills with 5% and 10% intermediate soil layer are 80m, 65m, and 60m respectively. The ratio of the applied stresses to saturated hydraulic conductivity in the current column tests is likely to apply to the higher stresses experienced at real MSW landfills. However, the impact of the daily cover on the drain spacing should be seen in its wider general context, much more than the basic simulation undertaken in this study.

General Discussion: The hydro-physical properties of the waste column in the tests were quantified by the application of soil mechanics to the measured parameters. As soil models are based on constant particle density of fill constituents, and the average particle density of waste, increases with increasing vertical stress (Powrie and Beaven, 1999), these quantities are not expected to be generically exact. Nevertheless, they are reasonable in the absence of widely accepted models for waste mechanics. The small magnitude of the applied stresses and particle sizes were in conformity with the scale of experimentation, as evident in a previous study [21], which showed similarity in results with tests undertaken in a full-scale compression cell.

The difference in the measured parameters of the waste-only fill and waste fills incorporating an intermediate soil layer was apparently due to the inclusion of soil particles in the latter. Obviously, the reduced compression in the composite layered fills was due to the additional resistance offered by the soil grains within the soil layer, and in the waste region that the grains ravelled into. The measurement of the volume of these regions requires the tracking of the movement of each soil grain with time, which was beyond the sophistication of the experiment.

It was observed that the dry density of waste fills with cover soil was significantly higher than the dry density of waste-only fill over the range of vertical stresses. The magnitude of the densification appeared to be proportional to the volume of the intermediate soil layer. As dry density is defined as the ratio of the dry mass to the dry volume of the waste fill, it implies that the increase in bulk weight of a waste fill owing to the intermediate sand grains (specific gravity-2.65) is significantly more than the volumetric reduction caused by compression of the soil layer, under similar vertical stress conditions. In terms of the densification of bulk waste particles, the impact of the intermediate soil layer in the waste fill is comparable to face compaction of freshly emplaced waste. It is also similar to the effect of increasing vertical stress, which is usually caused by subsequent waste filling on the waste layer. As "dry density" of waste implies the degree of compaction, waste fills with cover soil appeared compact than those without.

Despite the slightly higher drainable porosity of the waste fills with cover soil, their hydraulic conductivity was observed to be less than that of the waste-only fill, with the disparity appearing to reduce at high vertical stresses (Figure 8). The reasons attributed to this behaviour at lower stresses include: (a) the lower permeability of the cover soil layer, compared to the adjacent waste layers at low stresses; and (b) slight densification of the adjacent waste with the sifted soil grains. This effect, however, would fade, as the bulk permeability of adjacent waste layers, and thus entire fill, nears that of the cover soil, which occurs at high vertical stresses. From this point onwards, the transmission of water depends on the bulk microporosities of the waste particles. This was attributed the saturated hydraulic conductivity at the base of landfill, where waste porosity is near zero (at overburden stresses>600kPa), to the effective microporosity of soggy materials in the waste mass [23]. The impact the higher micropores of the waste-only fill (with predominantly paper and cardboard particles) have on hydraulic flow is clearly depicted in Figure 5, where the waste-only fill has a higher saturated hydraulic conductivity than the waste with intermediate soil layer at the same porosities.

There was a significant difference in the experimental and theoretical saturated hydraulic conductivities of the waste fills with cover soil, at low vertical stresses. This was probably due to the relatively loose placement of the intermediate soil layer, which resulted in a greater flow of water through the soil layer in the cell than there would be through a consolidated bed silty sand, whose value and assumed compact posture was used for the theoretical calculations. The effect of a possible increase in the flow rate due to a reduction in the thickness of the soil layer by ravelling would probably be annulled by the reduced permeability in the adjacent waste layer. In the long run and at high overburden stresses, the permeability of the waste layer will approach that of the soil cover, thereby diminishing the dissimilarity in measured and calculated values of hydraulic conductivities.

Simulation and design results have shown that a refuse fill with cover soil would retain more infiltrated water and require a larger area of drains to collect percolated leachate over a longer period of time. Considering the fact that the majority of the published data on waste tests were derived from refuse-only samples, it would be reasonable to factor down the calculated spacing of landfill drains obtained from such data. In fact, blanket drainage might be appropriate to use in practice for medium to deep refuse fills that have daily soil covers owing to its longer and possibly non-uniform spatial drainage.

The operator's objective is to profit from waste landfill without compromising safety. The compression of the waste-only column at the maximum prevailing stresses, being relatively higher by 2.26%, implies that the landfill operator can benefit financially from utilising this extra space, in addition to the space occupied by the daily cover not in the fill. On the other hand, the dry density of the waste with cover soil was more than 30% greater than that of the waste-only fill under a similar stress situation. This indicates that the inclusion of daily soil cover would greatly increase the density of the waste fill, in addition to its primary function of limiting rainwater infiltration, and preventing fly infestation. The soil materials are inert and will require less stabilisation time and cost than waste materials. With higher structural stability, less post-closure maintenance costs, and no having adverse impact on the moisture routing in refuse fills, the daily use of a suitable daily cover material, such as the one at White's Pit, appears to be appropriate for the sustainable landfill of waste.

In general, the scale of the present experimentation limits direct use of the test data. However, the characteristic impact of the intermediate soil layer on the model waste fills is considered a general trend, and should be considered in the preliminary design or modelling of a proposed MSW landfill facility. While it is acknowledged that the intermediate cover soil with characteristics used in this study will benefit the practice of MSW landfill, relatively more cohesive or clayey intermediate cover soils that would not place loosely, thus not ravel, and would be impermeable to water flow, causing localised clogging, as sometimes observed in landfills are not recommended. It is suggested that any soil cover to be used as daily cover should be classified and compared with the general guidelines relating to their suitability as in Table 1.

In developing countries like Nigeria, voids created by sand extraction in suitable geological formations, underlain by clay layers that can serve as a natural vertical barrier to groundwater contamination abound. In many cases, a sizeable proportion of the sand in such locations is not suitable for commercial purposes. These can be used as cheap daily soil cover for landfill of waste. However, un-engineered refuse dumps are still prevalent in many countries owing to the less importance given to the landfill of waste by the various governments. With this study, the use of cheap mineral sand residue will be beneficial to the sustainable landfill of refuse in many developing countries

Conclusions: The present study has shown that intermediate cover soil does modify the physical properties of a refuse fill. The real magnitude of the impact of daily cover on the properties of landfills is unlikely to be of the scale observed in the tests, but the characteristic trend would be similar. The inclusion of an intermediate soil layer in refuse fills has densification effects similar to the face compaction of an emplaced waste layer, and vertical stress applied by overlying waste layers on it. It is believed that the ravelling of the soil particles into the adjacent waste mass contributed to the structural changes in the waste fills with cover soil. Owing to complexity of the mechanism, the assimilated soil in underlying waste layers could not be accurately determined with the conventional set-up of tests, but was estimated as a maximum of 36% and 50% for waste fills incorporating 7.5% and 10% soil cover respectively, under the prevailing vertical stresses in this study.

The cover soil reduced the saturated hydraulic conductivity of the waste fill, but not up to the calculated values from soil mechanics, therefore suggesting that vertical flows in typical MSW landfills cannot be accurately estimated from soil mechanic models. The use of daily cover would relatively reduce the drainage rate of leachate, thus increasing the degree of saturation of the fill. In order to prevent leachate leakage, it might be appropriate to use a complete basal drainage blanket for landfills with daily cover soil. In broad terms, when designing waste facilities and leachate recycling schemes, it is essential to apply appropriate correction factors directly to published waste data, which have been obtained from waste-only samples.

General analysis of the impacts of cover soil on bulk waste properties has shown that the use of appropriate daily cover would be beneficial to sustainable landfill practice. Other issues, including quantification of ravelling, optimal thickness of cover soil, and its impact on biogas generation, using the Pitsea large-scale cell, are topics for future investigation.

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