1.0 INTRODUCTION

In General, **Landfills (waste dump areas) endure from a major post-closure settlement that takes place over a prolonged period of time**. A huge differential settlement may deteriorate structures, foundations, and other related facilities that constructed atop of a landfill. In addition, it may lead to shattering of the geomembrane and wastage of the cover system in the landfills. The refuse (waste) materials show diversified engineering properties that diverge over positions and time within the landfill. **Hence, with the conjunction of that the landfills behavior is not fully understood; recognize a conventional soil mechanics approach less appealing to predict the settlement. Instead, empirical and semi-empirical approaches of estimating the landfill settlement are commonly used side by side with field observations.** (Ling et al. 1998)

https://www.researchgate.net/publication/306378961_LANDFILL_SETTLEMENT_ANALYSIS to download full text

18.9 LANDFILL REDEVELOPMENT

The movement of brownfields redevelopment has helped invigorate existing slow process of remediation of contaminated sites. The use of risk based clean-up approaches now allowed in many states has facilitated brownfields redevelopment.

Landfills are a particular subset of brownfields, particularly older landfills in industrialized areas. Older landfills that were never properly closed are true brownfields with idle land from which pollutants are often discharged. With investigation and limited remediation, this subset of brownfields-like sites presents unique opportunities for redevelopment. Redeveloping landfills is particularly challenging not only due to clean-up issues, but also the geotechnical issues of building on waste. Most of the unregistered landfills were never properly closed. Only a handful of unregistered landfills were properly closed and received a Closure and Post Closure Plan Approval pursuant to the Amended State Solid Waste Management Act of 1975 and/or the Sanitary Landfill Facility Closure and Contingency Fund Act of 1992. The few properly closed landfills were either large private commercial landfills, sole source industrial landfills owned by major corporations, or municipal landfills. Hundreds of registered landfills were never properly closed because the owners lacked the resources to comply with regulatory closure requirements. While the Sanitary Landfill Facility Closure and Contingency Fund Act provides a revenue source through a tax on operating landfills, the State has historically not utilized these funds for closure of abandoned landfills and reserved the public funds for emergency actions, such as extinguishing a landfill fire or remediating methane migration. A wide variety of remediation techniques can be utilized in landfill redevelopment. In the simplest case, waste can be capped in place with one foot of silty, clayey material and one and one-half feet soil cover. In the most complex case, a slurry wall/sheet pile wall can be used to contain leachate from outflow from the site and an interior leachate system can be installed. The degree of capping, containment and leachate collection depends on the underlying geology, leachate strength and site specific cap design.

https://www.researchgate.net/publication/307436757_Landfill_Design_and_Operation to download full text

Subsidence is the sinking or settling of the ground surface. It can occur by a number of processes. Ground subsidence may result from the settlement of native low density soils, or the caving in of natural or man-made underground voids. Subsidence may occur gradually over many years as sags or depressions form on the ground surface. More infrequent, subsidence may occur abruptly as dangerous ground openings that could swallow any part of a structure that happen to lie at that location, or leave a dangerous steep-sided hole. In Colorado, the types of subsidence of greatest concern are settlement related to collapsing soils, sinkholes in karst areas, and the ground subsidence over abandoned mine workings.

Legal definition

H.B. 1041, 106-7-103(10): *Ground subsidence* means a process characterized by downward displacement of surface material caused by natural phenomena such as removal of underground fluids, natural consolidation, or dissolution of underground minerals, or by man-made phenomena such as underground mining.

https://coloradogeologicalsurvey.org/hazards/ground-subsidence/

Another type of ground subsidence that commonly occurs in Colorado is the settlement and ground collapse that occurs in certain types of geologically recent, unconsolidated sediments — usually referred to as soils by engineers and contractors. This group of soils those that can rapidly settle or collapse the ground are known as *collapsible soils*.

Collapsible soils are a major geologic hazard for land development in many locations across the state. This particular hazard manifests itself as ground settlement, which can be damaging to overlying structures if the soil problems are not mitigated or if the structure is not engineered properly. Ground settlement can cause severe damage to man-made structures such as foundations, pavements, concrete slabs, utilities, and irrigation works. Although not of the severity of damage related to swelling soils and heaving claystone bedrock, ground settlement has resulted in hundreds of millions of dollars in damage. As growth pressure increases in many places in Colorado, more areas susceptible to soil collapse are considered for development. The best illustration of this geologic hazard's potential liability was the case of townhomes damaged by collapsing soils in a Glenwood Springs development built in the early 2000s. The court case resulted in a $12 million payment by the developer and his engineering consultants to the townhome owners.

https://coloradogeologicalsurvey.org/hazards/collapsible-soil/

Abstract

Several noteworthy stability failures occurred at landfills in the United States in the 1980s and early 1990s, a timeframe coinciding with the promulgation of modern US environmental regulations. These failures were extensively studied, and lessons were learned. A state-of-practice developed to enable the design of waste fills to be stable throughout their construction, operation, and closure periods. However, a survey of landfill performance in the United States in the 2010–2019 timeframe shows that waste fill stability failures continue to occur. This paper, an expansion of the 2018 Terzaghi Lecture given by the first author, presents a brief review of several waste fill failures from the 1980s and 1990s and the lessons learned during that period. Several more recent waste fill failures are then reviewed, from which it is concluded that 20–30 years after the earlier failures, facility operators and design engineers are relearning the earlier lessons, as well as new lessons related to evolving waste streams and operating practices. The paper concludes with a discussion of the current standard-of-care for the design of US waste fills and suggests that this standard can be improved through application of the lessons described herein.
https://ascelibrary.org/doi/10.1061/%28ASCE%29GT.1943-5606.0002291

Avoid Soft Soil Problems at Landfills
October 30, 2017

Discovering unexpected pockets of soft soils at the time of construction can delay your project and drive up costs for landfills, support features, and many other types of construction. If you don't find them, building over them can result in unexpected settlement affecting a structure or building, or cause a slope stability problem for a berm or stockpile. You can avoid both of these scenarios with early investigation and appropriate construction planning.

While landfill development investigations typically require numerous soil borings within the proposed waste limits of the landfill, it's common to overlook perimeter areas. Pockets of soft soil deposits can be associated with nearby existing wetlands, lakes, or rivers; with wind-blown silt or ancient lake deposits from periods of glaciation; or with fill placed during previous site uses.

The landfill perimeter areas may contain tanks for leachate or fuel, buildings, perimeter berms for screening or landscaping, stockpiles, and other features. A tank or building constructed over soft soils could experience unexpected settlement affecting the performance and value of the structure. The potential for a slope stability problem can increase for a large berm or stockpile built on soft soils.

The first step to avoid these problems and identify problem soils is to include perimeter areas in your subsurface investigation. Perform soil borings or test pit excavations at the locations of the proposed perimeter features such as tanks or berms. If you encounter soft soils, address them like this:

- If the deposits are relatively shallow, excavate the soft soils and replace them with compacted engineered fill.
- If the deposits are deeper and there is sufficient time in the project schedule, pre-load the soft soil area to reduce future settlement and increase soil strength before construction, and monitor the pre-loading with instrumentation such as vibrating wire piezometers and settlement platforms to confirm when the pre-loading design goals have been achieved. Preloading can be accomplished with temporary soil fill placement that is later removed when the pre-loading is completed or by staged placement of fill for a permanent fill feature such as a berm.
- If the project schedule doesn't allow for pre-loading and the soft deposits are deep, consider a ground improvement method such as GeopiersTM to improve soil strength and stiffness in place. You can then proceed with constructing tanks, buildings, berms, or other structures over the improved soil area without special foundations. You may also use a deep foundation system such as piles or drilled piers to build over a soft soil area.

https://www.scsengineers.com/15236-2/

Geotechnical aspects of landfill design and construction. Part 1: principles and requirements

H. L. Jessberger

Proc. Instn Civ. Engrs Geotech. Engng, 1994, **107**, Apr., 99–104

Ground Board

Geotechnical Engineering Advisory Panel Paper 10435

Written discussion closes 15 June 1994

■ **This Paper, the first in a series of three, presents the requirements of geotechnical landfill design including site assessment, safety considerations and quality assurance. It also introduces the following parts of the series.**

Geotechnical aspects are essential factors to be considered in the course of the design and construction of waste landfills which often constitute waste piles. Basic geotechnical aspects relate to, among other factors, slope stability, settlement or permeability, including those of the structural elements such as the stabilizing elements, anchors or sealing layers and drainage blankets. Within this context, particular attention must be given to the specific landfill problems caused by the properties of the waste, the contaminant content of the leachate, etc. Furthermore, the landfill design must take into account long-term considerations, because the function of the containment elements has to be effective as long as there remains a risk of pollution of the groundwater, soil or air from the landfill.

2. This series of papers discusses a number of geotechnical aspects which are essential for landfill design and construction, and takes into account the landfill as a system that includes the subsoil and waste as well as the landfill operation. It is intended to highlight the problems and to present solutions or engineering approaches which may be of benefit to the designer, construction team and the operator or owner of the landfill. The papers are based on research projects directed by the Author, on the experience of his consulting group and, not least, on the work of the International Society for Soil Mechanics and Foundation Engineering European Technical Committee 8 (ISSMFE ETC 8), 'Geotechnics of Landfills and Contaminated Land'.

3. The series comprises three parts. In this Paper, the principles and requirements of geotechnical landfill design are presented; the second deals with relevant material parameters and test methods; and in the last, selected calculation methods for specific geotechnical problems of waste landfills are discussed.

Waste management

4. Waste management is the objective of sanitary engineering. For a landfill design project it is necessary to know the design volume and nature of the waste. Therefore, the future development of waste production and disposal is an important consideration with respect to appropriate containment technology.

5. Table 1 shows that in 1990 in Germany only a small proportion of the waste produced was disposed of by incineration; most was placed in landfills and about one-quarter was recycled or reused. These figures show that a relatively small amount of hazardous waste was disposed of (by incineration) but that a huge amount of less dangerous waste—construction debris and excavated soil—was disposed of in landfills or was recycled or reused. The disposal of waste in landfills requires containment elements designed with regard to the particular waste type.

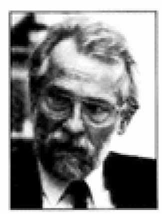
6. The situation will change within a decade due to the new Federal Legislation[1] which demands that municipal waste should be disposed of mainly by incineration. This will decrease the amount of waste disposed of in landfills. Further, it means that the constituents of waste will change from mainly organic to inorganic, and this development should be reflected in the technology used for landfill barriers. Added to this, the politics of this issue is focused on waste reduction in general and this will lead to another change in momentum.

7. We can draw four conclusions from the foregoing.

(*a*) There is a growing need for landfills.
(*b*) The nature of the waste will change and therefore so will the requirements for landfill containment elements.

Table 1. Some figures of waste production and disposal in Germany in 1990

Waste production: 10^6 t/year	
Municipal	40
Industrial including	244
Construction debris and excavated soil	126
Hazardous waste	15
Waste disposal: %	
Landfill	*c.* 90
By incineration	*c.* 8·5
Recycled or reused (e.g. construction debris): 10^6 t/year	69



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See last sentence of 1st paragraph--".....must take into account long term considerations…..as long as there remains a risk of pollution of the groundwater, soil, or air from the landfill."

https://www.icevirtuallibrary.com/doi/10.1680/igeng.1994.26377

Chapter 7 Slope Stability Analysis 7 .1

Overview Slope stability analysis is used in a wide variety of geotechnical engineering problems, including, but not limited to, the following:

- Determination of stable cut and fill slopes

- Assessment of overall stability of retaining walls, including global and compound stability (includes permanent systems and temporary shoring systems)

- Assessment of overall stability of shallow and deep foundations for structures located on slopes or over potentially unstable soils, including the determination of lateral forces applied to foundations and walls due to potentially unstable slopes

- Stability assessment of landslides (mechanisms of failure, and determination of design properties through back-analysis), and design of mitigation techniques to improve stability

- Evaluation of instability due to liquefaction

Types of slope stability analyses include rotational slope failure, translational failure, irregular surfaces of sliding, and infinite slope failure. Stability analysis techniques specific to rock slopes, other than highly fractured rock masses that can in effect be treated as soil, are described in Chapter 12. Detailed stability assessment of landslides is described in Chapter 13.

If groundwater varies seasonally, long-term monitoring of the groundwater levels in the soil should be conducted. If groundwater levels tend to be responsive to significant rainfall events, the long-term groundwater monitoring should be continuous, and on-site rainfall data collection should also be considered.

https://www.wsdot.wa.gov/publications/manuals/fulltext/M46-03/Chapter7.pdf to download full text