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Numerical model of MSW landfill stability after change in waste composition

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Abstract

Municipal waste management in Europe has evolved over the last two decades. Today, more emphasis is placed on prevention and recycling than on disposal. Despite increasing awareness, progress and new methods in waste management, the total amount of waste continues to increase. For this reason, there will continue to be a need for landfilling. Landfills are designed, constructed, managed and monitored to ensure compliance with government regulations. They are also designed to protect the environment from contaminants that may be present during and years after disposal. For this reason, the waste is deposited in the landfill between the upper and lower protective layers, which fulfil the function of sealing, drainage, separation and protection. The stability of the landfill is influenced by many factors, but the shear strength parameters play the biggest role. Considering the fact that the waste is a heterogeneous material and occupies the largest volume of the landfill, the shear strength parameters of the waste are of utmost importance for the stability of the landfill. In order to develop a numerical model of the landfill, suitable strength parameters for the waste as well as parameters for other layers in the landfill must be selected in the first place. In recent years, the management policy in Croatia has been gradually adapted to the European directives, which changes the composition of the waste. The components paper, plastic, glass and biowaste are separated from the waste, which significantly affects the density, moisture and granulometric composition of the landfilled waste. All of this affects the stability and deformation of the landfill body itself and the stability of the protective layer system. In this paper, a numerical model of the landfill was developed and the changes in the stability of the landfill body due to changes in the composition of the municipal waste were analysed

Keywords: landfill, stability, shear strength parameters, waste composition

1. Introduction

No matter which principles, methods and technologies are, and will be, used for municipal solid waste (MSW) management, landfills will remain a necessary part. Though the current, modern waste management, requires minimization of the amount of mixed waste which is to be disposed at landfills (**Puntarić et al., 2023**), and no matter how intensive 3R principle (*reduce, reuse, recycle*) and incineration (e.g.) are used, there will always remain something to be disposed of in some kind of landfill. Intensive separate collection of MSW, done in order to facilitate recycling, will result in a reduction of amounts of MSW which is to be disposed of at landfill, however, separate collection will also affect geomechanical properties of MSW, thus affecting stability of landfill (**Gomes et al., 2013; Singh & Uchimura, 2023**).

One of specific problems related to landfills which were operating before and after a decision of separate collection was made, or intensified, is – how one object constructed with two significantly different materials will perform, and which consequences can be expected? Also, there is always an issue of technology – how will the transition from one material to another be organized in sense of material emplacement? One material is mixed MSW with minimal amount of recyclable components removed, and other is significantly different kind of material with less glass, plastics, metals, and biodegradables. Again, the question is: what will change considering geomechanical properties of the disposed material and the stability of the landfill? To give a proper answer to that question, the reduction of certain waste components must be quantified, and from that either calculated and assessed or measured real changes of geomechanical properties of MSW.

While working on the publication preceding this one (**Vučenović et al., 2024**), which was dealing with the parametric study of stability in landfills due to changes in waste composition, an accident happened at the Zagreb's (capital of the Republic of Croatia) landfill. Likely, but still unconfirmed and unproven, the reason is either change in geomechanical properties of waste material due to intensive separate collection, or unadjusted disposal technology, or high level of leachate. Whether the real reason for landslide occurrence is either one or combination of all above mentioned potential causes, change in the composition of waste related to amounts of certain materials, will definitely change properties of waste being disposed of, and hence the disposal technology is supposed to be adjusted (geometry and high of layers, number of compaction cycles, rate of disposal, etc.).

Prudinec, Zagreb's MSW landfill, was formed in 1965 as an illegal dumpsite, at the location of old gravel and sand exploitation. In 1995 started a remediation of the site which included the preparation of the new disposal surface and the construction of the bottom protective layer system (BPLS). Simultaneously both, the old waste from the original dumpsite and a fresh waste collected at the time in Zagreb, were disposed of at the newly prepared disposal surface (**Budiša et al., 2014**). In 2003 all the existing waste from the dumpsite was dealt with and the disposal of only fresh waste begun.

Separate waste collection in the city of Zagreb intensively begun in 2002 (**Fundurulja, 2009**) and in the period 2002-2018 there was a gradual increase of the separate waste collection of plastics, metals, glass, paper, and textile. According to the "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" (**City of Zagreb, 2018**), from the January 30th, 2018, separate collection of the mixed plastic and metal waste, in yellow bags provided by city, and the compostable materials, in also provided brown biodegradable bags, become mandatory. Paper and container glass were separately collected, but at a smaller intensity, since the 80's. On September 23rd, 2022, a decision was made by the *Zagreb Holding*, city owned company, according to which mixed MSW must be collected in "blue bags" whose purchase price is 2,6 €/10 pcs of 10 l bag; 5,3 €/10 pcs of 20 l bag and 10,6 €/10 pcs of 40 l bag (**Zagreb Holding, 2022**). The intensity of separate collection of paper also increased somewhat with the introduction of a larger number of bins and containers for wastepaper, while the separate collection of waste container glass, textiles and other components carried on in the same manner as previously. The quantities of separated container glass and textile certainly has increased, but in large part due to the increase in the total amount of produced waste in the city of Zagreb (**Puntarić et al., 2023**). Therefore, since the September of 2022 collected and landfilled mixed MSW has a reduced amount of paper, metal, plastics, and compostable (NOT all biodegradable) waste.

Variations in the composition of waste, due to removing compostable materials, plastic and metal, paper and cardboard, reflects in changes in cohesion, angle of the internal friction, density, water content and some other parameters (**Cho et al., 2011; Gomes et al., 2013; Singh & Uchimura, 2023**). For that reason, this paper gives different solutions of numerical models of sliding a MSW landfill slopes due to a change in waste composition, and hence changes in geomechanical properties.

2. The MSW landfill site Prudinec

Landfills are constructions which are designed as to contain MSW and products of its decomposition, with an option of controlled release of landfill gases and leachate through the system for their treatment and management. In that way the environment is protected from the harmful effects of materials contained in landfill (Vucenovic et al., 2017). The engineered protective system of landfill include:

- surface protective layer system: SPLS (top cover);
- bottom protective layer system: BPLS (bottom screen);
- gas extraction and management system and
- leachate removal and management system.

The Prudinec landfill (colloquially known as the "Jakuševec landfill") is situated in the south-eastern part of the City of Zagreb, on the southern bank of the Sava river, not far from the ornithological reserve Savica, system of lakes artificially made as the as a result of gravel exploitation nearby the Sava River. In 1965 the dumpsite Jakuševec was also constructed in one of depressions made by gravel excavation. Therefore, not only that the dumpsite and later landfill is located nearby the river but in the river alluvium, with the direct contact of Zagreb's aquifer. From 1965 till 1995 waste was disposed of inadequately and without protective layer systems. Work on the reclamation of the dumpsite began in 1995 with the construction of "cell 1" (**Fig. 1**), prepared surface in the immediate vicinity of the dumpsite where old waste was disposed of. The remediation was completed in 2003 with the construction of cell 5 and the transfer of the remaining old waste to a new disposal surface. In all, 7 000 000 m^3 of old waste was relocated. The fresh waste was deposited in cells 4 and 5, and today the waste is being deposited in the cell 6. The average volumetric weight of the waste of 0.8 t/m^3 is assumed (**Vukelić et al. 2004; Budiša et al., 2014; Vujević et al., 2014**).

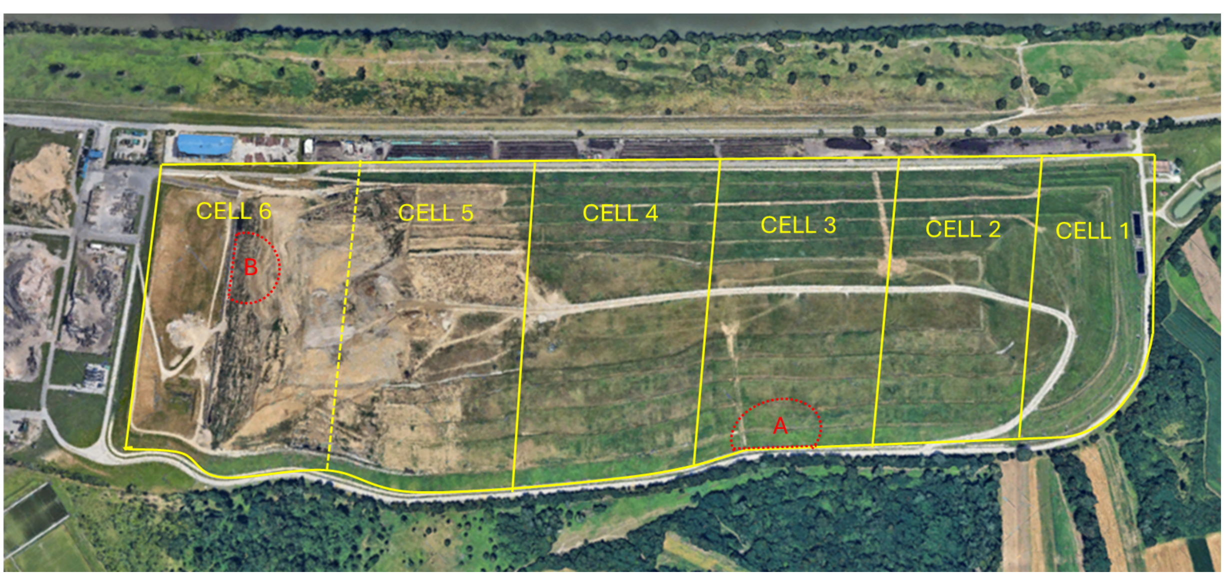

Figure 1: Satellite image of the Prudinec landfill with disposal cells (1-6), and failures (A & B) marked (Google maps, 2024).

Today, the cell No. 6 is being filled, and the size (area) of cells 1-6 vary between 6 and 9 ha. The footprint of the landfill is 1400 m and a width of approx. 450 m. The lower level of the landfill is on average 109.00 m above sea level, and the landfill body was designed for a final height of approx. 155.00 m above sea level, with the actual height of 46 m, and slopes with gradient 1:2.85.

Since the Prudinec landfill is located in the alluvium of the Sava River, the subsoil at the site of the landfill consists of gravel-sand mixtures with the gravel prevailing. When considering the profile of the site, with depth sand and sand-clay mixtures prevail. However, the very material in which the landfill is placed represents aquifer which extends from, practically, the surface to a depth up to 100 metres (**Nakić, 2003**). In the area of the Prudinec landfill, groundwater level is at 3 m. Apart from the mentioned issues, the fact that the landfill is within the city limits, nearest houses are located merely 400 m from the landfill, it is obvious that the location of the landfill is at least unfavourable.

2.1. Landfill protection layers

To form the landfill during the remediation, add to stability of the construction and help the installation of the protective layers, an 8 m high berm was constructed at the foot of the disposal cells. The BPL consists of 1 m compacted clay liner, 2,5 mm thick HDPE geomembrane (protected by geotextile), 0,5 m thick leachate drainage system and filter layer made of geotextile. Compacted clay liner is made with highly plastic clay with average values of w_L=55%, I_p=30% and w_{opt}=20% (**Vukelić et al., 2004**).

The SPLS consists of gas drain composite, geosynthetic clay liner (GCL), 2,5 mm HDPE geomembrane, water drainage composite for the drainage of precipitation water, 0.85 m thick protective soil layer (protection from the freezing of lower protective layers) and 0,15 m thick recultivating layer made of humus. The geomembrane is only used in the top part of the landfill's SPLS, on the slopes only GCL is used as a liner.

2.2. Historical instabilities

In August 2002, a localised slope failure on the south side of cell 3 occurred (Fig. 1). Failure happened on the contact between SPLS and the berm. The estimated affected area of the landfill was approx. 52 m long and 140 m wide, and the amount of the displaced waste was 100 000 m^3 (**Vukelić et al., 2004**)

Field investigation showed that the content of materials in waste that was affected did not differ from the waste deposited elsewhere in the landfill (**Vukelić et al., 2004**) it was a mixture of old municipal waste, soil and construction waste. It is important to point out that the leachate level was at the 0,7-11,5 m, measured from the top of the BPLS (**Vukelić et al., 2004**).

The second slope failure was observed in 2023 on the north side of cell 6, at the very place of current deposition of waste, after a brief but intense period of rain. This failure was more intensive than the first one, and hence received much intensive media coverage.

If "usual" reasons for slope failures at landfills are saturation of the waste material or protective layers materials with rainwater or leachate, next group of reasons is definitely related to geomechanical properties of waste and protective materials, e.g. poor compaction or composition related poor geomechanical properties or the geometry of landfill (the angle of the slope).

2.3. The impact of waste composition on landfill stability

The stability of a landfill slope depends on several factors, including geotechnical characteristics, slope geometry, hydrogeology, load distribution, sealing systems, monitoring and maintenance. In addition to the main causes of instability, climate change also influences landfill stability of landfills through changes in precipitation patterns, soil behaviour, erosion and sea level rise. In addition to the aforementioned influences, it is important to point out that the stability of the slope is significantly influenced by the properties of the waste material itself, namely: the composition of the waste (Singh & Uchimura, 2023; Cho et al. 2011; Jahanfar et al., 2017; Ivšić et al., 2004).As it was mentioned in the Introduction, the change of MSW that is being disposed of at the Prudinec, occurred in recent years as a result of the introduction of a new waste separation and disposal policy conditioned by European Commission. Change in the composition of wase affected the unit weight of waste, and thusly shear strength parameters of waste (cohesion and internal friction angle). These changes certainly had impact on the stability of the landfill slope, which was proved by research and numerical model presented in this paper.

As it was mentioned previously, the changes in waste management system in Zagreb (separate waste collection) began with implementation in 2002 and gradually increased until 2018. For this reason, 2018 was considered a turning point when the composition of waste began to change significantly.

The quantity of individual components e.g. paper, glass, plastic and biowaste, previously made up a large proportion of mixed waste which was disposed of in the landfill, however, the composition gradually changed to finally become significantly different from the one at the beginning of the disposal. It is therefore logical that the majority of newly disposed waste consists of kitchen waste (non-compostable biodegradable materials), which is actually processed food waste. The term processed food waste refers to all waste that is produced during the preparation of food and should not be disposed of in organic waste. This includes the remains of thermally processed food, meat, fish, bones, skin, dairy products, oils and fats, etc. Due to this, one can assume that the geomechanical parameters of newly disposed of waste would change the stability of landfill, especially if the geometry, disposal technology and control did not change as the composition of waste changed.

For the numerical analysis of stability, it was necessary to acquire parameters of the BPLS layers and the waste. All parameters were taken from previous investigations (**Vukelić et al., 2004; Kovačević Zelić et al. 2002.; Petrović et al. 2015; Cho et al. 2011**). For the subsoil, liners and drainage material, parameters are known and used in various previous analyses, but the parameters for municipal waste are in a very wide range, especially since the composition changed with time. The fact that the materials in MSW are continuously degrading and their parameters are being changed with time due to various chemical and biological processes, while the properties of certain materials (smaller amount in the mixture) do not change (**Štefanák & Chalmovský 2022; Machado et al., 2002**). For this reason, it was necessary to use parameters corresponding to a specific composition of the waste. Therefore, from several studies acquire parameters of the BPLS layers and the waste. All parameters were taken from previous investigations of the change in strength parameters depending on the waste material composition (**Cho et al. 2011; Singh 2023; Machado et al. 2002**) the parameters corresponding to the composition of the waste in Prudinec landfill, over a certain period of time were deduced and applied to numerical model.

3. Numerical model

The numerical analysis of the landfill stability was carried out using the finite element method. Plane strain models were created with Plaxis 2D 2024. Fifteen-noded triangular finite elements were used. The slope is analysed as a plane strain model. Displacements and strains in the z direction are assumed to be zero. The mathematical model was created with dimensions of 306 m width and 77 m height. The geometry of the landfill is simplified and consists of a subsoil, a protective layer, a drainage layer, dyke on the edge of the waste layer and the waste layer (**Figure**

2). The standard fixings are used to define the boundary conditions or are considered as standard boundary conditions. A medium coarse grain size was selected for the mesh generation.

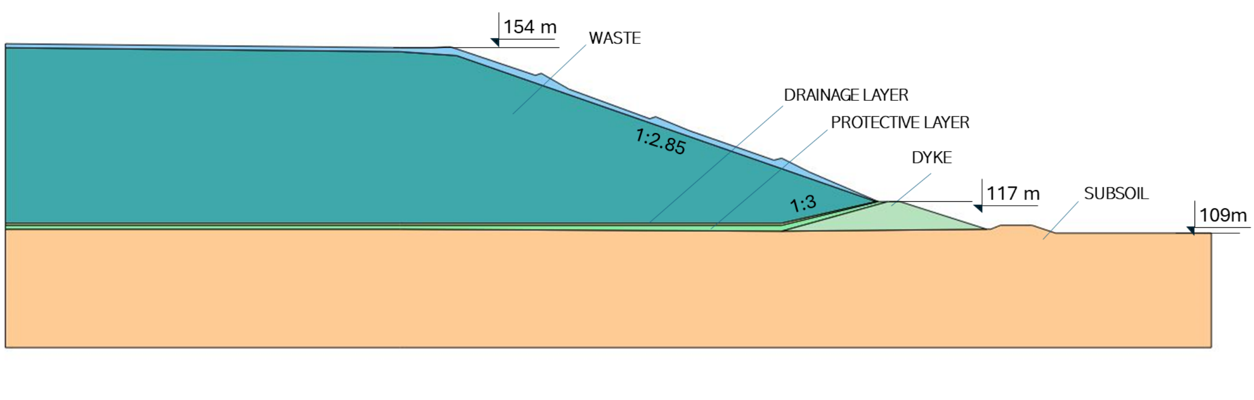

Figure 2: Prudinec landfill cross-section

The properties of the soil and the waste material were modelled using the Mohr-Coulomb model and stored in the material data set. In order to determine the influence of the proportion of processed food waste in the waste layer, the analysis was carried out for three proportions of processed food waste in the municipal waste: 10%, 30% and 60%.

The input parameters for the waste were obtained from previous experimental studies (**Cho et al. 2011; Ivšić et al. 2004**). The material properties of the municipal solid waste layers were selected based on the results of extensive statistical analyses of the strength parameters of MSW from studies describing the Prudinec landfill (**Petrović et al. 2015, Kovačević Zelić et al. 2002, Vukelić et al. 2004**). The geotechnical parameters are listed in **Table 1**.

Table 1: Geotechnical parameters

Parameter	Unit weight γ (kN/m^3)	Friction angle φ (°)	Cohesion c (kN/m^2)	Young's modulus E' (kN/m^2)	Poisson's ratio ν' -
Subsoil	18	32	10	40000	0.33
Drainage layer	18	30	0.3	30000	0.3
Sealing layer	19	21	24	10000	0.3
Dyke	19	24	15	12000	0.3
Processed food waste 10%	8	33	5	3000	0.33
Processed food waste 30%	9	26	6	2500	0.33
Processed food waste 60%	10	17	7	2500	0.33

The calculation was carried out in stages. In the initial phase all existing layers are defined, in the first phase plastic analysis is defined and in the second phase the safety analysis begins. In the Safety approach the shear strength parameters *tan φ* and *c* of the soil as well as the tensile strength are successively reduced until failure of the structure occurs. If that is the case, the factor of safety is given by **Eq. 1**:

$$SF = \frac{\tau_f}{\tau} \quad (1)$$

Where are:
SF - Safety factor
τ_f – available strength (kN/m^2),
τ – strength at failure (kN/m^2),
The principal results of a Safety calculation are the failure mechanism and the corresponding ΣM_{sf}, which is the safety factor (**Plaxis, 2020**).

4. Results of numerical analysis

In the stability analysis, the results are presented in graphical and numerical form. The graphical form is a slip surface, which is selected as the critical slip surface, and indicates the smallest safety factor, which is determined numerically from the previously mentioned expression.

The numerical analysis was performed three times The same model with the corresponding layers and parameters was used for each individual calculation, whereby the layer with the municipal waste was replaced by a different proportion of processed food waste. Three cases were modelled with 10%, 30% and 60% of processed food waste in the composition of municipal waste (**Figure 3**).

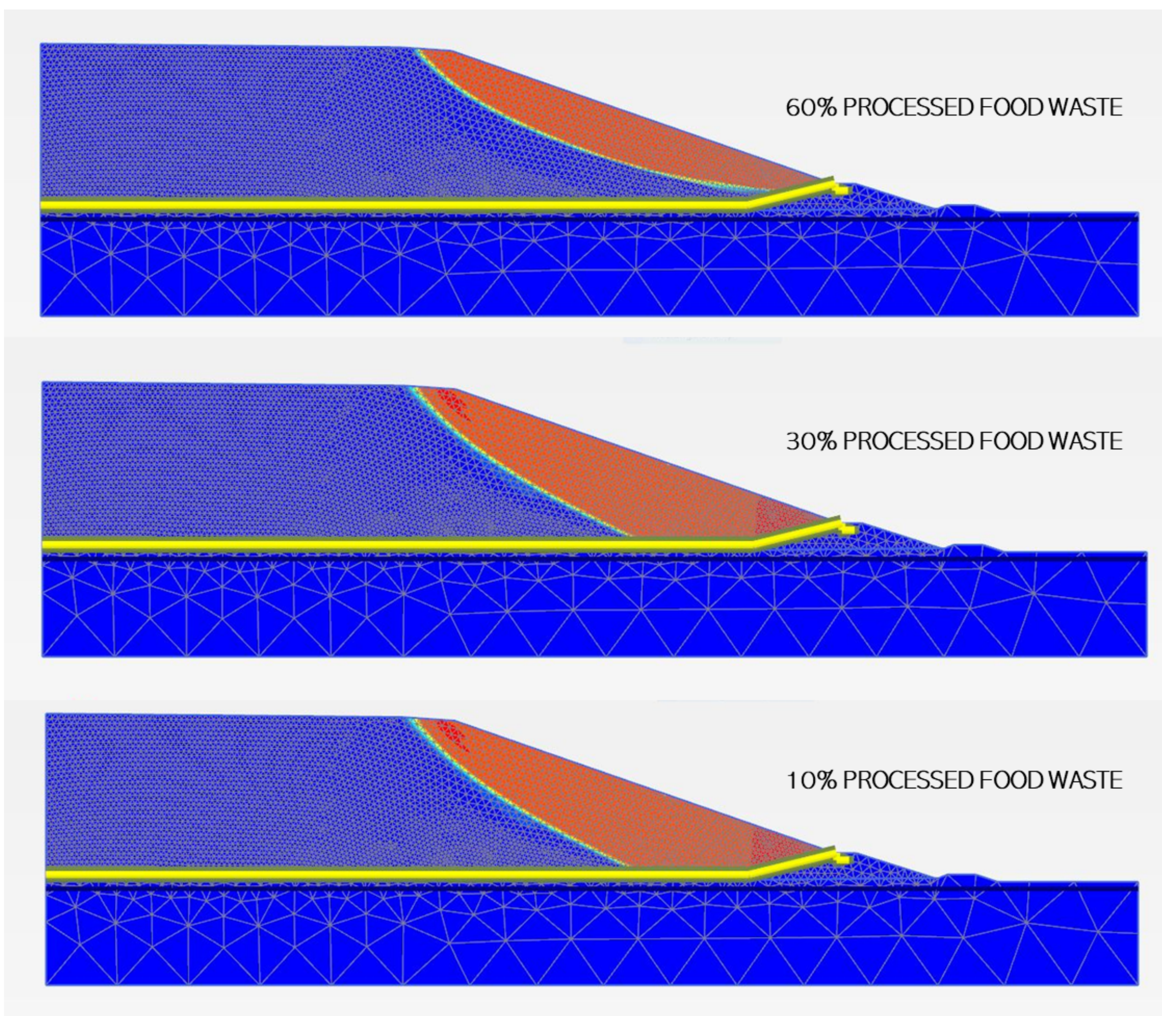

Figure 3: Failure planes for different amount of processed food– 10%, 30% and 60% (from PLAXIS software)

The results of the numerical analysis show that as the proportion of processed food waste increases, the safety factor decreases and the slip surface is shallower, as shown in **Figure 4**.

Figure 4: Change in the factor of safety due to the change in the proportion of the processed foodwaste and the friction angle of the waste

In the model in which the waste layer contains a low proportion of kitchen waste, the layers in the lower sealing layer have a greater influence and the sliding surface occurs mainly at the contact points of these layers. For waste with a higher proportion of processed food waste, the probability of a slip surface forming in the landfill body itself is higher.

5. Conclusions

The stability of municipal solid waste landfills depends largely on the mechanical parameters of the waste and the protective layers. The mechanical properties of the waste, in particular the internal friction angle and cohesion, depend on its composition. These parameters vary greatly and change over time as the waste ages. For this reason, the numerical analysis of the slope stability of the landfill requires a careful selection of parameters.

With the change in waste management policy over the last two decades, the composition of waste has also gradually changed. Waste with the largest proportion of plastic and paper has now been replaced by waste with the largest proportion of processed food waste. Since paper and plastic, due to their fibrous composition, fulfilled the function of reinforcement, the composition of today's waste has changed considerably.

The results of the numerical analysis carried out in Plaxis show that the change in the composition of the waste significantly affects the reduction of the safety factor and therefore the stability of the landfill slope. In order to select the parameters that define the model, it is important to continuously collect data on the composition of the waste as well as research results from measurements of waste samples at landfills. It can be concluded that the selection of the relevant waste parameters and the protective layer system is very important when creating a mathematical model for assessing the overall safety of the landfill.

This paper also shows how a change in waste management policy can affect the change in strength parameters, which ultimately affects the stability of the landfill slope. For these reasons, it is particularly important to continuously collect and monitor direct data and take appropriate measurements at landfill sites in order to recognise changes that may result in undesirable consequences.

6. References

1. 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.
2. 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.
3. Cho, Y. M., Ko, J. H., Chi, L., and Townsend, T. G. (2011): "Food waste impact on municipal solid waste angle of internal friction." Waste Manage., 31(1), 26–32.
4. 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.
5. 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.
6. Ivšić, T., Petrović, I. i Verić, F. (2004): Overview of parameters for stability analysis on waste disposal sites, Građevinar, 56 (11.).
7. 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.
8. Kovačević-Zelić, B.; Kvasnička, P.; Domitrović, D. (2002): Stability Analysis for the Landfill Jakusevec, Proceedings of the 12TH; Danube-European Conference, Passau, 27-28 May 2002., pp. 503-506
9. Machado S.L., Carvalho M.F., and Vilar O.M. (2002) Constitutive Model for Municipal Solid Waste, Journal of Geotechnical and Geoenvironmental Engineering, Volume 128, Issue 11, https://doi.org/10.1061/(ASCE)1090-0241(2002)128:11(940)
10. Petrović, I; Hip, I; Fredlund, M (2016): Application of continuous normal–lognormal bivariate density functions in a sensitivity analysis of municipal solid waste landfill // Waste management, 55, SI; 141-153 doi:10.1016/j.wasman.2015.11.021
11. PLAXIS (2020): PLAXIS 2D Reference Manual, Bentley Systems International Limited, Dublin.
12. 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.
13. 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.
14. Štefaňák, J.; Chalmovský, J. (2022): Assessment of the Landfill Barrier System through Numerical Analysis: Rehabilitation and Expansion of Belgrade Landfill Case Study. Sustainability 2022, 14, 7647. https://doi.org/10.3390/su14137647

15. Vučenović, H., Herceg, K., Domitrović, D., Veinović, Ž. (2024): Parametric study of stability in landfills due to changes in waste composition, Proceedings of the XVIII European Conference On Soil Mechanics and Geotechnical Engineering in Lisbon, Portugal, 26-30 August 2024.
16. Vučenović, H., Domitrović, D. i Kovačević-Zelić, B. (2017): Gas permeability of geosynthetic
17. clay liners. Rudarsko-geološko-naftni zbornik, 32 (1), 7-16. https://doi.org/10.17794/rgn.2017.1.2
18. Vujević, D., Čalopek, M., Novosel, M., Anić Vučinić, A., (2014): Sastav odlagališnog plina na odlagalištu Prudinec/Jakuševec // Environmental engineering = Inženjerstvo okoliša, 1; 33-41.
19. 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
20. Zagreb Holding (2022): Decision on the collection of municipal waste in the center of the city of Zagreb Zagreb holding, Zagreb, Croatia.
21. Zagreb Holding (2014): Waste disposal plan on the cell 5d and 6 Zagreb holding, Zagreb, Croatia.

SAŽETAK

Numerička simulacija odlagališta komunalnog otpada uslijed promjene sastava otpada

Gospodarenje komunalnim otpadom u Europi znatno se razvilo u posljednja dva desetljeća. Međutim danas se veći naglasak stavlja na prevenciju i recikliranje nego na zbrinjavanje otpada. Unatoč sve većoj svijesti, napretku i novim metodama gospodarenja otpadom, ukupna količina otpada i dalje raste. Iz tog razloga će i dalje postojati potreba za odlaganjem otpada. Odlagališta otpada trebala bi biti projektirana, izgrađena, upravljana i nadzirana u skladu sa državnim propisima. Također bi se trebala projektirati kako bi se očuvao okoliš i kako bi se zaštitilo od štetnih utjecaja koja mogu biti prisutna tijekom odlaganja i godinama nakon zatvaranja odlagališta. Zbog toga se otpad na odlagalištu odlaže između gornjeg i donjeg zaštitnog sloja koji ispunjavaju funkciju brtvljenja, odvodnje, filtriranja i zaštite. Na stabilnost odlagališta utječu brojni čimbenici međutim najveću ulogu u tome imaju parametri čvrstoće. Obzirom da je otpad heterogen materijal i da zauzima najveći volumen odlagališta, parametri čvrstoće otpada su od primarne važnosti za stabilnost odlagališta. Za razvijanje numeričkog modela odlagališta primarno je odabrati odgovarajuće parametra čvrstoće za otpad kao i parametre za ostale slojeve na odlagalištu. U Republici Hrvatskoj se proteklih godina politika gospodarenja postupno prilagođava europskim smjernicama, a time se mijenja i sastav otpada. Iz otpada se odvajaju komponente papira, plastike, stakla i biootpada sto bitno utječe na gustoću, vlažnost i granulometrijska sastav odloženog otpada. To sve pak utječe na stabilnost i deformacije samog tijela odlagališta, kao i na stabilnost sustava zaštitnih slojeva. U ovom radu razrađen je numerički model odlagališta otpada te su analizirane promjene stabilnosti tijela odlagališta uslijed promjene sastava komunalnog otpada.

Ključne riječi: odlagalište, stabilnost kosina, parametri posmične čvrstoće, sastav otpada

Author's contribution

Helena Vučenović (1) (Asisstant professor) preformed conceptualization, methodology, numerical modelling, data collection, writing - original draft. **Želimir Veinović (2) (**Associate professor) preformed methodology, visualization, data collection, writing - original draft. **Dubravko Domitrović (3) (**Associate professor) preformed data collection, visualization, writing - original draft. **Karolina Herceg (4) (**Asisstant professor) preformed data collection**,** numerical modelling - original draft.