Proceedings of the XVIII ECSMGE 2024
GEOTECHNICAL ENGINEERING CHALLENGES
TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-677

ECSMGE 24
XVIII EUROPEAN CONFERENCE ON SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

Parametric study of stability in landfills due to changes in waste composition

Etude paramétriqueet de la stabilité dans les décharges dues aux changements dans la composition des déchets

H. Vučenović*, K. Herceg, D. Domitrović, Ž. Veinović
University of Zagreb Faculty of Mining, Geology and Petroleum Engineering, Zagreb, Croatia
**helena.vucenovic@rgn.unizg.hr*

ABSTRACT: The modern trend in waste management in most developed countries in Europe and the world is based on waste reduction, reuse and recycling, while landfilling is considered the least desirable method in the waste management process. Despite this trend, landfilling is still the leading method of waste disposal in most countries. Considering the increasing amount of waste, even if all methods to reduce the amount of waste are used, there will still be a need to build a landfill. Waste is a heterogeneous material whose physical, mechanical and chemical properties are highly dependent on the composition of the waste, so even minor changes in composition can affect the change in these properties. In Croatia, in the process of approaching European Union standards, the composition of disposed waste has changed significantly, primarily due to the fact that biowaste, plastic waste and paper are increasingly separated from total municipal waste. The separation of these constituents significantly affects the density, moisture and granulometric composition of the deposited waste, which in turn affects the stability and deformations of the landfill body itself, as well as the stability of the protective layer system. In this work, the effects of changes in the physical and mechanical parameters of the landfilled municipal waste on the stability of the landfill body were analyzed.

RÉSUMÉ: La tendance moderne en matière de gestion des déchets dans la plupart des pays développés d'Europe et du monde est basée sur la réduction, la réutilisation et le recyclage des déchets, tandis que la mise en décharge est considérée comme la méthode la moins souhaitable dans le processus de gestion des déchets. Malgré cette tendance, la mise en décharge reste la principale méthode d'élimination des déchets dans la plupart des pays. Compte tenu de la quantité croissante de déchets, même si toutes les méthodes visant à réduire la quantité de déchets sont utilisées, il sera toujours nécessaire de construire une décharge. Les déchets sont des matériaux hétérogènes dont les propriétés physiques, mécaniques et chimiques dépendent fortement de leur composition, de sorte que même des changements mineurs dans leur composition peuvent affecter l'évolution de ces propriétés. En Croatie, en voie de se rapprocher des normes de l'Union européenne, la composition des déchets éliminés a considérablement changé, principalement en raison du fait que les biodéchets, les déchets plastiques et le papier sont de plus en plus séparés des déchets municipaux totaux. La séparation de ces constituants affecte de manière significative la densité, l'humidité et la composition granulométrique des déchets déposés, ce qui à son tour affecte la stabilité et les déformations du corps de décharge lui-même, ainsi que la stabilité du système de couches protectrices. Dans ce travail, les effets des changements dans les paramètres physiques et mécaniques des déchets municipaux mis en décharge sur la stabilité du corps de la décharge ont été analysés.

Keywords: Landfill; MSW; kitchen waste; stability.

1 INTRODUCTION

Municipal solid waste (MSW) landfills are still a necessary part of the MSW management system although the current, modern waste management, requires minimization of the amount of mixed waste which is to be disposed at landfills (Puntarić et al., 2023). The 3R principle (*reduce, reuse, recycle*), and especially the intensive separate collection of waste, will certainly reduce the quantities of waste ending up at the landfill thus affecting the characteristics and properties of the disposed waste which will in turn affect the stability of landfill (Gomes et al., 2013; Singh & Uchimura, 2023). There is an open question: if the large, old landfill which is being filled for a couple of decades with the mixed MSW, starts receiving different waste material, with less glass, plastics, metals, and biodegradables, what will change considering geomechanical properties of the disposed material and the stability of the landfill? To answer that question, it is necessary to quantify the reduction of certain waste components and either measure or assess changes in the properties of waste.

Construction of Prudinec, the MSW landfill for the city of Zagreb, Croatia, begun in 1995 with the preparation of the new disposal surface and the construction of the bottom protective layer system (BPLS), on which a part of the old waste was transferred from an insanitary dumpsite in the immediate vicinity, as well as the newly collected waste (Budiša et al., 2014). A mixture of old and fresh waste was disposed of on the new prepared location, until 2003 when the disposal of only fresh MSW begun (Budiša et al., 2014). Separate waste collection in the city of Zagreb begun in 2002 (Fundurulja, 2009) and in the period 2002-2018 there was gradual increase of the separate waste collection of plastics, metals, glass, paper, and textile. According to the Companies Act (City of Zagreb, 2018) from the January 30th 2018, separate collection of the mixed plastic and metal waste. On September 23rd 2022 a decision was made by the Zagreb Holding, company which was incorporated in 2007 in line with the Companies Act and is 100% owned by the City of Zagreb, according to which mixed MSW must be collected in "blue bags" whose purchase price is 1,06€/40 l (Zagreb Holding, 2022). Therefore, since the September of 2022 collected and landfilled mixed MSW has a reduced amount of paper, metal, plastics, and compostable waste.

Changes in the composition of waste by removing compostable materials (unused cooked food is still being collected as a part if the mixed waste), plastic and metal, paper and cardboard, are reflected by changes in cohesion, angle of the internal friction, density, water content and other parameters (Gomes et al., 2013; Singh & Uchimura, 2023). Taking into consideration these changes it can be concluded that the stability of the Prudinec landfill might be changed, and the possible changes and effects are addressed in this paper.

2 THE MSW LANDFILL SITE PRUDINEC

Modern landfills are designed to protect human health and the integrity of the environment by controlling water and air emissions. The engineered protective systems incorporate advanced design features, including multi-layered liner construction, gas extraction and leachate removal systems.

The landfill site Prudinec is located on the southern bank of the Sava River, today, in the City of Zagreb. The decision to open dumpsite was made back in 1964.

The current Prudinec landfill is divided into cells 1 to 6, the area of each cell varies between 6 and 9 ha. The landfill has an almost rectangular shape with a length of approx. 1400 m and a width of approx. 450 m.

2.1 Landfill protective layers

An approx. 8 m high berm construction were erected at the foot of the deposited waste. The BPLS consists of 1 m thick clay layer and a 2.5 mm thick geomembrane as a barrier layers, above which a protective geotextile, a 0.5 m thick drainage layer for leachate collection and a filter geotextile are placed. The clay protective layer consists of highly plastic clay (Vukelic et al. 2004).

The final protective layer system of the landfill consists of gas drain composite, GCL and geomembrane, water drainage composite for the drainage of precipitation water, 0.85 m thick protective soil layer and 0.15 m thick humus layer. The membrane is only used in the upper part of the landfill, on the slopes only GCL is used as a barrier layer.

2.2 Historical instabilities of landfill site Prudinec

Slope stability analyses of municipal solid waste landfills are important to determine a safe landfill height and slopes inclination.

In August 2002, a localised landslide of the mentioned landfill was observed on the south side of landfill at the contact between the cover protection layer and the berm. The estimated affected area of the landslide was approximately 50 m long and 140 m wide. It had spread an estimated 100,000 m^3 of waste.

The field investigations carried out showed that the waste deposited in the area of the landslide did not differ in content and characteristics from the waste deposited elsewhere in the landfill. These were large quantities of old inert waste consisting of deposited municipal waste, soil and construction waste. As part of a field investigation, the leachate height was measured at the top of the bottom barrier layer in wells. The height of the leachate varied from 0.7 m to 11.5 m (Vukelic et al. 2004). In determining the cause of the landslide, other factors were also taken into account, such as the composition and properties of the protective layers and waste, the contacts of the layers and the performance and construction control of the landfill design.

The planning of a MSW landfill requires an appropriate characterization of the mechanical properties of the waste it contains. This is often very difficult due to the heterogeneity and highly variable composition of the waste. However, this is necessary to accurately assess the slope stability of the landfill and the interaction of the waste with other landfill

structures such as liners and gas and leachate collection systems (Gomes et al. 2013).

2.3 The impact of waste composition on landfill stability

In addition to the geometry, parameters such as compaction effort, pore pressure, protective layers, etc., the stability of the landfill is significantly influenced by the composition of the waste. Therefore, knowledge of the waste composition is generally one of the most valuable factors for estimating the properties of municipal waste (Cho et al. 2011; Jahanfar et al. 2017).

The changes that have occurred in recent years because of the introduction of a new waste separation and disposal policy can be seen, among other indicators, primarily in changes in waste parameters, unit weight, cohesion, and the friction angle. These changes certainly have an impact on the stability of the landfill slope. Based on these assumptions, an analysis of the effects of the change in strength parameters on the stability of the landfill slope and the safety factor was carried out.

The quantity of individual components such as paper, glass, plastic and biowaste previously made up a large proportion of municipal waste. Between 2002 and 2018, this composition gradually changed and is now significantly different. According to this trend, it is assumed that since the end of 2022 the proportion of plastic, paper, glass and metal has largely decreased and therefore the largest proportion of the total composition of municipal waste is kitchen waste. For this reason, it is assumed that the geotechnical parameters of the waste have also changed as a result of this change, which has an impact on the stability of the landfill.

For the numerical analysis of stability, it was necessary to collect data for the protective soil layers and the waste at the landfill. Certain materials in MSW are continuously degraded over time by various chemical and biological processes, while the properties of some materials do not change (Štefanák and Chalmovský 2022; Machado et al., 2002). For this reason, it was necessary to use parameters corresponding to a specific composition of the waste.

3 NUMERICAL MODEL

For the slope stability analysis of the landfill, a model with dimensions of 306 m width and 77 m height was created. The geometry of the landfill is simplified and consists of a subsoil, protective layer, drainage layer, dyke on the edge of the waste layer and the waste layer. The slope stability analysis of the model was carried out using Plaxis and soil and waste material were modelled using the Mohr-Coulomb model. The analysis was carried out for three proportions of kitchen waste in municipal waste, in percentages of 10%, 30% and 60%. The input parameters for waste were obtained from previous experimental studies (Cho et al. 2011; Ivšić et al. 2004). The material properties of the soil layers were taken from studies describing the Prudinec landfill (Kovačević Zelic et al. 2002, Vukelic et al. 2004). Geotechnical parameters are presented in Table 1.

Table 1. Geotechnical parameters.

Parameter	Unit weight (kN/m^3)	Friction angle (°)	Cohesion (kN/m^2)
Subsoil	18	32	10
Drainage layer	18	30	0,3
Sealing layer	19	21	24
Dyke	19	24	15
Kitchen waste 10%	8	33	5
Kitchen waste 30%	9	26	6
Kitchen waste 60%	10	17	7

3.1 Results of numerical analysis

The numerical analysis was performed for different percentages of kitchen waste in the waste composition. Three cases were modelled with 10%, 30% and 60% of kitchen waste in the composition of municipal waste (Figure 1).

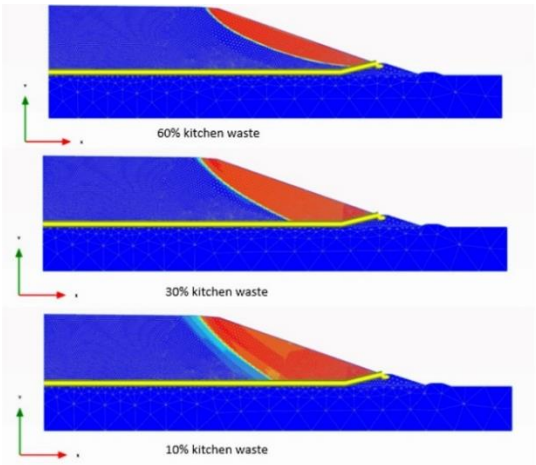

Figure 1. Failure planes for different amount of kitchen waste – 10%, 30% and 60%.

The results of the numerical analysis show that as the proportion of kitchen waste increases, the safety factor decreases and the slip surface is shallower (Figure 2).

For waste with a low proportion of kitchen waste, the contact layers in the lower sealing layer have the greater influence and the sliding surface runs largely

through the contact of these layers. For waste with a low proportion of kitchen waste, the contact layers in the lower sealing layer have the greater influence and the sliding surface runs largely through the contact of these layers. For waste with a higher proportion of kitchen waste, the probability of a sliding surface forming in the landfill body itself is higher.

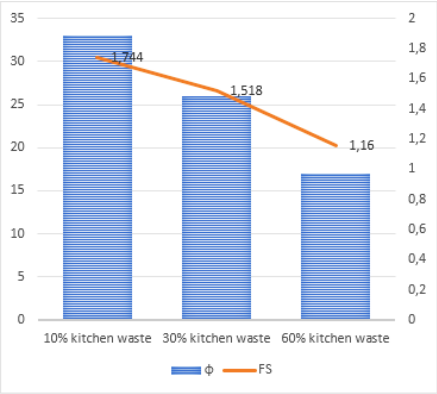

Figure 2. Change of the factor of safety with the change in the proportion of kitchen waste and friction angle of waste.

4 CONCLUSIONS

The stability of the landfill depends largely on the mechanical properties of the waste and the protective layer system. In contrast to the material parameters of the protective layers, the waste parameters change considerably over the years, not only due to the aging of the waste, but also due to changes in the composition of the deposited waste. Due to frequent changes in the waste management policy, the composition of the waste has changed significantly during the operational life of the Prudinec landfill. The composition of waste with the largest proportion of paper and plastics has now been replaced by waste with the largest proportion of kitchen waste. These changes mainly affected the reduction of the friction angle and, to a lesser extent, the reduction of cohesion. The results of the numerical analysis show that such a change has a significant effect on the reduction of the safety factor and the stability of the landfill. It can be concluded that the selection of relevant waste parameters and protective layer system is very important when assessing the overall safety of a landfill.

During the writing of this article, two landslides occurred at the Prudinec landfill. The first smaller one occurred in mid-November 2023 after a short but very intense period of rainfall. According to initial estimates, the area affected by this landslide was around 100 metres wide and 30 metres high. The second occurred in early December 2023 in the early morning when the air temperature was around -5 °C.

This landslide affected a significant part of the eastern side of landfill.

REFERENCES

City of Zagreb (2018). Act on the method of providing the public service of collecting mixed municipal waste and biodegradable municipal waste and services related to public service in the City of Zagreb, 2/2018, Official Act by the City Assembly of the City of Zagreb, Croatia.

Zagreb Holding (2022). Decision on the collection of municipal waste in the center of the city of Zagreb Zagreb holding, Zagreb, Croatia.

Cho, Y. M., Ko, J. H., Chi, L., and Townsend, T. G. (2011a). "Food waste impact on municipal solid waste angle of internal friction." Waste Manage., 31(1), 26–32.

Budiša, M., Burela, S., Šeparović, M., Končurat, L. (2014). Technical – technological solution of the existing waste disposal facility Prudinec/Jakuševec ECOINA, Zagreb, Croatia, Rep. 1.

Fundurulja, D. (2009). A combination of tradition and interesting solutions (original title: *Spoj tradicije i zanimljivih rješenja*, in Croatian). FONDEKO svijet – Naučno popularna revija o prirodi, čovjeku i ekologiji, 29, pp. 23-25.

Gomes, C, Lurdes Lopes, M. Venda Oliveira, P. J. (2013). Municipal solid waste shear strength parameters defined through laboratorial and in situ tests, *Journal of the Air & Waste Management Association*, 63(11), 1352-1368, http://doi.org/10.1080/10962247.2013.813876.

Ivšić, T., Petrović, I. i Verić, F. (2004). Overview of parameters for stability analysis on waste disposal sites, Građevinar, 56 (11.).

Jahanfar, A.; Gharabaghi, B.; McBean, E.; Dubey, B. (2017). Municipal Solid Waste Slope Stability Modeling: A Probabilistic Approach. Journal of Geotechnical and Geoenvironmental Engineering. 143. http://doi.org/10.1061/(ASCE)GT.1943-5606.0001704.

Kovačević-Zelić, B.; Kvasnička, P.; Domitrović, D.: Stability Analysis for the Landfill Jakusevec, Proceedings of the 12TH; Danube-European Conference, Passau, 27-28 May 2002., pp. 503-506.

Puntarić, E., Požgaj, Đ., Korica, Ž., Gumhalter Malić, L., Kušević-Vukšić, M., Bulat, V., Vešligaj, G., Krivanek, G. (2023). Report on municipal waste for 2022, Croatian Ministry of Economy and Sustainable Development, Zagreb, Croatia, Rep. 1.

Singh. V., Uchimura, T. (2023). Effect of Material Composition on Geotechnical Properties—Study on Synthetic Municipal Solid Waste, *Geotechnics*, 3, 397-415, https://doi.org/10.3390/geotechnics3020023.

Zagreb Holding (2014). Waste disposal plan on the cell 5d and 6 Zagreb holding, Zagreb, Croatia.

Vukelić, A, Kovačević Zelić, B. and Drnjević, B. (2004). "Landslide at the Jakusevec landfill." Geotechnical Engineering with Geosynthetics, eds. Floss, R., Brau, G., Nussbaumer, M. and Laackmann, K.. München, DGGT, 2004. 87-9.