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Edited by
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SIMSG ISSMGE

Preface

Coupled Phenomena in Environmental Geotechnics (CPEG) is a quadrennial event organized under the auspices of the Technical Committee No.215 on Environmental Geotechnics of the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE), with a focus on coupled processes (e.g., chemical-physical, bio-physical, multiphase flow, etc.) in environmental geotechnics. The first symposium of the series was held in Torino, Italy, in 2013, and the second one was in Leeds, UK, in 2017. The third symposium, CPEG2020, was conjointly organized by the Japanese Geotechnical Society (JGS) and Kyoto University.

CPEG2020 was supposed to be held at the Clock Tower Centennial Hall of Kyoto University's main campus on October 29–30, 2020, instead of 2021, in order to avoid conflict with other ISSMGE events. However, it was postponed twice due to the COVID-19 pandemic, the first time to March 17–18, 2021, and the second time to October 20–21, 2021, with the expectation of holding an on-site symposium. Despite the postponement, the pandemic was anticipated to continue until the subsequent year. Therefore, in June 2021, the organizers decided to hold the symposium on October 20–21, 2021, with all the presentations and exchanges held online. The symposium included four keynote lectures by Prof. Craig Benson (USA), Prof. Toru Inui (Japan), Prof. Catherine Mulligan (Canada) and Dr. Dimitrios Zekkos (USA). Additionally, there was a special presentation by Prof. Abdelmalek Bouazza (Australia) and a special session on column testing by Prof. Charles Shackelford (USA) and Dr. Tetsuo Yasutaka (Japan).

One hundred and fifty-three abstracts were originally submitted to the symposium. The submitted papers were subjected to rigorous peer review by at least two reviewers. About 80 papers were accepted for publication in the proceedings, including the written version of the keynote lectures, and were published in October 2021 in JGS Special Publication (JGSSP) volume 9. The proceedings constitute a wide array of articles delivered by authors from 16 counties, including Australia, Canada, China, Finland, France, India, Italy, Japan, Nigeria, Poland, Russia, Saudi Arabia, Serbia, the United Kingdom, the United States of America and Vietnam. The topics featured in these proceedings were divided into eight broad themes that deal with:

- Bentonite-based barriers
- Radioactive wastes
- Waste landfills
- Environmental monitoring and risk assessment
- Geotechnical and environmental characterization
- Remediation and contaminant characterization
- Soil-water-chemical interactions
- Energy geotechnics

It is hoped that the proceedings of CPEG2020 will be of interest to developers, practitioners, consultants, academics, researchers and students of this field.

The editors would like to thank all authors and participants who contributed to making this CPEG successful and fruitful, filled with enriching presentations and exchanges. Special gratitude is expressed to the reviewers of the papers for their time and efforts in ensuring a high standard of the proceedings. A word of thanks is also expressed to those who served as session chairs. We also appreciate the Organizing Committee and ISSMGE's TC215 for their great efforts even under the COVID-19 pandemic. The ISSMGE Conference Review Platform was used for handling the review works. The support of Dr. D. Zekkos and Mr. Alexandros Tsavalas regarding the use of this system is greatly appreciated. Financial support from Obayashi Foundation made the conference registration fee and paper publication free to the attendees, and it is truly appreciated. Our sincere appreciation to Dr. Lincoln W. Gathuka for his great contributions to the success of the symposium.

Editors
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Phase relations and physical indicators of municipal waste from old landfills in Serbia

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ABSTRACT

Due to certain similarities of municipal waste and soil, usually for the determination of basic parameters of physical state, laboratory and field tests which are common in geotechnical investigations are used. It is often to construct an apparatus for special purpose to perform some specific laboratory and field tests. Therefore, different values of indicators of municipal waste physical state can be found in the literature. The basic reasons should be found in different definitions and methods that researchers use during their determinations, which further complicate a comparison of obtained results. Unlike soil, determination of physical parameters of municipal waste is more complex, because of its extremely heterogeneous composition, consistency, biodegradability etc. In addition, physical properties of waste change over time, so the method of taking and selection of representative samples is problematic and has not yet been standardized. In this paper, the most common determination methods of basic parameters of municipal waste physical condition will be presented (moisture content, organic substances content, unit weight, specific gravity, porosity, grain size distribution), using standard geomechanical laboratory equipment. In addition, average values of these parameters based on literature data, as well as results obtained by testing the old municipal waste from two landfills in Serbia (closed landfill Ada Huja in Belgrade and city landfill in Novi Sad) will be presented.

Keywords: municipal waste, moisture content, unit weight, specific gravity, grain size distribution, porosity.

1 INTRODUCTION

Unlike soil, determination of physical parameters of municipal waste is more complex, because of its extremely heterogeneous composition, consistency, biodegradability etc. (Vosniakos and Patronic, 2009). Therefore, data on the composition, shape and size of particles in the landfill can be of great use in defining the phase composition and physical indicators of municipal waste. In addition, physical properties of waste change over time, both in depth and from location to location, so the method of taking and selection of representative samples is problematic and has not yet been standardized (Rakić et al., 2011). The results presented in this paper were obtained on wastes of different ages which were taken from one active landfill that is currently used for waste disposal Novi Sad and from one closed landfill Belgrade – Ada Huja (Rakić, 2013). All laboratory tests were performed on waste material that was taken from the landfills by exploratory drilling or by digging exploratory pits. After that, the waste was sorted, classified and samples were prepared for further testing (Figure 1). Because of the fact that waste components cannot be easily identified, as well as because differences in the choice of material for specific groups that are published by different authors, EU member countries have developed and proposed formal method for the waste composition definition called „S.W.A. – Tool“ (European Commission - EC, 2004).

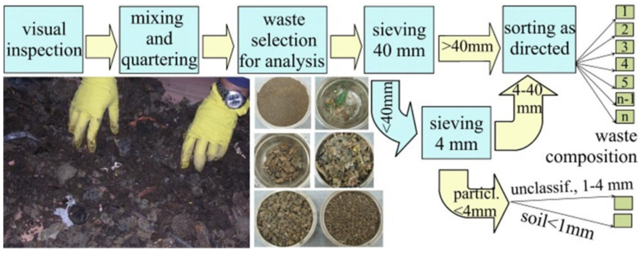

Fig. 1. The applied procedure of municipal waste classification.

The main objective of this methodology is to increase the accuracy and comparability of data related to the characteristics, i.e. the amount of municipal waste at the European level. It is proposed that after sampling, sorting and classification of municipal waste should be performed, according to a specially prepared catalogue, which contains 12 mandatory categories - groups, and 35 subcategories (secondary categories). This paper uses this catalogue according to which the

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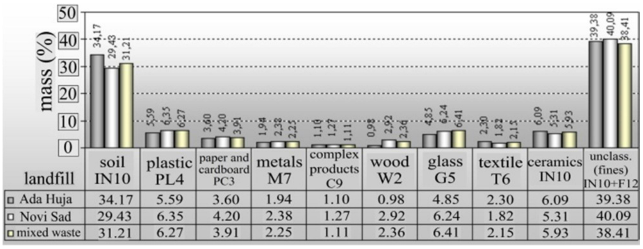
material composition of waste is determined by the mass participation of basic components (Figure 2). As it can be seen, waste contains significant percentage of unclassified and soil material (either from the material used for covering or due to the advanced stage of decomposition), which is typical for an old waste and represents already formed landfills in which the process of biodegradation is in advanced stage.



landfill	soil IN10	plastic PL4	paper and cardboard PC3	metals M7	complex products C9	wood W2	glass G5	textile T6	ceramics IN10	unclass. (fines) IN10+F12
▫ Ada Huja	34.17	5.59	3.60	1.94	1.10	0.98	4.85	2.30	6.09	39.38
▫ Novi Sad	29.43	6.35	4.20	2.38	1.27	2.92	6.24	1.82	5.31	40.09
▫ mixed waste	31.21	6.27	3.91	2.25	1.11	2.36	6.41	2.15	5.93	38.41

Fig. 2. Composition of analysed municipal waste.

2 PHASE RELATIONS IN MUNICIPAL WASTE

Starting from the soil mechanics basis, phase indicators of municipal waste are defined based on relationships which can be expressed by three basic physical parameters, assuming that the unit weight of water is known ($\gamma_w = 9.81$ kN/m^3) as well as unit weight of solid particles (γ_s). The most common parameters are: dry unit weight (γ_d) expressed by weight-volume ratio - W_s/V; porosity (n) expressed by volume ratio - V_p/V and moisture content (w) expressed by weight ratio - W_v/W_s. All three parameters are defined by weight – W (or mass – m) and volume – V (Table 1). This concept is convenient because on its basis, other important physical parameters that are used in geotechnical practice can be derived.

Table 1. Definition of the most important physical parameters of municipal waste (Fassett et al., 1994).

Parameter	Mark	Unit	Relations
Unit weight	γ	kN/m^3	$\gamma = W/V = (1+w) \cdot \gamma_d$
Void ratio	e	m^3/m^3	$e = V_p/V_s = \frac{n}{1\text{-}n}$
Unit weight of solid particles	γ_s	kN/m^3	$\gamma_s = \frac{W_s}{V_s} = \frac{\gamma_d}{1-n}$
Volume water content	v	m^3/m^3 - %	$v = \frac{V_v}{V} = w \cdot \frac{\gamma_d}{\gamma_w}$
Volume gas content	a	m^3/m^3 - %	$a = \frac{V_a}{V} = n - w$
Saturation degree	S_r	m^3/m^3 - %	$S_r = \frac{V_v}{V_p} = \frac{w}{n}$

The three-phase system for municipal waste does not take into account a fact that the composition and thus the volume of organic materials, i.e. part of a solid phase, changes over time. Therefore, it should be noted that there is a different representation of municipal waste phase composition, where the four-phase system is proposed and it consists of: gaseous, liquid, fibrous and sticky material phase similar to paste (Machado et al., 2008). Within the fibrous phase, authors have included plastic materials, textile and other similar materials. Thus defined four-phase system divides solid materials by type and shape but does not take into account their temporal variability. A different proposition of four-phase municipal waste system consists of: inert – solid (s), organic (o), liquid (v) and gaseous (a) phase (Figure 3). Inert phase consists of non-degradable materials such as plastic, metal, rock pieces, ceramics, glass and similar materials. All other materials would be in organic phase. This four-phase representation of municipal waste phase composition allows to determine basic physical parameters in a certain stage of degradation and to display their change, if the initial conditions are known.

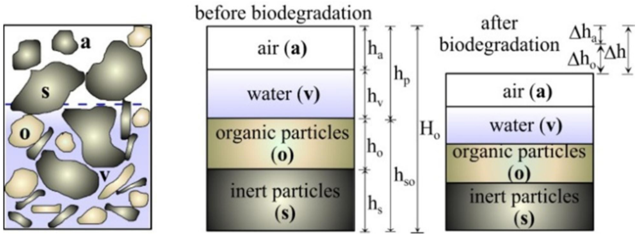


Fig. 3. Phase system change of municipal waste during biodegradation (Gourc and Staub, 2010).

Values of basic physical parameters in a certain stage of biodegradation are determined according to the following expressions:

$$\gamma_d = \frac{\gamma_{d0}}{1 - \frac{\Delta h}{H_0}} \tag{1}$$

$$n = n_0 - \Delta n = n_0 - \frac{(1-n_0)\frac{\Delta h}{H_0}}{1 - \frac{\Delta h}{H_0}} \tag{2}$$

$$w = w_0 - \frac{m_{vd}}{m_s} \tag{3}$$

where:

m_s, m_{vd} – initial dry mass and mass of drained water

γ_{d0}, γ_d – initial dry unit weight and dry unit weight in degradation stage

n_0, n – initial porosity and porosity in a certain stage of degradation

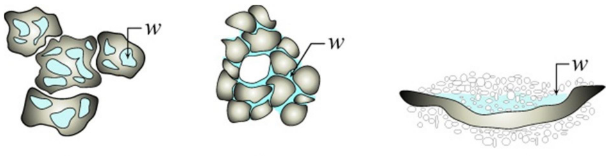
w_0, w – initial moisture and moisture content in a certain stage of degradation.

3 BASIC INDICATORS OF PHYSICAL STATE

In the paper, a three-phase system of waste was adopted and organic particles were classified in solid phase for which, in soil mechanics, is assumed that its total volume does not change in time.

3.1 Water content

Water content of municipal waste has a significant impact on its geotechnical characteristics, and it is of particular importance during the planning process of its further processing (for example combustion, composting), as well as for transport organization and temporary storage. It is defined as soil water content by relation of mass lost and remaining material mass, obtained by drying to a constant temperature (usually 55-60^{0}C due to the risk of combustion of some materials at higher temperatures). Municipal waste moisture content can be observed based on the mechanism of fluid retention within the pore space of waste: a) moisture within waste particles i.e. moisture in pores inside particles, b) moisture between particles i.e. in pores between particles and c) moisture that waste particles with low hydraulic conductivity retain (Figure 4).



a) b) c)

Fig. 4. Different types of fluid within the pore space of waste (Zornberg et al., 1999).

Very wide intervals of municipal waste moisture can be found in the literature. As a rule, municipal waste moisture is the highest in the spring and autumn period (about 50%), because besides higher rainfalls and content of organic component is the highest. For the purpose of this paper, water content was determined by drying of material at a temperature of 60^{0}C. Since that full waste was taken from two boreholes at Ada Huja landfill and at the same time it was mixed, samples were randomly selected for the moisture content determination. Obtained values were in interval of 31 – 39 %, except that in one sample moisture of 68 % was measured. Waste moisture from the landfill in Novi Sad was determined on small samples taken from boreholes and obtained values were in interval of 19 – 53 % (Rakić et al., 2013). The general trend is that due to the increase of decomposition degree with depth, the moisture content of waste increases too (Figure 5).

3.2 Organic matter determination

In determination of organic matter content of municipal waste, it is recommended that representative sample of material, before annealing, firstly sieve and separate into two fractions: finer and larger of 20 mm. Thereafter, loss of material is determined, particularly on particles smaller than 20 mm and particularly on particles larger than 20mm, during three phases of heating.

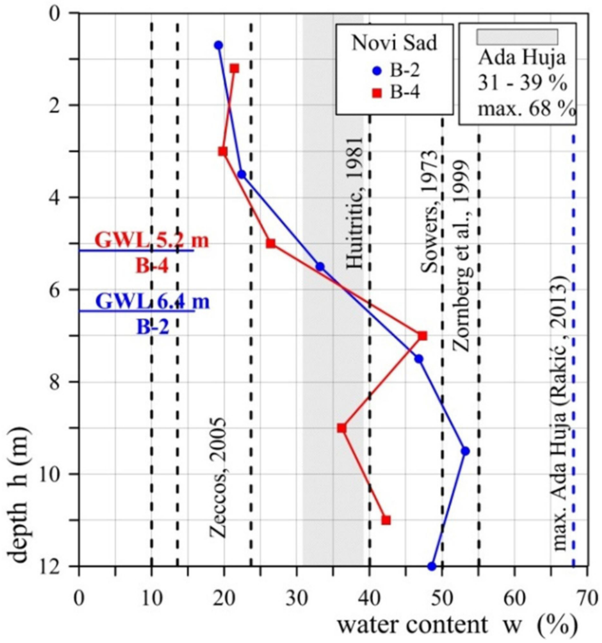


Fig. 5. Water content change in relation to the depth of taken sample.

The first phase means heating at a temperature of 55ºC to constant mass. In this stage, loss of mass compared to a constant mass is defined as moisture (w). Thereafter, samples are heated to a temperature of 105ºC and again masses of separately analysed fractions are determined. Eventually, only samples of material smaller than 20 mm are placed in muffle furnace, and heated at a temperature of 440ºC until material reaches constant mass. This method is in accordance with ASTM D2974-87 standard, according to which the content of organic matter (OS) is defined as a relation of mass of lost material smaller than 20 mm and remaining mass of material after heating, at a temperature of 440ºC. Since the values are obtained on particles smaller than 20 mm, Zekkos method for determination of organic matter content was used, which determined percentage mass loss for different materials (paper, wood, plastic) after annealing at 440^{0}C (Zekkos et al.,2006). The percentage content of individual materials was previously determined and their grouping was performed. Based on this, the following values of organic matter content were obtained: Ada Huja – 25.4%, Novi Sad – 36.7 %, mixed waste from these landfills – 34.2 %. The results show a decrease tendency of organic matter content with waste age.

3.3 Unit weight

Unit weight of municipal waste is very different because of its different composition, degradation stage i.e. waste age, disposal way i.e. thickness of daily disposal, compaction method during disposal, height-thickness of landfill i.e. overlay weight, content of water or filtrate etc. Therefore, certain assumptions are used in order to simplify determination of municipal waste unit weight. Those assumptions are: knowledge of waste composition, percentage of earth overlay, moisture, method and degree of compaction, waste age etc. (Rakić et al.,2016). Due to similarity of municipal waste and soil, for the determination of unit weight usually used laboratory and field tests are those that are common in geotechnical investigations such as: direct field measurements (excavation of exploration pit at the landfill with measurement of volume and weight of excavated waste), measurements on samples from exploration boreholes, geodetic surveying of geometry and calculation of landfill volume with knowing the mass of disposed waste, nuclear methods, measuring of mass and volume of individual components etc. Average dry unit weight based on weight parts of separated components is expressed in the following form:

$$\gamma_d = \frac{1}{\frac{1}{W_s}\cdot\sum_{1}^{n} W_i\cdot\frac{1}{\gamma_{di}}} \qquad (4)$$

where:

γ_{di}- dry unit weight of ith component

W_i- dry weight of ith component

W_s- dry weight of all components

n- total number of separated components

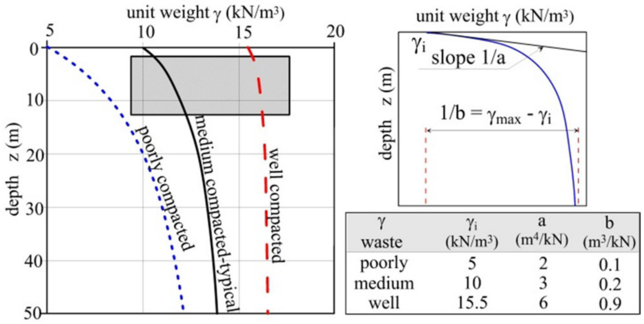
When the waste is under the influence of water, the unit weight increases due to components that are tend to absorb water. In this case, average unit weight of components is equal to:

$$\gamma = \gamma_d\left[1+\frac{1}{W_s}\cdot\sum_{1}^{n} W_i\cdot\frac{\Delta\gamma_i}{\gamma_i}\right] \qquad (5)$$

where:

$\Delta\gamma_i$ - increase of unit weight of component i

In the literature we can find values that range in wide interval (γ =3 – 17 kN/m^3). As a rule, higher values were measured at landfills with larger and more often use of earth materials for daily overlays and at landfills with higher content of water (filtrate). Municipal waste composition also greatly influences on average unit weight. As an illustrative example for this, we can specify "PET" packaging, or a can whose unit weight is γ = 2 kN/m^3 when it is empty, or around γ = 12 kN/m^3 when it is filled with fluid, and when it is compressed under high pressures its unit weight is approximate to a metal unit weight from which it is produced. For municipal waste from mentioned landfills, unit weights were determined on artificially prepared samples. In relation to the depth of taken samples (depth of boreholes from which waste was taken was 1.0 – 12.0 m), values ranged in a wide interval of γ = 9.5 – 17.6 kN/m^3. It can be seen that the values are in the domain of possible values of waste unit weight that correspond medium to well compacted waste (Figure 6).



γ waste	γi (kN/m³)	a (m⁴/kN)	b (m³/kN)
poorly	5	2	0.1
medium	10	3	0.2
well	15.5	6	0.9

Fig. 6. Hyperbolic change of the unit weight and interval of tested samples (Zekkos et al., 2006; Rakić, 2013).

3.4 Specific gravity

Determination of the specific gravity on samples of municipal waste is complex because waste contains pores inside particles and between particles. In the literature certain terms can be found based on which specific gravity can be determined depending on the content of organic matter, noting that the most of results were obtained by the research of peat (Skempton and Petley, 1970; Kanirajand Joseph, 1996; De Haan, 1997; Huat, 2004). Using the expression proposed by mentioned authors, values were obtained in interval of G$_s$ = 1.98 – 2.39, and the average values are adopted depending on the location of tested waste, i.e. G$_s$ = 2.0 - 2.2 (Figure 7).

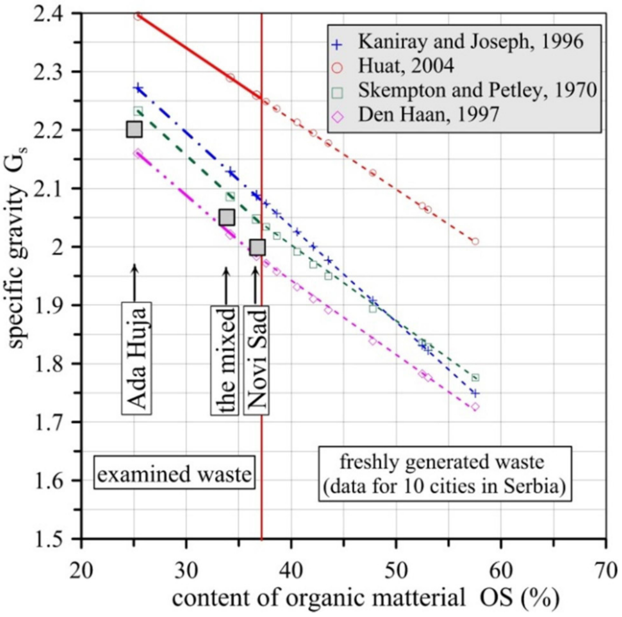


Fig. 7. Specific gravity depending on the content of organic matter.

Besides, specific gravity was also determined by laboratory test using completely automated pycnometer AccuPyc 1330 (Figure 8).

Fig. 8. Automated pycnometer AccuPyc 1330.

The pycnometer allows obtaining the volume of irregularly shaped solid particles, based on measuring the difference in helium pressure in the calibrated volume, and thus automatically calculates the density of solids, using a pre-defined dry sample mass. The pycnometer produces accurate results based on ten consecutive measurements. The analyses were performed on five municipal waste samples of different composition. The obtained specific gravity values ranged from Gs = 1.977 to 2.39, and the highest values were obtained for waste samples with the highest soil material content (Figure 9).

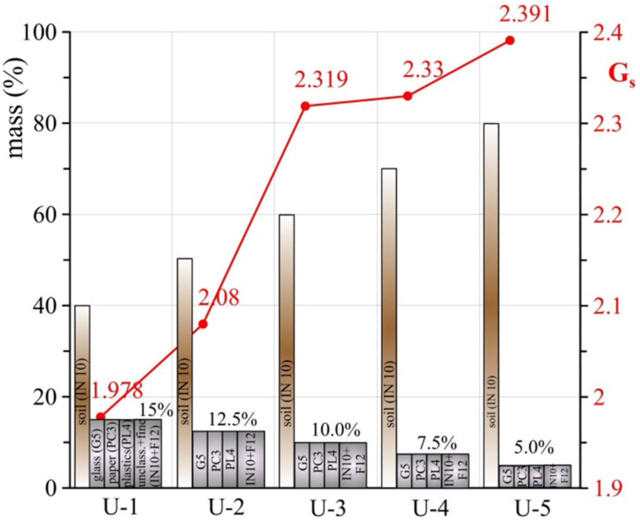


Fig. 9. Laboratory obtained values of specific gravity depending on mass composition of municipal waste.

3.5 Porosity

Due to the complex nature of municipal waste structure (within the individual components of waste material is an interspace filled with landfill leachate, landfill gas or with gas and leachate, either free or ‘’captured’’ gas), porosity (n) can be analysed as secondary porosity (porosity within particles) and porosity between particles. However, in this way definition of phase composition as well as determination of mechanical properties of municipal waste is further complicated, because in the landfill can be found particles saturated inside with contacts between them dry and other way around. Therefore, only porosity between particles was analysed in this paper. For the determination of void ratio, artificially prepared samples for testing of shear strength and compressibility of municipal waste (44 samples in total) were used. They were grouped in four characteristic series with a certain unit weights based on location and waste composition. The specific gravities G_s, which have been previously described, were adopted. Considering the wide interval of dry unit weights, void ratio ranged $e = 0.576 - 2.060$.

3.6 Grain size distribution

Determination of grain size distribution is necessary for the classification of municipal waste. Besides, knowledge of grain size distribution is particularly important in the construction of facilities for municipal waste classification within separation and transfer stations. Grain size distribution analysis separates fine grained particles which are usually earthen origin – earthy waste (material from cover, degraded material and similar) as well as large particles of different materials in waste – other waste. When it comes to earthy waste, methods which are common in soil mechanics are used for the determination of its grain size distribution. However, when it comes to the other waste, these conventional methods are not fully applicable. In this case is necessary to determine particle size, i.e. separated components, usually on one of the following ways:

$$d_c = l; \qquad d_c = \frac{l+b}{2}; \qquad d_c = \frac{l+b+h}{3} \tag{6}$$

where:

d_c - size of particle - component (cm)
l – length of particle (cm)
b – width of particle (cm)
h – height of particle (cm)

For particles whose dimensions exceed 40 mm, sieving can be performed using improvised sieves. Grain size distribution of municipal waste was determined on the selected material from both landfills. Material was firstly mixed and homogenized, so the depth of taken material was not taken into consideration. Regardless of the fact that during the waste sorting, particles of larger dimensions were separated, sieving was performed with series of sieves with the largest sieve diameter of 80 mm and the smallest diameter of 0.075 mm. Results of performed analyses are presented in Figure 10. In general it can be said that the waste from the Ada Huja landfill contains a higher percentage of smaller particles and this confirms an assumption that the waste age effects to its grain size distribution.

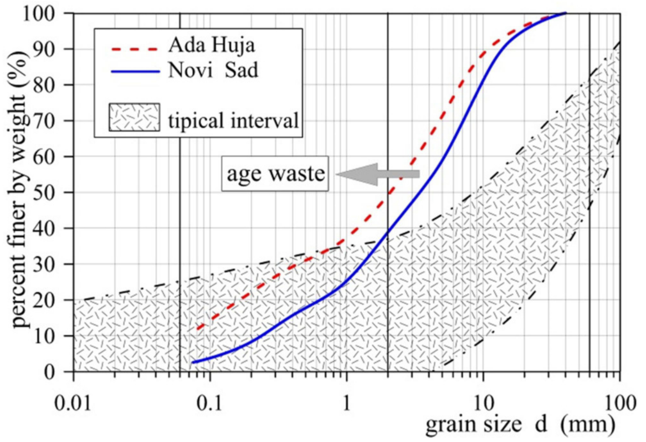


Fig. 10. Grain size distribution curves of wastes of different ages.

4 CONCLUSIONS

Due to certain similarities of municipal waste and soil, usually for the determination of basic parameters of physical state, laboratory and field tests which are common in geotechnical investigations are used. It is often to construct an apparatus for special purpose to perform some specific laboratory and field tests. Therefore, different values of indicators of municipal waste physical state can be found in the literature. The basic reasons should be found in different definitions and methods that researchers use during their determinations, which further complicate a comparison of obtained results. All this indicates the necessity of defining specific procedures of geomechanical tests of municipal waste.

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