Available online at www.sciencedirect.com
ScienceDirect
Waste Management 28 (2008) 1509–1517
waste management
www.elsevier.com/locate/wasman

# Comparison of slope stability in two Brazilian municipal landfills

B. Gharabaghi [a,*], M.K. Singh [b,1], C. Inkratas [a,2], I.R. Fleming [b,1], E. McBean [a,3]

[a] *School of Engineering, University of Guelph, Guelph, Ontario, Canada N1G 2W1*
[b] *Department of Civil and Geological Engineering, University of Saskatchewan, Saskatoon, Canada S7N 5A9*

Accepted 30 July 2007
Available online 25 September 2007

**Abstract**

The implementation of landfill gas to energy (LFGTE) projects has greatly assisted in reducing the greenhouse gases and air pollutants, leading to an improved local air quality and reduced health risks. The majority of cities in developing countries still dispose of their municipal waste in uncontrolled 'open dumps.' Municipal solid waste landfill construction practices and operating procedures in these countries pose a challenge to implementation of LFGTE projects because of concern about damage to the gas collection infrastructure (horizontal headers and vertical wells) caused by minor, relatively shallow slumps and slides within the waste mass. While major slope failures can and have occurred, such failures in most cases have been shown to involve contributory factors or triggers such as high pore pressures, weak foundation soil or failure along weak geosynthetic interfaces. Many researchers who have studied waste mechanics propose that the shear strength of municipal waste is sufficient such that major deep-seated catastrophic failures under most circumstances require such contributory factors. Obviously, evaluation of such potential major failures requires expert analysis by geotechnical specialists with detailed site-specific information regarding foundation soils, interface shearing resistances and pore pressures both within the waste and in clayey barrier layers or foundation soils.

The objective of this paper is to evaluate the potential use of very simple stability analyses which can be used to study the potential for slumps and slides within the waste mass and which may represent a significant constraint on construction and development of the landfill, on reclamation and closure and on the feasibility of a LFGTE project. The stability analyses rely on site-specific but simple estimates of the unit weight of waste and the pore pressure conditions and use "generic" published shear strength envelopes for municipal waste. Application of the slope stability analysis method is presented in a case study of two Brazilian landfill sites; the Cruz das Almas Landfill in Maceio and the Muribeca Landfill in Recife. The Muribeca site has never recorded a slope failure and is much larger and better-maintained when compared to the Maceio site at which numerous minor slumps and slides have been observed. Conventional limit-equilibrium analysis was used to calculate factors of safety for stability of the landfill side slopes. Results indicate that the Muribeca site is more stable with computed factors of safety values in the range 1.6–2.4 compared with computed values ranging from 0.9 to 1.4 for the Maceio site at which slope failures have been known to occur. The results suggest that this approach may be useful as a screening-level tool when considering the feasibility of implementing LFGTE projects.


## 1. Introduction

The assessment of waste mass stability is a critical step in reducing the risk to the landfill operatives and the general public. Major slope failures can occur, as demonstrated by the July 10, 2000, Payatas Landfill Failure, Quezon City, Philippines (Merry et al., 2005) and the subsequent slide at the Bandung landfill in Indonesia (Kolsch et al., 2005). In both of these cases, major failures led to significant loss of life. The largest slope failure in a North

* Corresponding author. Tel.: +1 519 824 4120x58451; fax: +1 510 836 0227.

*E-mail addresses:* bgharaba@uoguelph.ca (B. Gharabaghi), cinkrata@uoguelph.ca (C. Inkratas), ian.fleming@usask.ca (I.R. Fleming), emcbean@uoguelph.ca (E. McBean).

[1] Tel.: +1 306 966 5341.
[2] Tel.: +1 519 824 4120x56248.
[3] Tel.: +1 519 824 4120x53923.

0956-053X/$ - see front matter 
doi:10.1016/j.wasman.2007.07.006

American municipal solid waste (MSW) landfill occurred on March 9, 1996 and involved 1.2 M $m^3$ of waste, providing the industry with lessons for the operation, expansion, and stability of existing landfill slopes (Eid et al., 2000). One of the largest, previous waste slope failures involved 500,000 $m^3$ in Maine, USA (Richardson and Reynolds, 1991). A number of researchers have concluded that major landfill failures are usually associated with site-specific factors such as excessive pore pressures or weak foundation soils (Koerner and Soong, 2000; Kavazanjian, 2001). The purpose of this paper is to discuss the use of simple, generic stability analyses for shallow failures which occur completely within the waste mass, i.e., which do not involve factors such as weak foundation soils. Analyses involving such site-specific and non-generic factors require, in any event, substantial additional site information.

A secondary consideration is minimizing the risk to the environment by reducing the chances of slope failure and damage to the landfill infrastructure such as lining elements, leachate control systems and landfill gas collection systems. It is these relatively smaller failures within the waste mass that are the subject of this paper.

Methane is both a primary constituent of biogas generated from landfilled refuse and also an important greenhouse gas. Therefore, reducing emissions to the atmosphere by capturing the landfill gas (LFG), and using the LFG as an energy source can yield substantial energy value, economic opportunities, and environmental benefits. As a consequence, there is extensive interest in the implementation of landfill gas to energy (LFGTE) projects which involve collection of LFG and combustion for their energy value.

While potential energy projects in developed countries have been largely captured (e.g., McBean et al., 2002 indicate there are hundreds of such projects already in operation), the situation is not the same in the developing world. For example, the Latin American Caribbean (LAC) region is highly urbanized with nearly 75% of its 500 million inhabitants living in large cities. Many of these LAC cities still dispose of their MSW in uncontrolled open dumps. Due to the absence of any barrier system, the leachate and biogas emanating from decomposing waste contaminates the surrounding environment.

Lately, a few prosperous cities in the developing world have begun to improve disposal practices and some have even commenced operation of engineered landfills (Johannessen and Boyer, 1999). For instance, many landfills in South Africa have started collecting tipping fees, have weigh scales (for landfills receiving more than 1000 tonnes of waste per day), have compactors to grade and compact waste in 2 m lifts and are applying daily cover soil (Johannessen and Boyer, 1999). In China and Indonesia, a number of solid waste projects have recently been implemented to upgrade open dumps to engineered landfills. Nevertheless, while there are improvements, a substantial number of large municipalities in the developing world still dispose of their wastes in open dumps.

Landfill gas in these open dumps is generally managed, if at all, through installation of vertical gas wells for passive ventilation. Such practice results in the release of large quantities of methane directly into the atmosphere, thereby promoting global warming through the greenhouse effect (Johannessen and Boyer, 1999). Although Brazil has been active in implementing improved gas management at some sites, many countries in the LAC still adhere to the bare minimum protective measures stipulated in their legislations, which require only passive venting of gas from wells located in the waste body (Johannessen and Boyer, 1999).

A compounding problem at open dumps is due to the limited space remaining for refuse disposal, and the siting for new landfills is extremely challenging. As a result, the depths and slopes at these open dumps are increasing as a means of keeping the sites functioning for longer times. Managing the landfills in this matter has led to the stability of slopes being a major concern (Singh and Murphy, 1990).

The issue of slope stability is critical for: (i) the safety of on-site workers; (ii) the safety of people living near the base slopes of the landfill; (iii) protection of investments made in improving the level of engineering of the landfill, such as on-site equipment to collect the LFG; and (iv) prevention of large remediation costs. At these open dumps, attention is seldom paid to the subsurface and related conditions, and therefore complete and reliable data are rarely available with respect to the depth and geometry of subsurface formations, pore pressures in foundation soils and the waste mass, leachate head, shear strength of solid waste and underlying native soil.

Therefore, stability with respect to deep-seated failure may only be evaluated by a geotechnical engineer familiar with local ground conditions and, as provided with often-extensive data regarding the various contributing factors which may, as discussed above, trigger instability. The purpose of this paper is not to consider such major and complex potential failures, but rather to evaluate the potential application of a very simple generic approach to relatively small slumps and slides which are contained entirely within the waste mass and which represent an operational hazard and a threat to buried landfill infrastructure such as LFG collection facilities. The authors propose that simple analyses such as those carried out herein might be useful to identify potential problem areas during planning and feasibility studies for LFGTE projects at existing MSW landfills, particularly in developing countries.

Two case studies are employed; the first site is an open dump at which waste is end-dumped with little or no compaction other than that provided by self-weight. The second site has some level of engineering and is constructed in lifts by compactors (approximately 37,000 kg), resulting in an increase in the unit weight of the material. Given the importance of unit weight in influencing the stability of landfill slopes, selection of a reasonable value for this parameter is very important. In the absence of reliable, site-specific data, the reader is directed to Zekkos et al. (2006) and Dixon and Jones (2005) for guidance on the