Waste Management xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Estimating degradation-related settlement in two landfill-reclaimed soils by sand-salt analogues

J.R. McDougall [a,*], I.R. Fleming [b], R. Thiel [c], P. Dewaele [d], D. Parker [b], D. Kelly [e]

[a] Edinburgh Napier University, United Kingdom
[b] University of Saskatchewan, Saskatoon, Canada
[c] R.Thiel, Thiel Engineering, Oregon House, United States
[d] Golder Associates, Barrie, Canada
[e] SWECO, Edinburgh, United Kingdom

ARTICLE INFO

Article history:
Received 7 September 2017
Revised 11 March 2018
Accepted 10 April 2018
Available online xxxx

Keywords:
Landfill
Settlement
Degradation
Laboratory testing
Field comparison
Landfill reclamation

ABSTRACT

Landfill reclaimed soil here refers to largely degraded materials excavated from old landfill sites, which after processing can be reinstated as more competent fill, thereby restoring the former landfill space. The success of the process depends on the presence of remaining degradable particles and their influence on settlement. Tests on salt-sand mixtures, from which the salt is removed, have been used to quantify the impact of particle loss on settlement. Where the amount of particle loss is small, say 10% by mass or less, settlements are small and apparently independent of lost particle size. A conceptual model is presented to explain this behaviour in terms of nestling particles and strong force chains. At higher percentages of lost particles, greater rates of settlement together with some sensitivity to particle size were observed. The conceptual model was then applied to two landfill reclaimed soils, the long-term settlements of which were found to be consistent with the conceptual model suggesting that knowledge of particle content and relative size are sufficient to estimate the influence of degradable particles in landfill reclaimed soils.

1. Introduction

The disposal of waste to landfill poses both short- and long-term challenges originating in the interaction of hydraulic, biodegradation and mechanical phenomena. In the short-term, the presence of organic matter commonly leads to high compressibility of the waste body. In the long-term, mass loss due to biodegradation is the main challenge, the mechanical consequences of which are not well understood. The factors that control the interaction between biodegradation and mechanical consequences reside in different academic disciplines – biochemistry and geotechnics – which are difficult to combine. Nevertheless, a number of landfill models, e.g. HBM, LDAT, Moduelo (see McDougall (2011) for a summary) account for the impact of biodegradation on volume change. These models either (i) use a secondary compression coefficient calibrated according to the degradable content of the waste or (ii) account directly for mass loss. In the former, time is the controlling variable, sometimes in the guise of a gas production model; in the latter, some means of coupling mass loss to volume change is required.

The impact of mass loss on volume change is complex but it might be expected that the amount, relative size of material to be lost and grading of the host (inert) soil are significant controlling factors. With this in mind, a programme of dissolution testing of sand-salt mixtures in the oedometer (McDougall et al., 2013a,b) has been undertaken at Edinburgh Napier University to explore the effect of physical factors, such as void ratio and particle size ranges, on volume change. A parallel investigation has been done at the University of Saskatchewan (Fleming et al., 2012), and is combined with the Edinburgh Napier tests to obtain a more comprehensive insight.

The Saskatchewan tests were commissioned as part of a project to reclaim fill from old landfills in the US and Canada, as reported by Dewaele et al. (2011). The reclamation process begins with excavation of degraded waste from a landfill site. Screening then separates large items from the smaller (<50 mm) residual materials (see Fig. 1). If the old waste contains a substantial amount of concrete, especially for construction and demolition debris dumps, a crushing plant may be used in conjunction with the screening plant to reduce the particle size of the concrete and brick material so that it may also be re-used as controlled backfill.

* Corresponding author at: School of Engineering & Built Environment, Edinburgh Napier University, 10 Colinton Road, Edinburgh EH10 5DT, United Kingdom.
E-mail address: j.mcdougall@napier.ac.uk (J.R. McDougall).

https://doi.org/10.1016/j.wasman.2018.04.013
0956-053X/

Fig. 1. Photographs showing the landfill soil reclamation process: material post screening (left) and screening plant (right).

Depending on the original waste composition and screening process, an amount of contamination is encountered in the soil reclamation effort. Contamination, in this regard, is defined as the carryover of undesirable waste components, such as wood, paper, plastic, metals, glass, etc., into the reclaimed soil. While the inclusion of some glass, metal, or other non-degradable materials is probably not a problem from a geotechnical point of view (all of these could legitimately be considered a soil material), the residual organic fraction may be of concern because of the potential for degradation and its effect on settlement. Considering that residential and commercial developments have septic leach fields, water lines, sewer lines, storm-water drainage, or other environmental features that may leak or overflow into the underlying soil, it would have to be assumed that any degradable organic fraction in the soil mass would eventually degrade. There is then the question of the long-term performance of the reclaimed soil as a geotechnical foundation soil. What will be the impact of the loss of an amount of (degradable) particles of known size on the settlement of foundations built over this reclaimed soil?

Field investigations show that the screened reclaimed soil is very homogeneous (Dewaele et al., 2011), and the distribution of contaminants is likewise so. Laboratory testing, presented in this paper, has shown for one case study (site 2), that degradation-induced settlement is well under 0.5%, suggesting that this material is suitable as structural fill assuming good compaction control. It is a rationale for this behaviour that this paper seeks to elucidate.

2. Previous work & aims

There is a history of work related to particle loss, in relation to internal stability, in the field of dam engineering (e.g. Sherard, 1979; Kenney and Lau, 1985; ICOLD, 2013). However, it is important to distinguish this work from that presented in this paper. Internal erosion, commonly characterised by processes of suffusion and suffosion (Moffat et al., 2011), describes the movement of intact fine particles through a coarser (host) soil matrix. This movement is driven by hydraulic gradient and constrained by pore geometry and intergranular stress states. Under dissolution, the 'unstable' particle gradually disappears (at least as a solid phase component) so hydraulic gradients are not necessary nor is pore geometry a constraint and particle removal is then not limited to fines.

Studies of particle dissolution in coarse-grained soils have been done by Fam et al. (2002), Shin and Santamarina (2009) and Truong et al. (2010). They all report a change in soil structure and fabric manifest as void ratio change but with relatively little settlement. However, these studies focused primarily on the amount of particle loss in mixes with a relatively narrow range of sand to salt particle size ratios. The diameter ratio, given by the ratio of d_{50} values of sand to salt, i.e. $d_{50\ sand}/d_{50\ salt}$ is fundamental to the tests reported on here. Fam et al. (2002), who conducted tests on salt-sand particle mixtures with a diameter ratio of 2.30, noted virtually no settlement. Shin and Santamarina (2009) measured settlement between 1.2% and 8.2% for salt-sand mixtures with diameter ratios of 2.33 at contents of 5% to 15%. Truong et al. (2010), tested mixes with diameter ratios of 1.44, showed settlements of 2% and less for mixes containing up to 10% of salt particles.

There is little experimental data and hence understanding of the influence of particle size on fabric changes due to particle loss. Hence, in this paper are presented the findings of experimental investigations undertaken at Edinburgh Napier University and University of Saskatchewan into the volumetric consequences of both the amount and size of particles lost and host particle size distributions under oedometric conditions. A total of 158 salt-sand mixtures were tested: 118 at University of Saskatchewan, the remaining 40 at Edinburgh Napier University. In addition, two reclaimed landfill soil tests were tested at Saskatchewan. The results are brought together firstly, to explore the influences of particle amount, size and grading of the host sand on volume change and secondly, to provide an early benchmark for the long-term performance of reclaimed landfill soils. A comparison is also made with a test on aged refuse in a consolidating anaerobic reactor at University of Southampton (Ivanova et al., 2008).

3. A conceptual model for the volumetric consequences of particle loss

Before the experimental programme and results are presented, it is instructive to consider, from a conceptual standpoint, the likely consequences of particle loss, where the particles in question differ in both amount and size relative to the inert soil fraction. The main physical properties of the mixtures are captured by (i) the amount of soluble particles, expressed as a percentage of the total solid mass and (ii) particle size, expressed as a diameter ratio. For the purposes of this conceptual outline, the inert fraction is taken to be a uniform soil, i.e. $C_U \approx 1.0$. A well-graded soil is considered in the experimental programme and will be discussed later.

Consider the four salt sand mixture amount and size combinations shown in Fig. 2. The values given to the amounts and diameter ratios are approximately those of the sample mixtures of the experimental programme.

3.1. Mixture A: small amounts of small particles

In this mixture, the small salt particles 'nestle' within the assembly of larger inert sand particles. From a mechanical