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GEOTECHNICAL EFFECTS OF MUNICIPAL SOLID WASTE DESTRUCTION WITH DIFFERENT COMPACTION METHODS

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Abstract

Disposal of waste in municipal solid waste landfills is the only way of waste disposal in Serbia, with daily compaction and covering with soil material. Due to less space for the construction of new landfills, it is necessary to use their maximum capacity. Well-compacted municipal solid waste takes up less volume and enables safer storage, so it is useful to previously determine the compaction parameters in the laboratory: maximum dry unit weight (γ_{dmax}) and optimal water content (w_{opt}). In the practice so far, the standard method has been used to obtain these parameters (Proctor compaction test) which is common in soil mechanics. However, although this methodology has been adopted, different treatments of municipal solid waste at the landfill (including pre-treatment) indicate the need to change this classical approach. Therefore, during the research, various innovative solutions are introduced, such as the change of the classic flat Proctor hammer, by adding spikes, whose function, in addition to compaction, is partial destruction and shredding of municipal waste. In this way, the operation of compactors (hedgehogs) in the field is simulated. The paper presents the behaviour of four artificially prepared samples of municipal solid waste of different composition. The samples were tested in the standard Proctor apparatus at the same compaction energy, using different hammers,

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a standard flat hammer, and an innovative hammer with spikes. After that, the geotechnical effects of compaction depending on the applied approach were analyzed.

Key words: municipal solid waste landfill, compaction, Proctor compaction test, hammer with spikes

Introduction. Despite numerous activities in the world that have been undertaken to reduce the generation of municipal solid waste, its quantities continue to grow annually. In Serbia, landfilling is the basic method of waste disposal. Although according to the waste hierarchy it is considered the most unfavourable solution, in the same time landfilling is often not in accordance with the relevant regulations and standards. It is common that official landfills do not meet basic sanitary requirements. About 60–70% of municipal solid waste is collected, while the rest ends up in illegal landfills (dumps) that are often along river banks, which in the long run lead to environmental problems and even their frequent pollution. Although the so-called "landfill-free concept" is slowly introduced in the world, in less developed countries it is completely absent. For these reasons, the reduced choice of locations leads to the need for maximum utilization of existing, but also the construction of new landfills for municipal solid waste.

A landfill is most often defined as a "waste disposal site". However, regardless of that, it certainly represents a structure that, with accompanying facilities, which, in addition to economic and environmental aspects, should also meet the general technical requirements for construction [1]. Due to the heterogeneity in the composition and size of the components, each of the storage processes must be specially prepared and monitored. Compaction is one of the basic phases of waste storage. In parallel with it, the physical and mechanical characteristics of the waste change (shear strength, deformability, water permeability). Compaction of waste with optimum water content results in increased workability, compaction conditions, change in unit weight and amount of waste that can be disposed (increase in landfill capacity), with a reduction in compaction time [2]. In order to maximally use the landfill capacity, it is necessary to determine the maximum dry unit weight (γ_{dmax}) and the optimum water content (w_{opt}) in laboratory. These data are increasingly encountered in the world literature. The authors mostly used standard methods [3,4] to determine the compaction parameters of municipal solid waste [2,5–15], with an eventual reduction of compaction energy. By analyzing the literature, different conclusions are obtained, with a noticeably large range of results. Optimum water content (w_{opt}) varies in the range of 10–160%. The reason for this mainly "lies" in the different ages of waste, which directly affects the content of organic matter and the shredding of municipal solid waste. Municipal solid waste processed in this study is considered a material in which the process of decomposition of organic matter is almost completely finished, so its results at a standard compaction energy of about 600 kJ/m^3, made with a standard hammer, can be compared with the results obtained by some authors, mainly by performing experiments on older waste and artificially prepared samples without an organic component. Gabr and Valero [6] at optimum water content (w_{opt}) of 31%, obtained a maximum dry unit weight (γ_{dmax}) of 9.3 kN/m^3. On the municipal solid waste that was taken from the landfill in Tokyo, Itoh et al. [8] obtained a maximum dry unit weight (γ_{dmax}) of 5.9 kN/m^3 at an optimum water content of 20%. Hyun et al. [11] obtained maximum dry unit weight (γ_{dmax}) in the range of 13–14 kN/m^3 on waste aged around 15 years, with a variation of optimum water content (w_{opt}) of 21–24%. However, although this method of testing can be accepted, the different municipal solid waste treatments at the landfill indicate the need to change the approach. The main reason for this is the simulation of the operation of compactors (hedgehogs) during waste compaction. Therefore, various innovative solutions are introduced during the research. The solution applied in this paper is to change standard flat Proctor hammer, by adding spikes, whose function is, in addition to compaction, destruction and shredding of municipal solid waste.

The paper presents a new way of performing Proctor compaction test, which is adapted to municipal solid waste, and the obtained results were used to perform an analysis with the results obtained using standard hammer of Proctor compaction test. Waste from an unregulated landfill in Plandište (about 10 years old) was used to form four artificially prepared samples of different composition. In this way, the influence of the waste composition on compaction was analyzed.

Methods and materials. Compaction of municipal solid waste in landfills is one of the daily work processes during its disposal. Slightly different equipment is used for field performance compared to the one used during soil compaction. As already mentioned, most often those are compactors with hedgehogs that are used for compacting and shredding of waste. In order to demonstrate the operation of the compactor in the field/landfill, in addition to the standard equipment for performing the Proctor compaction test, innovative, non-standard equipment was used, which included the installation of spikes on the flat surface of compaction hammer (Fig. 1).

Compaction was performed in a standardized Proctor cylinder of larger dimensions (Fig. 1), 152 mm in diameter, which enables compaction of different fractions with maximum dimensions up to 31.5 mm. The main role of spikes is to destroy different fractions of waste with mechanical destruction with each impact of the hammer on the waste, i.e. to shred the waste in order to achieve better compaction conditions. Compaction was performed in 3 layers with 56 strokes per layer, and 2.5 kg hammer falling from a height of 30.5 cm was used. During the experiment, a compaction energy of approximately E = 600 kJ/m^3 was used, which is common in the standard Proctor test.

Laboratory testing of municipal solid waste compaction is a complex process, primarily due to the impossibility of preparing undisturbed samples. Therefore,

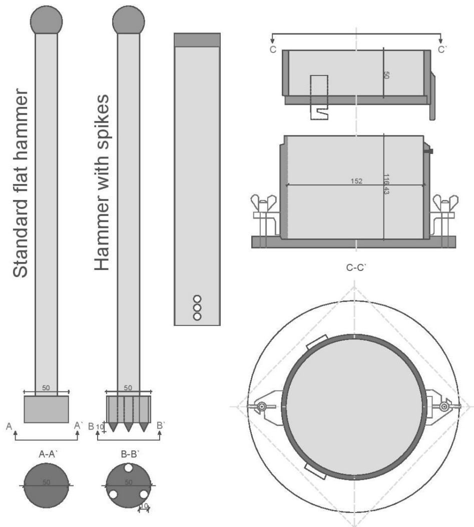


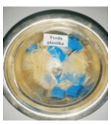
Fig. 1. Equipment used for Proctor compaction test (standard flat hammer and hammer with spikes)

the researchers usually performed experiments on artificially prepared samples [2, 9, 11, 12, 14, 15], where the composition, age, size of components, etc., were controlled.

For the needs of the paper, waste was taken from an unregulated landfill in Plandište (Serbia) by exploratory drilling, which is also used in soil mechanics. After sorting and preparation of the material, four samples of different composition were formed which was determined on the basis of the representation of the

T a b l e 1

Composition of waste

	hard plastic	soft plastic, textile, rubber	metal, glass, ceramics	paper	wood	other waste
	%					
S-1	8	13	22	1	1	55
S-2	15	15	23	1	1	45
S-3	19	16	27	1	2	35
S-4	23	22	28	1	1	25
						

material obtained by exploratory drilling (Table 1). Separated components are: hard plastic (PET packaging, dishes, etc.), soft plastic (plastic bags, food packaging, etc.) textile-rubber, metal-glass-ceramics, paper, wood and other waste. "Other waste" means all waste that could not be separated into one of the previously mentioned groups during sorting [16]. It is characterized by a large content of the "soil" component, which was assumed to have different behaviour in relation to artificial materials, and which is often in the role of daily coverings in landfills, and partially represents decomposed organic waste.

Previously, waste preparation was performed, which includes homogenization and mixing of components. During the preparation of the waste that will be used during compaction, the recommendations of the relationship between the dimensions of the individual fractions and the mould in which the experiment is performed were taken into account. Considering the specificity of the material, the recommendations from the standard were adopted that the maximum size of the components be up to 31.5 mm, from which it follows that the ratio of the maximum dimension of the fractions in relation to the mould is about 20%.

Before and after performing Proctor compaction test (with standard hammer and hammer with spikes), the material was sown. Grain size distribution curves of municipal solid waste are presented in Fig. 2.

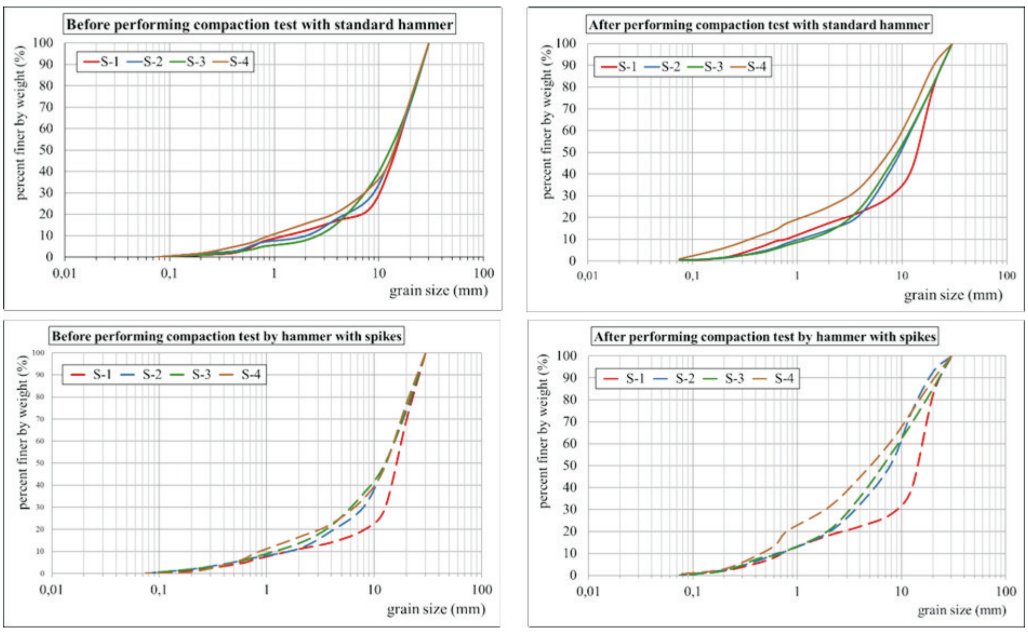


Fig. 2. Grain size distribution curves of municipal solid waste before and after performing compaction test

Results and discussion. For the needs of geotechnical analysis of the obtained results using different equipment, the results for standard and non-standard innovative hammer were processed separately. The analysis included the influence of the equipment on the change of the grain-size distribution of the waste and the compaction parameters: optimum water content (w_{opt}) and maximum dry unit weight (γ_{dmax}). However, in the case of the innovative hammer with spikes, this percentage is slightly higher, which is attributed to the destruction of the waste components by the spikes. This result can be linked directly to the hedgehog compactor which passes over the waste at the landfill in order to shred it. It can also be seen that the composition of the waste, i.e. the increase in the percentage of artificial materials has a more significant impact on shredding compared to the sample with a higher content of unclassified – mainly soil waste ("other waste").

As the differences in the change in grain size distribution are noticeable, the differences related to the definition of compaction parameters can also be clearly seen (Fig. 3). The curves can be grouped into two categories, sample S-1 and S-2 with a higher percentage of the "other waste" component and S-3 and S-4 with a higher percentage of artificial materials.

In sample S-1, with the largest content of unclassified waste ("other waste"), the maximum dry unit weight $\gamma_{dmax} = 13.39$ kN/m^3 was obtained, at optimum

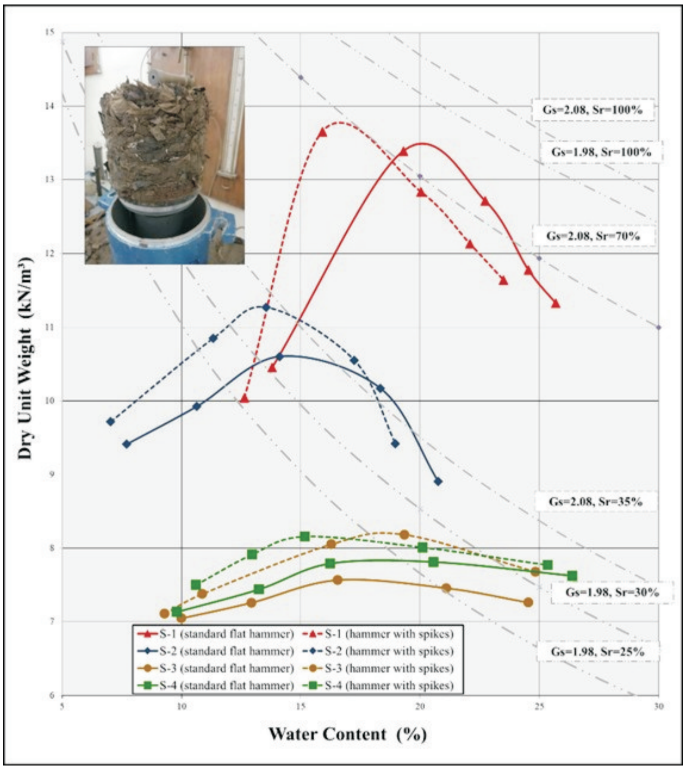


Fig. 3. Obtained results with Proctor compaction test (standard hammer and hammer with spikes)

water content $w_{opt} = 19.30\%$ in the case of using standard equipment during Proctor compaction test. When it comes to the results obtained by using an innovative hammer with spikes, on the same sample S-1, a slightly higher value of the maximum dry unit weight was obtained $\gamma_{dmax} = 13.66$ kN/m^3 at optimum water content of $w_{opt} = 15.90\%$. It can be seen from the diagram that the compaction curves are of a similar shape (Fig. 3), and that a significant difference is expressed by the reduction of the optimum water content by over 3%, in the case of compaction of material using an innovative hammer with spikes. However, when it comes to changes in the maximum dry unit weight, no significant difference was achieved in relation to the results obtained using standard equipment. These results are partly expected given that the composition of sample S-1 is dominated by "other waste" containing about 55% of materials whose behaviour can be compared with the soil, and therefore the maximum dry unit weight is higher than in the case for other samples, with reduced content of the "other waste" component. Analysis of grain size distribution curves of municipal waste (S-1) which was compacted with standard hammer and hammer with spikes, it can be determined that the higher content of soil material did not affect the significant shredding of waste, which would lead to better packaging of different fractions, and thus increase dry unit weight.

Sample S-2 contains a slightly higher percentage of hard plastic and soft plastic-rubber-textile components, which resulted in lower maximum dry unit weight and lower optimum water content in both cases compared to sample S-1. With a standard hammer, $\gamma_{dmax} = 10.60$ kN/m^3 was obtained at an optimum water content of $w_{opt} = 14.11\%$. With innovative hammer with spikes $\gamma_{dmax} = 11.27$ kN/m^3 was obtained at an optimum water content of $w_{opt} = 13.55\%$. As can be seen in the diagram (Fig. 3), a larger change in the maximum dry unit weight is observed in the experiment in which a hammer with spikes was used. The grain size distribution curves show a slightly higher destruction of municipal solid waste compared to S-1, which is attributed to the increase in the percentage of artificial components. However, there is still a large impact of the "other waste" component, which goes up to 45%, so this difference is not significant.

For sample S-3, the maximum dry unit weight $\gamma_{dmax} = 7.57$ kN/m^3 and the optimum water content $w_{opt} = 16.54\%$ were obtained by applying a standard hammer for the Proctor compaction test. In the case of unconventional performance of the Proctor compaction test, by applying an innovative hammer with spikes, the maximum dry unit weight $\gamma_{dmax} = 8.18$ kN/m^3 was obtained, at the optimum water content $w_{opt} = 18.10\%$. In the S-3 sample, a similar curve shape is observed, but with a significantly smaller bell shape [17]. This behaviour can be attributed to the much higher content of artificial components. In addition, it can be concluded that there is a higher content of components that are tend to shredding, which was also noted on the grain size distribution curves of the sample. By using a hammer with spikes, a slightly higher maximum dry unit weight was obtained with a smaller change in the optimum water content, about 1.5%.

For sample S-4, the maximum dry unit weight $\gamma_{dmax} = 7.80$ kN/m^3 and the optimum water content $w_{opt} = 18.00\%$ were obtained using a standard hammer for the Proctor compaction test. In the case of unconventional performance of the Proctor compaction test, by applying an innovative hammer with spikes, the maximum dry unit weight $\gamma_{dmax} = 8.15$ kN/m^3 was obtained, at the optimum water content $w_{opt} = 15.18\%$. Analyzing the results, it is concluded that the curve has a similar "behaviour" as the previous one, with a slightly greater reduction in optimum water content using a hammer with spikes, about 2.8%. The grain size distribution curves of this sample show the highest shredding of components, which is a consequence of the minimum percentage of the component "other waste", of 25%.

Conclusions. Since waste disposal at municipal solid waste landfills is still the most common type of waste disposal in Serbia, it is necessary to approach each of the disposal phases carefully. Compaction of municipal solid waste is certainly one of the basic processes and therefore it is necessary to determine its parameters in the laboratory (maximum dry unit weight (γ_{dmax}) and optimum water content (w_{opt})). The same procedure is used to define compaction conditions in the laboratory as for soil compaction. This is Proctor compaction test which defines the conditions of compaction during the construction of earth embankments, dams and other backfilled facilities. However, different equipment is used for municipal solid waste compaction in the field (so-called hedgehog compactors), which results in the need for adjustment of laboratory equipment.

Due to all the abovementioned, there is a need to innovate existing standards and equipment used in laboratory testing, in this case the Proctor compaction test. For these reasons, spikes have been added to the standard hammer to destroy and shred the waste and thus simulate the operation of compactors in landfills. In addition, the tests were performed using a standard Proctor apparatus, which enabled the comparison of the results of the performed tests, on the basis of which certain conclusions were made. Various data are available in the literature, often without basic information on how to perform experiments, so special attention is needed during their analysis and comparison.

The tests were performed on four different waste compositions, which can be separated according to the behaviour in two groups. The first group consists of samples S-1 and S-2, which have a higher percentage of soil material that is categorized as "other waste", 55% and 45%. In both samples, there is an increase in the maximum dry unit weight when performing the experiment using an innovative hammer, from 2.2% to 6.3%. The optimum water content is lower in both cases using the hammer with spikes in the range of about 0.5% to 3.0%. Due to lower content of artificial materials, which suffer greater destruction by spikes, the grain size distribution curves did not undergo major changes with compaction with an innovative hammer. The second group consists of samples S-3 and S-4 with a higher percentage of artificial materials, which in both cases resulted in a slightly lower maximum dry unit weight. Testing by applying the hammer with spikes gave slightly higher values of maximum dry unit weight compared to the standard hammer, from about 4.5% to 8.3%. In S-3 sample, the water content was increased in the case of hammer with spikes by about 2%, while in S-4 sample it was lower by about 2.5%. This can be attributed to the increased content of the hard plastic and soft plastic-rubber-textile components, which absorb water poorly in certain parts of the sample, so plastic components should be used carefully and evenly when forming a compacted sample to reduce errors and avoid greater deviations when defining compaction parameters. From the grain size distribution curves, it can be concluded that using the hammer with spikes, there was a greater shredding of artificial materials.

The results of Proctor compaction test indicate certain changes in the behaviour of municipal solid waste during compaction using a non-standard innovative hammer with spikes. However, in order to improve and refine the technology, it is necessary to perform more research. In addition to all that, the analyses of the obtained results, especially the grain size distribution curves, clearly show the influence of the waste composition on the workability of the waste itself, i.e. on shredding during compaction. The content of soil material that is separated as a special component – "other waste" dictates the "behaviour" of other components in the sample itself. Besides, the plastic component is of great importance due to the "resistance" which gives when compacted with a hammer due to the low density-volume mass and slightly higher volume it occupies in the mould.

Based on the analysis of the obtained results, it can be generally concluded that the application of new equipment resulted in slightly different compaction parameters compared to standard equipment, but also that the number of performed tests was insufficient to result a possible proposal for defining a new standard for municipal solid waste. This approach is new in both the domestic and world scientific public, and it is assumed that its development path is still ahead of us.

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