MASS LOSS AND LANDFILLED WASTE MECHANICS

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SUMMARY: The impact of mass loss on a particulate medium is investigated. Through a series of laboratory tests on a partly soluble sand, the quantitative impact of mass loss is measured at different applied loads. It is shown that for the material in question, the volume change caused by mass loss exhibits a systematic and quantifiable response, even over a range of stresses. The purpose of these tests is to understand better the mechanical consequences of mass loss in order that landfill process models may improve their interpretation of biodegradation-related settlement.

1. BACKGROUND

There is a need to understand better the internal processes that control the behaviour of the landfilled waste because it is these processes – a complex mix of hydraulic, biochemical and mechanical phenomena – that define the operational conditions and long-term performance of the engineered containment system. The need presents a unique engineering challenge, i.e. the application of hydraulics, biochemistry and geomechanics to a porous particulate system that has been deposited in a remarkably short time period (at least by comparison to more conventional geologic media) and which undergoes hydraulic, biochemical and geomechanical change at an equally rapid rate.

For the purposes of design and construction, individual landfill behaviours, i.e. the hydraulic, biochemical and mechanical, are usually idealised as discrete systems. Leachate generation is a product of infiltration and a cell-averaged absorptive capacity, gas generation is a simple function of time and waste composition, as is long term landfill settlement. The discrete approach can be expedient but a more fundamental interpretation of this complex system offers deeper insights into landfill behaviour and an enhanced predictive capability.

The form of the more fundamental, integrated framework is not difficult to imagine – the physical composition, especially density and its variation with depth, control void space and hydraulic and gas permeabilities. These physical conditions define the hydraulic domain. In turn, the amount and distribution of moisture control the progress of decomposition. Biodegradation models that respond to moisture content already exist (e.g. HBM - McDougall, 2007). The real challenge, however, is to understand the impact that mass loss (in landfill, the enzymatic hydrolysis of cellulolytic matter and ensuing subsequent methanogenesis) has on phase composition. It is this interaction of the hydraulic, biodegradation and mechanical systems, more specifically the mechanical consequences of decomposition, which is the focus of this work.

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Third International Workshop "Hydro-Physico-Mechanics of Landfills"
Braunschweig, Germany; 10-13 March 200

A programme of laboratory tests and results is presented herein. The tests reveal how mass loss impacts on the volumetric state of a part-soluble particulate medium. Obtaining this information at field scale in landfill is a huge challenge so the main aim of this programme is to establish an appropriate strategy and anticipate analytical procedures.

2. MECHANICS OF MASS LOSS IN A PARTLY-SOLUBLE SANDY SOIL

A series of inundation tests on a sandy soil containing 20% by mass of soluble salt was performed to reveal the effect of particle dissolution on volume change and phase composition. Vertical displacement and pore-fluid conductance data were collected and interpreted using a dissolution-induced void (DIV) change relation. The data obtained suggest that dissolution leads to a systematic and quantifiable change in phase composition.

2.1 Theoretical Background

The DIV change relation quantifies the relationship between solids volume loss V_S and an induced change in void volume V_V,

$$dV_V = \Lambda \, dV_S \tag{1}$$

Certain values of Λ can be associated with foreseeable mechanical consequences, as summarised in Table 1. It is important to note that in a decomposable soil, the conventional void ratio is not a unique indicator of the volumetric state. For example, when $\Lambda = e$ (the current void ratio), mass loss induces void volume changes that result in a constant void ratio, yet significant overall volume reduction occurs (see McDougall & Pyrah, 2004 for more details).

2.2 Experiment: materials and equipment

Dry particles of Leighton Buzzard quartz sand (a poorly graded uniform sand with D_{60} = 0.92 mm, C_U = 1.5) and rock salt (all particles between 2.0 and 3.35 mm) were combined in proportions 80:20 by mass (see Fig. 1). The samples were placed in an oedometer to an initial dry density of approximately 1600 kg/m^3, loaded, then subsequently inundated with distilled water. The soil was tested at five different vertical loads: 12, 25, 50, 112 and 237 kPa. Dissolution of all rock salt occurs within 60-90 minutes.

Table 1: Some key values and associated mechanical consequences of Λ

Λ	Void ratio	Overall volume	Phase composition and its expected strength
-1	Maximum increase	No change	Much looser & possibly weaker
0	Increase	Reduction	Looser & possibly weaker
e (= void ratio)	No change	Large reduction	No change
>e	Decrease	Maximum reduction	More compact & possibly stronger

2.3 Displacement and conductance with time

Figure 2 shows the vertical displacement and Fig. 3 shows the conductance, both with time, during dissolution of the 50 kPa sample. Vertical displacement begins relatively slowly, accelerates to reach a maximum rate after about 15 minutes, then gradually slows to a negligible rate after about 60 minutes. The general pattern of conductance readings is consistent with the displacement time frame and emphasises the link between dissolution and vertical displacement. A more insightful interpretation is obtained if displacement is presented as a function of dissolution rather than time.

2.4 Displacement as a function of dissolution

Figure 4 shows vertical displacement with degree of decomposition for the 50 kPa sample. The degree of decomposition is a dimensionless measure of the progress of dissolution (Al-Khafaji & Andersland, 1981), in this case calculated from the dissolved ion concentration.

From Fig. 4, the relationship between vertical displacement and dissolution, independent of time, is observed. Little overall vertical displacement is evident during the early stages of dissolution. The relationship between displacement and dissolution then increases becoming linear in the second half of dissolution process.

Figure 1. Leighton Buzzard:rock salt (80:20) mix.

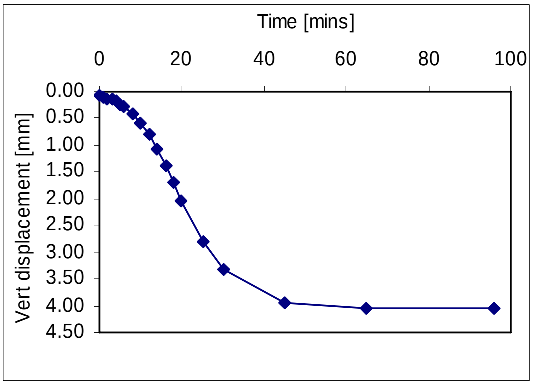

Figure 2. Vertical displacement with

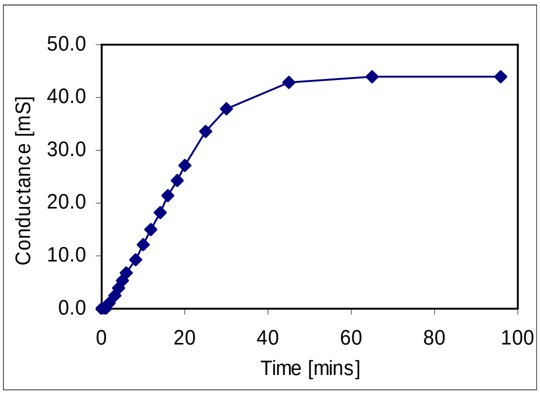

Figure 3. Conductance with time

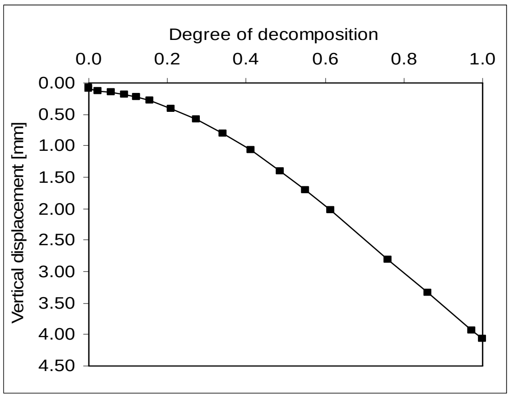

Figure 4. Vertical displacement with degree of decomposition.

2.5 Interpretation of dissolution using Λ

A quantitative interpretation of the relationship between void phase changes and dissolution can be gained from the DIV parameter *Λ*. Total solid (salt) volume loss due to inundation is calculated from the change in salt mass and salt specific density (2.16 Mg/m^3). Conductivity data allows the rate of solid volume loss to be calculated. Change in void volume is the difference between vertical displacement and solid volume loss.

Figure 5 shows the variation of *Λ* as a cumulative and an incremental parameter. The cumulative form of Λ is appropriate for predicting post-dissolution volumetric states, whereas the incremental form provides insights into the instantaneous mechanics of dissolution. The data in Fig. 5 show that cumulative *Λ* is at all times negative, which means that dissolution leads to a looser or more open soil skeleton and the void ratio is at all times greater than its initial value.

More specifically, cumulative Λ is initially about -0.5 and decreases in the early part of the dissolution process – increases in void ratio are at their greatest. After about 10-15% dissolution, cumulative Λ steadily rises to reach a final value of -0.05. In other words, the long-term phase composition comprises a void volume that is 5% larger than the corresponding loss in solid phase volume. It is interesting to note that the HBM model was deployed in the HPM2 Landfill Modeling Challenge with Λ = -0.2; see McDougall (2008) & Beaven (2008).

The incremental *Λ* data shows initial values of approximately -0.8. Recall (Fig. 1) that when *Λ* = –1.0, any loss in solid volume induces an equal increase in void volume and there is no change in overall volume. Dissolution at this stage leads to a much more skeletal structure. Incremental values of *Λ* then rise steadily and eventually become positive. Although not densifying the sample, the void volume during this stage is decreasing (but by less than the corresponding decrease in solid phase loss). This is consistent with the greater rate of vertical displacement observed in Fig. 4.

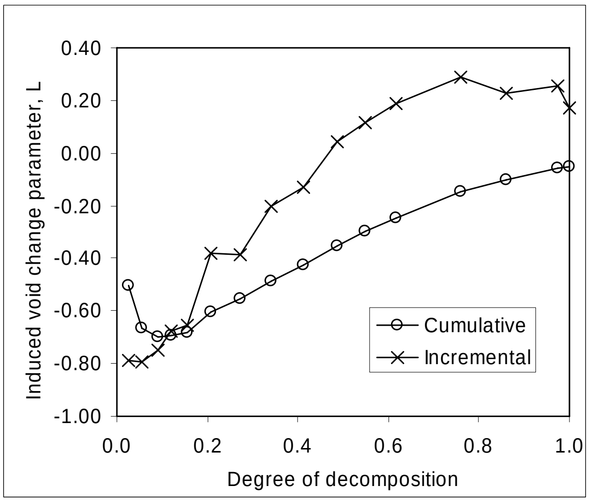

Figure 5. Variation of void change parameter Λ during dissolution

2.6 Dissolution at other applied loads

Figure 6 shows cumulative Λ values for four tests (at vertical stresses of 12, 50, 112 & 237 kPa). There is a remarkable consistency in the four test data records and it is tempting to conclude that for this case, the mechanical consequences of dissolution are predictable. Furthermore, at the frequency of monitoring, the rearrangement is a gradual, rather than episodic, process. The insensitivity to vertical load was not expected as data from landfills suggest a pronounced influence of waste depth (= applied load) on long term settlement (McDougall et al, 2004).

There are, however, other factors likely to control soil behaviour in these circumstances. They will not be discussed here but, to note, would include: (i) relative proportions and (ii) particle size distributions of the sand and salt fractions, (iii) initial density, (iv) rate of dissolution, (v) shear strength and (vi) stiffness of the particulate skeleton. This latter factor may explain the insensitivity to load observed here.

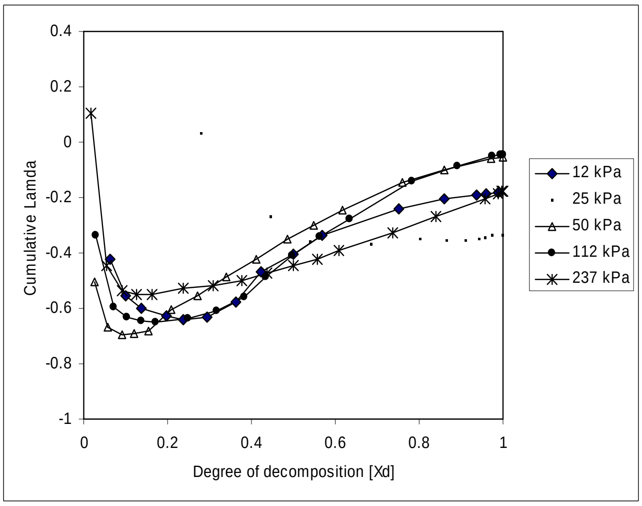

Figure 6. Cumulative *Λ* for all tests, at loadings 12, 25, 50, 112, 237 kPa.

3. CLOSING REMARKS

There are many scientific questions in landfill engineering that are avoided because waste is considered too unpredictable, too complicated or too heterogeneous to justify a more detailed analysis. In the Author's opinion, decomposition-induced landfill settlement is one such question. It may be that the quantitative validation of an integrated landfill system model is still some way off – and the difficulties of translating the controlled laboratory-scale tests described herein to the landfill sale are one reason for that. The difficulties are not, however, insurmountable (see, for example, Ivanova et al, 2005) and the additional insights, based only on a qualitatively plausible interpretation are sufficient to warrant further investigation.

Indeed, if a systematic mechanism of decomposition can be found in waste refuse then the ability to analyse and to predict long-term landfill settlement can be improved. This would be a key ingredient in a broader, more fundamental interpretation of landfill behaviour, which could revitalize landfill analysis and landfill modelling capabilities generally.

4.0 REFERENCES

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