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CONSIDERATIONS FOR THE STABILITY OF WASTE FILLS

CONSIDERATIONS POUR LA STABILITE DES STRUCTURES D'ENFONISSERMENT DE DECHETS

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SYNPOSIS: Prior to the stability failure of the Kettleman Hills Unit B-19, Phase I-A hazardous waste landfill on March 19, 1988, attention in the design, construction and operation of modern waste landfills had been focussed primarily on the prevention of migration of unacceptable levels of contaminants from the waste fill to the surrounding groundwater and atmosphere. Over the five years which have followed this stability failure, the issues of both static and seismic stability have come to the fore, and rapid advances have occurred in both of these areas with regard to waste fill engineering. This paper will briefly discuss some of the more important lessons learned regarding material properties, potential failure modes, and rapidly evolving standards of practice in the evaluation and design of waste fills and waste fill cover systems with regard to considerations associated with both static and seismic stability. The emphasis is on advances in practice over the past decade, and a number of issues which merit further study and/or research are highlighted and discussed. A somewhat more extensive discussion of issues concerning static stability of waste fills is presented by Mitchell, et al. (1993), and an expanded discussion of seismic stability issues is presented by Seed and Bonaparte (1992).

INTRODUCTION

The stability failure of March 19, 1988 at the Kettleman Hills waste repository has been extensively studied (e.g.: Seed et al., 1988; Mitchell et al., 1990; Seed et al., 1990; Byrne et al., 1992; and Mitchell et al., 1993). The causes and mechanism of this precedent-setting failure are now well understood, and the lessons learned have resulted in the focussing of considerable attention towards issues associated with both static and seismic stability of waste landfills.

The Kettleman Hills slippage was a static (non-seismic) stability failure. Slippage occurred along sliding surfaces within the multi-layer lining system underlying the waste fill, mainly on an interface between smooth (non-textured) HDPE geomembrane and compacted liner clay. The average shear strength along this critical basal liner interface was found to have been on the order of 800 to 1000 lb/ft^2 (40 to 50 kPa), based on both laboratory testing and back-analyses, despite overlying fill depths of up to 120 feet, and associated overburden stresses of up to 10,000 lb/ft^2 (500 kPa). In some areas, slippage within the base liner system occurred along an interface between geotextile filter fabric and HDPE geomembrane, and the residual strength of this interface appears to have corresponded to a friction angle of approximately $\phi = 8°$.

This stability failure serves well to highlight some of the important issues associated with stability of waste fills. There are major difficulties associated with evaluation of the engineering properties of waste itself, and both basal and cover liner systems commonly contain layers and combinations of geosynthetics and geotextiles, as well as compacted clayey soils, which result in potential sliding planes of low shear strength.

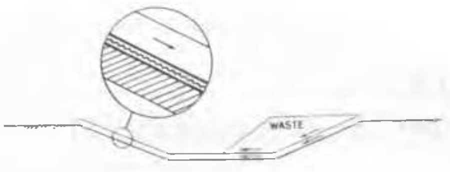
Static Stability Issues

Figure 1 presents a schematic illustration of many of the principal potential stability failure modes to be considered in engineering of waste fills. Not all waste fills have a basal liner system, but these are becoming increasingly common and evolving regulatory pressures make it likely that these will continue to be common to most new waste fills in the United States of America. Potential failure modes are several-fold, and may be subdivided into four general categories: (1) failures due to shearing primarily through the actual waste pile itself, (2) failure due, at least in part, to shearing through weak material (e.g.: foundation soils) underlying the waste fill, (3) shearing along planes of weakness within a multi-layer liner system underlying the waste fill, and (4) slippage within the surface cover/liner system.

Evaluation of suitable shear strengths for each of these waste fill system components is critical if suitable levels of overall stability are to be maintained. Evaluation of suitable strengths of foundation units (soil and/or rock) is a straightforward issue and will not be discussed here.

Conversely, evaluation of shear strength parameters for waste piles themselves is an extremely difficult task. Waste piles can be extremely heterogeneous in nature and composition, and no two waste fills are identical. Moreover, the nature and characteristics of the "waste stream" being deposited within a fill can vary considerably over the active life of a waste fill, rendering it often impossible to precisely assess likely fill characteristics for design studies which precede completion of actual fill placement. For "closure" design studies, which typically follow completion of fill placement, the massive heterogeneity and the scale of some of the fill components typically render conventional sampling and testing, as well as conventional in-situ testing methods, largely useless with regard to assessing waste fill strengths.

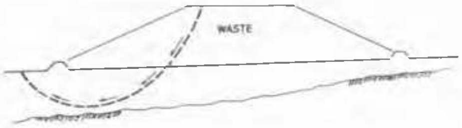
Accordingly, the common approach to fill strength assessment is a conservative estimation of likely strength characteristics (generally expressed in terms of c and ϕ), based on back-analysis of the previous performance of similar fills. Accordingly, considerable effort has been devoted to back-analysis of existing waste piles over the past few years, and these efforts continue. Many such efforts have been proprietary, however, and results of such studies have not yet been widely published. In addition, for any given waste fill, there are a range of combinations of c and ϕ that would provide for a minimum "Factor of Safety" (F.S.) of at least 1.0. It should also be noted that strength parameters back-calculated from stable fills are minimum (conservative) values, and that actual strengths may be higher. As a result, particularly useful values come from back-analyses of: (a) unusually high fills with unusually steep faces, (b) fills subjected to inertial forces during seismic events, and (c) fills exhibiting ongoing creep deformations suggesting that the overall static factor of safety is probably not significantly greater than 1.0. (It should be noted that such deformations can be confused with ongoing settlements



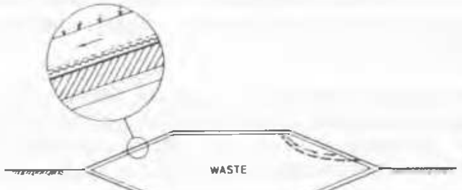
(a, b) Slippage and/or Fill Displacement Along Shear Surfaces Within the Liner System - Partially Completed Fill

(c, d) Side Slope Movement and/or Displacement of Fill and/or Impoundment Faces - Partially Completed Fill

(e, f) Slippage/Displacement Primarily Along Shear Planes Within the Liner System and/or Along Sliding Surfaces within Underlying Geologic Materials



(g) Slippage/Displacement Through Deep Alluvial Foundation Soils



(h, i) Schematic Illustration of Potential Modes of Slippage and/or Displacement of Final Fill Slopes and Surface Cover System

Fig. 1 Schematic Illustrations of Examples of Potential Waste Fill and/or Foundation Failure/Slippage Modes

due to fill compression and waste fill degredation.) Finally, most waste fills are subject to ongoing degredation (decomposition), and the effects of this on overall long-term fill strengths and stability are not yet well understood. Having said all of that, it is then noted that ranges of c and ϕ for "common municipal waste" currently used in recent U.S. practice appear to be on the order of: $\phi \approx 20°$ to $40°$ (for $c \approx 0$), $c \approx 1{,}200$ to $2{,}500\ \mathrm{lb/ft^2}$ (for $\phi = 0$), and intermediate combinations of c and ϕ providing similar overall strengths but assuming that neither c nor ϕ equals 0.

When present, base liner systems typically consist of alternating layers of impervious geomembrane (e.g.: HDPE), "impervious" compacted clay, and drainage and leachate collection layers composed of pervious soils and/or geosynthetics and usually bounded by geotextile filter fabrics. Additional geosynthetic "grids" can also be present to provide increased tensile strength within the liner system. Unlike waste fill masses, the shear strengths of the components and interfaces within a base liner system can and should be rigorously evaluated by means of laboratory testing. Interface shear strengths between various combinations of geosynthetics, geotextiles and geomembranes within the liner system can be very low, with values as low as $\phi \approx 5°$ to $8°$ for some cases. Many of these interface combinations exhibit a transition from "peak" shear strengths to lower "residual" values at very small shear displacements (often less than 0.1"). As most waste fills are subject to ongoing deformations due to fill compression and decomposition, it is routinely assumed that these small shear displacements may be exceeded, and residual liner interface shear strength are commonly used for design.

Many of the weakest potential interface combinations within liner systems are associated with the geomembrane in combination with any of several other components. An important innovation in recent years has been the development of "textured" geomembranes, which can provide considerably improved interface shear strengths relative to those associated with "smooth" (non-textured) geomembranes. It should be noted, however, that not all "texturing" processes are equally effective; some geomembrane surface "textures" can degrade or even detach when sheared under high normal stresses: the effectiveness of "textured" geomembranes should thus be verified (by testing.) In many cases, the weakest interface within a liner system is that between the geomembrane and compacted clay. Seed and Boulanger (1991) have shown that shear strengths along this type of interface can vary by as much as a factor of two due to small changes in compacted water content (variations in w of only 2 or 3%.) Similar considerations apply when evaluating interface shear strengths within surface cover liners, though here it should be further noted that: (a) normal stresses are very small (and should be so in laboratory shear strength testing), and (b) geonets and/or soil anchors can be used to "hang" surface covers on relatively steep slope faces in some cases.

Seismic Stability Issues

It is not possible to address these at length herein. Instead it is noted that:

1. Waste fill and liner shear strengths are again crucial, and there is little dynamic experience available.
2. Dynamic properties of waste (e.g.: strain-dependent shear moduli and damping) are poorly defined at present.
3. Evolving "standard" U.S. practice typically involves the use of Newmark-type seismic displacement analyses, with more sophisticated deformation/displacement analyses beginning to see use in some cases.
4. Conservatively-predicted permanent seismic displacements of approximately 6-inches or less are commonly considered "acceptable" with regard to base liner protection, and criteria are occasionally slightly relaxed for surface covers (which are more easily repaired.) Analyses of actual expected liner performance under varying displacement conditions are only just beginning to see routine useage.

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