Deformable characteristics of the old municipal solid waste from Ada Huja location, Belgrade - Serbia

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Abstract

For remediation of existing landfills, it is important to determine additional physical and mechanical characteristics of waste. However, for more precisely defining of modelling and numerical simulation of long-term settlement, the most important thing is parameters determination of compressibility and consolidation of the municipal solid waste material. In contrast to the natural soil, where the settlement mainly takes place due to initial compression and primary consolidation, waste material settlement takes place for the duration of the landfill's active life. Because of that, it is very important to determine secondary compression index C_α and modified secondary compression coefficient C_α' of the waste material.

This paper presents the values of compressibility parameters obtained by laboratory tests, which are performed on samples that have been taken from the old municipal solid waste from Ada Huja in Belgrade, Serbia.

Key words: Municipal solid waste (MSW), compressibility, secondary compression, primary compression.

Sažetak

Za modeliranje i numeričku simulaciju dugotrajnog sleganja deponije komunalnog otpada, od najvećeg značaja su parametri stišljivosti i konsolidacije. Za razliku od prirodnog tla, gde se sleganje najvećim delom obavi u fazi inicijalne i primarne konsolidacije, kod komunalnog otpada sleganje se dešava u toku čitavog trajanja deponije, pa glavnu komponentu ukupnog sleganja predstavlja sekundarna kompresija. Zato je određivanje indeksa sekundarne kompresije C_α i koeficijenta sekundarne kompresije C_α' komunalnog otpada posebno važno.

U radu se prikazuju parametri stišljivosti komunalnog otpada koji su dobijeni laboratorijskim ispitivanjima uzoraka uzetih sa deponije na Ada Huji u Beogradu.

Ključne riječi: Čvrsti komunalni otpad, stišljivost, sekundarna kompresija, primarna kompresija.

1. Introduction

Determination of the numerical indicators of the physical-mechanical behaviour of the municipal solid waste (especially mechanical properties) is a complex process due to the following: changeable and heterogeneous composition of the waste which is porous and unsaturated, difficult sampling and testing of the representative samples, non-existence of a generally accepted methodology of sampling and testing, considerable changes of the characteristics depending on the time i.e. state of decomposition of the waste etc.

There is legislation in various countries worldwide which define the conditions for disposing of the municipal solid waste. Within this legislation, concrete numerical data can be found which describe the behaviour of the municipal solid waste. It is necessary to cease the use of the geomechanical parameters such as shear strength and the deformability characteristics, based on the literature data. But, it has to make research and evaluation and to determine the domestic correlations based on results of those tests. Data on physical-mechanical characteristics of the waste that are often found in literature are mainly based on empiric and/or limited field research. That is why this is one of the bigger challenges for the majority of global researchers (and which can be seen based on the research conducted in recent years: H. Li Park [1], S. L. Machado [2], Md. S. Hossain [3], N. Dixon [4], D. P. Zekkos [5]), in the sense of defining physical-mechanical characteristics of municipal solid waste.

Research shown in this paper has been conducted in the Laboratory for Soil Mechanics at the Faculty of Mining and Geology of the University of Belgrade. This is the first time this type of research has been conducted in Serbia.

2. Basic geological characteristic of the location

Location of an old municipal solid waste dump for Belgrade area on Ada Huji is officialy closed in 1978. This closing is meant only covering of waste by inert material, without recultivation and using of modern materials and techniques of closing. Therefore, the practice of uncontrolled disposal has been continued even after closing, and some parts of the landfill are still place for construction waste dumping.

The current appearance of the site has approximately rectangular shape with longer side of over 500 m, while the shorter side length is 300 m. Location is limited with Danube river, from North, to a distance of about 100 m. Boundaries between the landfill and natural terrain are relatively steep slopes of the landfill with dips of 30 – 40˚. During field research, for the purpose of shopping center construction on the location [6], 21 prospecting boreholes are drilled, with a total drilling depth of 331 m. In addition to prospecting drilling, 31 static penetration tests were carried out, with an overall sounding length of 473,4 m, of which 364,4 m are from the surface of natural terrain (alluvial sediments of Danube river) and the remaining 109 m from the surface of the landfill. Seven prospecting pits were carried out from surface of landfill (Fig. 1).

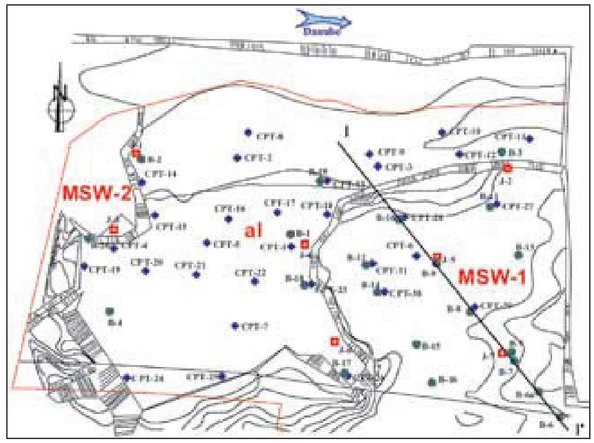

Fig. 1. Terrain situation with the location of prospecting boreholes, CPT and open pit

Wider part of location is built by alluvial sediments of Danube river: younger terrace deposits, beds, and alluvial fills of various categories. Natural terrain on the landfill location was built by younger alluvial sediments that are deposited in aquatic environment in periodic floodings during high water level of Danube river. In surface part of the terrain alternately take turns unconsolidated silty and sandy clays (CH, CL-CI, MH) in both directions, vertical and horizontal, which are enriched with organic matters in some intervals. Sediments of bed are deposited below them and they are represented by light gray sands and silty-gravely sands (SP, SU-SF, SU), within which occasionaly occurs organic matter in form of partially decompoused remains of plants. At this location, locally, are also noted sediments, who are created in an abandoned branch of Danube river. Characteristic geotechnical cross-section of the terrain with basic physical and mechanical parameters of layers is shown in Figure 2.

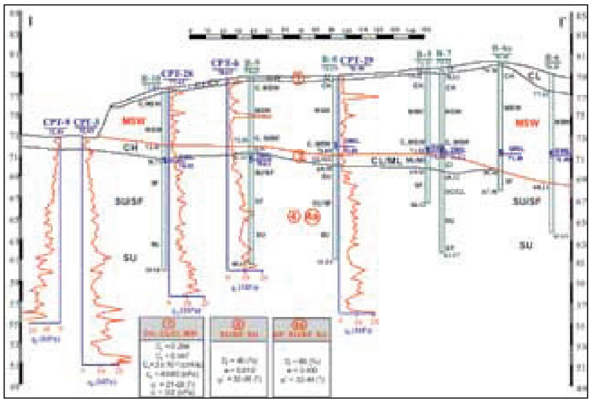

Fig. 2. Characteristic geotechnical cross-section of the terrain I-I'

3. Method for samples preparation and equipment for testing

Conventional method for laboratory determination of deformability and consolidation characteristics is performed by the oedometer testing. The underlying problem for performing oedometer tests is securing the necessary ratio of the particle size composition of the tested material, in this case municipal solid waste, and dimensions of the equipment that is used. As a rule, soil mechanical laboratories have the available equipment that will enable testing of the samples Ø7.0 cm in diameter and h = 2.0 cm in height, and rarely Ø10.0 cm in diameter and h = 4.0 cm in height. Recommendation which has been included as part of the European standard requirements (EN 1997-2 [7]) is the ratio of the smallest dimension of the sample (in this case the height of the sample) to the largest dimension of the non-homogeneousness (size of the largest particle) as h/5, where h represents the height of the sample. Another required characteristic during the oedometer testing is the dimensions of the equipment i.e. the ratio of the diameter and height of the tested sample. This ratio should be greater than 1:2.5.

Compressibility of the municipal solid waste was performed with the oedometer equipment of Ø20 cm in diameter and h = 8 cm in height (Fig. 3). The ring itself is made of Beryllium-Bronze, resistant to the corrosive effects of the waste samples being tested.

With municipal solid waste, it has to be said that there is no internationally accepted standard sampling and testing procedure, primarily due to its extreme heterogeneousness. This is the reason why most of the testing is performed on artificially prepared samples, bearing in mind the percentage content and shape of individual components of the waste.

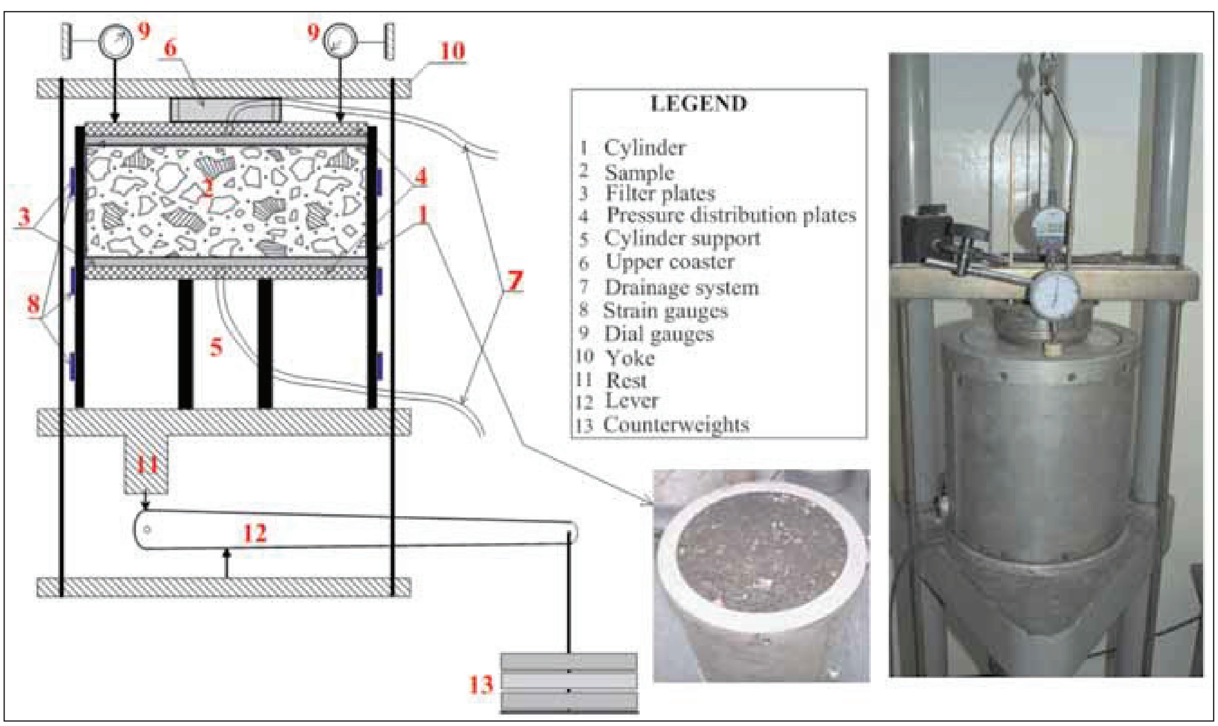

Fig. 3. Construction of oedometer apparature

Complete cores from two boreholes taken from the closed municipal waste landfill site at Ada Huja, Belgrade were used in preparing the samples.

Preparation of the samples included previous homogenisation certain components of the waste. Composition of the waste expressed through the percentage of the mass of basic components and subsequent particle-size analysis has been performed on a sample prepared in this way (Fig. 4). Percentage of the mass of soil material was the greatest, which is quite common in old waste (landfill was closed in 1978), as the process of biodegradation is mostly completed.

By ignition loss tests the content of burnable matter in the range of 13.0-13.8 % was obtained. Natural moisture content was determined by drying the samples taken directly from the core of the boreholes at temperatures of 60^{0}C, and average values obtained were in the range of w = 31 - 39 %. One of the samples, however, had the value of

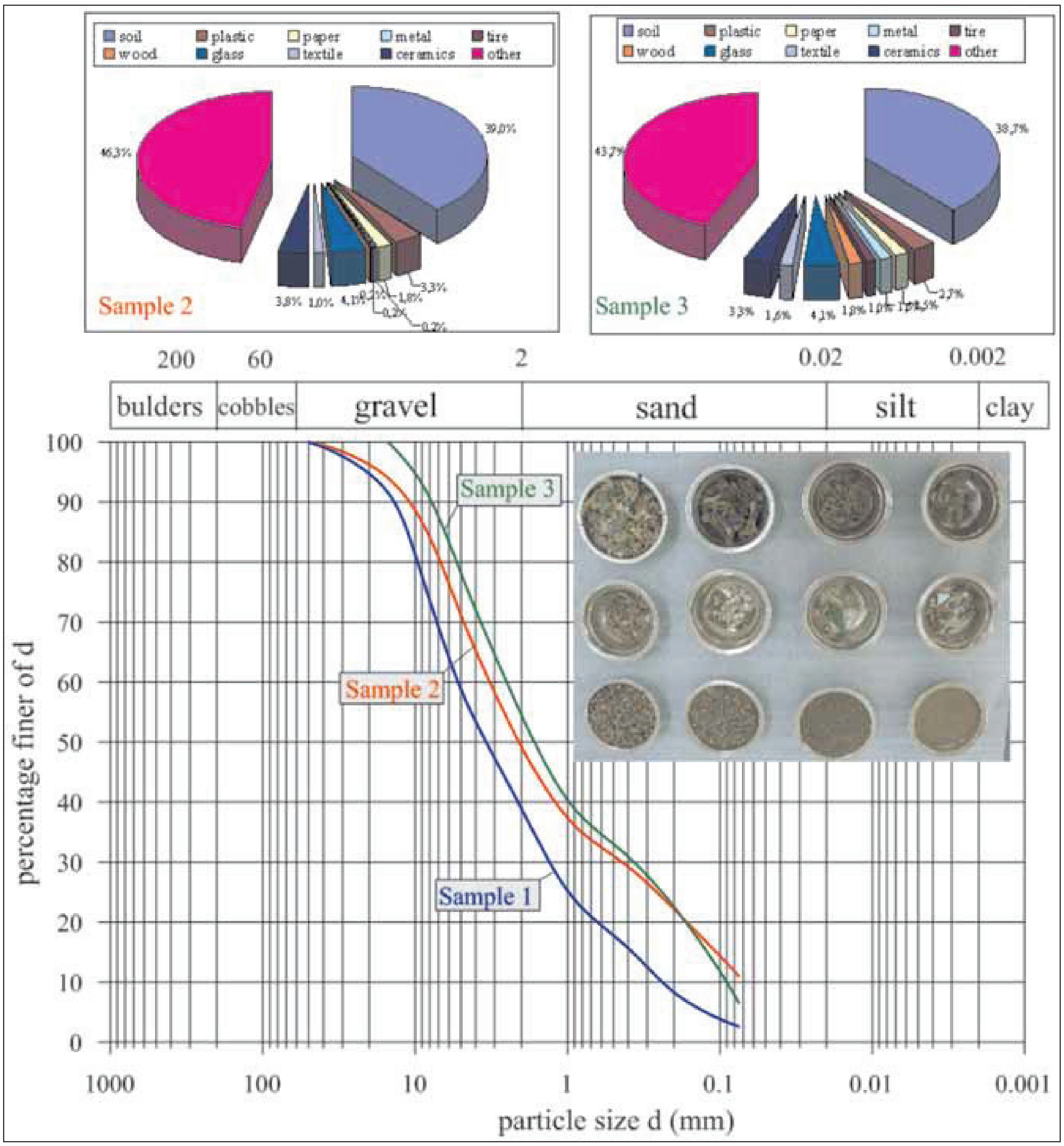

Fig. 4. Composition and particle size distribution curve of a waste sample

68 %, which indicates local fluctuations of moisture in the landfill. Specific gravity of the waste was calculated based on the relationship suggested by Skempton and Petley [8].

$$G_{so} = \frac{G_s \cdot G_p}{(G_s - G_p) \cdot P + G_p}$$

where

- G_{s0} – Specific gravity of the waste
- G_s – Typical value of the specific gravity of the mineral component (2.55–2.75)
- G_p – Specific gravity of the organic component (1.4)
- P – Percentage of soil loss due to ignition

Specific gravity of the tested waste samples calculated in this way (2.35 – 2.37) has also been used to determine void ratio e.

4. Compressibility parameters of municipal solid waste

Consolidation theory which is used in the soil mechanics is applied to the municipal solid waste as a rule, meaning that the same parameters are used. From this it follows that the total settlement is calculated as a sum of the initial (due to the initial compression and primary consolidation in the classical view settlement) and secondary settlements.

During the calculations, up to the activation of the secondary settlement, primary compression index C_c or primary compression coefficient C_c', are used. These are dependent on the changes of vertical stress and are determined by the following equations:

$$C_c = \frac{\Delta e}{\log(\sigma'_{v1} / \sigma'_{v0})};$$

$$C_c' = \frac{\Delta H}{H_0 \cdot \log(\sigma'_{v1} / \sigma'_{v0})} = \frac{C_c}{1 + e_0}$$

where:

- e_0 - initial void ratio,
- Δe - change of the void ratio,
- σ'_{v0} - initial effective vertical stress,
- σ'_{v1} - final effective vertical stress,
- H_0 - initial height of the waste layer, and
- ΔH - change of thickness of the waste layer, i.e. waste settlement

Secondary compression happens throughout the "active life" of the waste landfill and represents the main component of the total settlement. Secondary compression includes all "hidden" effects such as degradation, regardless of whether it is chemical or biological. For this reason, secondary compression index C_α or secondary compression coefficient C_α' are used for evaluation of settlement following the completion of the primary phase:

$$C_\alpha = \frac{\Delta e}{\log(t_2 / t_1)};$$

$$C_\alpha' = \frac{\Delta H}{H_0 \cdot \log(t_2 / t_1)} = \frac{C_\alpha}{1 + e_0}$$

where t_1 and t_2 represent the time at the beginning and at the end of the secondary settlement.

Based on the parameters shown, total settlement is calculated, bearing in mind that the mechanics of the total settlement are quite complex. There are several reasons for this complexity, such as settlement of the waste due to its own weight and the weight of each next layer, reduced values of the secondary compression coefficient during time, different speed of degradability which in turn causes differential settlement in a relatively small zones, settlement of the landfill's bed etc. Long-term behaviour of the municipal solid waste can be shown through a qualitative model (Fig. 5), where secondary settlement is expressed in four characteristic phases (II – V) [9].

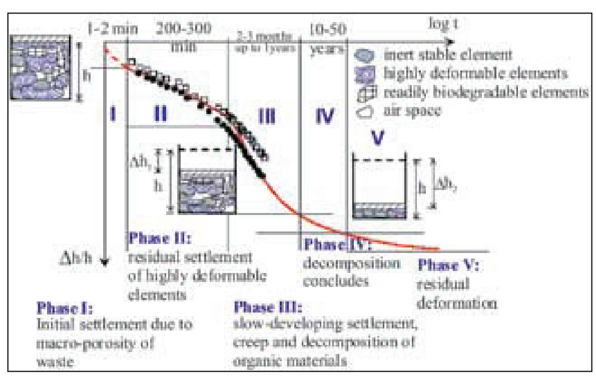

Fig. 5. Qualitative model behavior of MSW in time (M. Grisolia [9])

5. Results of laboratory tests

To determine numerical values of the above-mentioned parameters (C_c, C_c' C_α and C_α'), laboratory tests have been performed on artificially prepared samples with unit weight γ = 10, 10.5 and 11 kN/m^3. Load has been added inceremental over relatively long periods of time and intensity of vertical stress was σ_1' = 10, 30, 50 and 150 kPa. The results of tests for increments of stresses σ_1' = 10, 30, 50 and 150 kPa, are shown on Fig. 6.

By comparing this to the model shown on Fig. 3, it can be concluded that the laboratory tests included phases II and III, which have the highest settlement. Considering the type of deformation, from the part of the diagram corresponding to the phase II, minimal secondary compression index ($C_{\alpha min}$) value has been determined, whilst part of the diagram corresponding to phase III, maximum value ($C_{\alpha max}$) is evaluated.

To determine deformation corresponding to the primary settlement, so called Taylor's metod

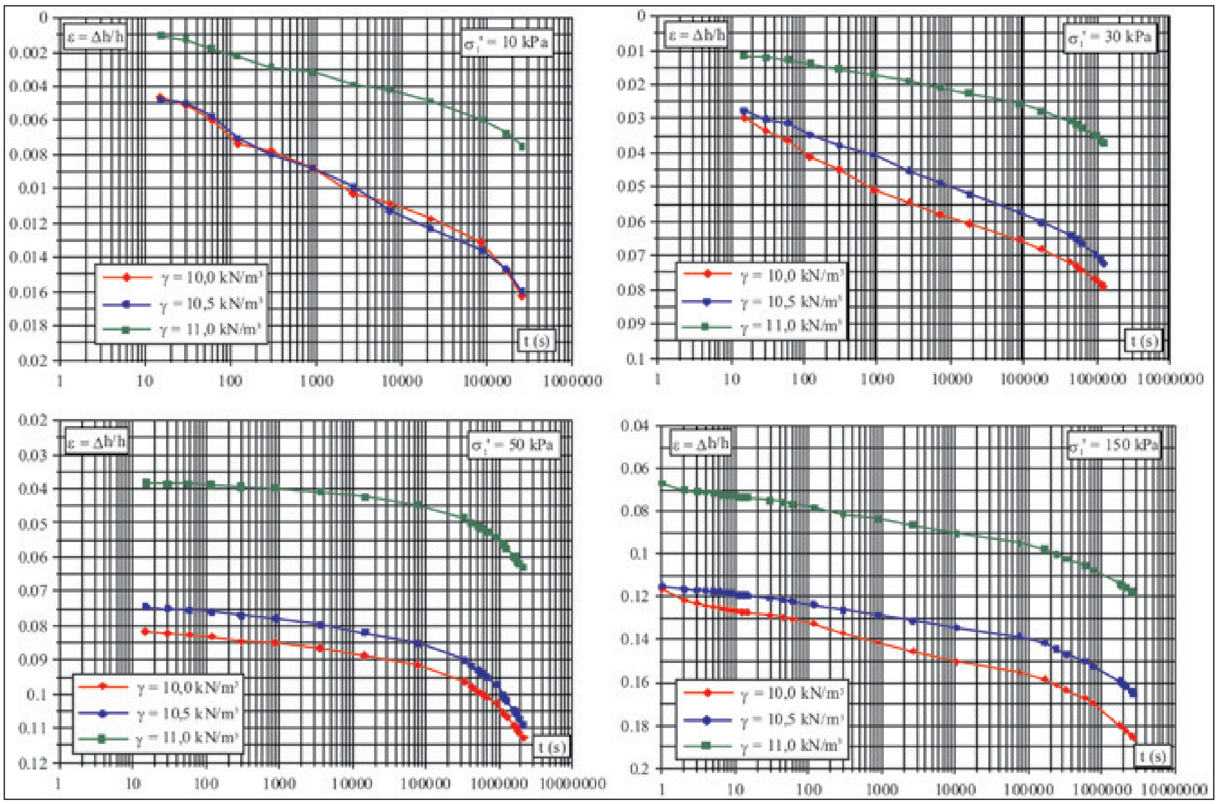

Fig. 6. Compressibility diagram for loading σ_1' = 10, 30, 50 and 150 kPa

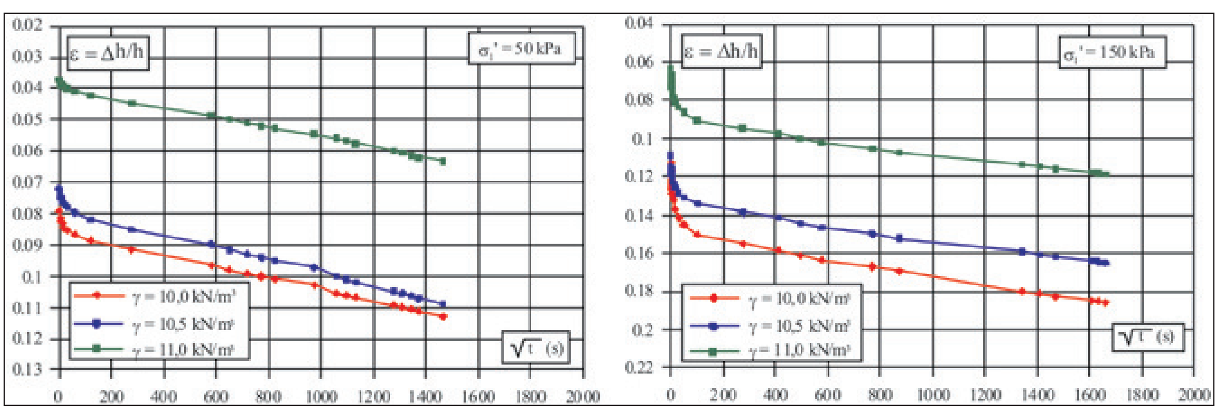

Fig. 7. Compressibility diagram for loading σ_1' = 50 and 150 kPa (Taylor's metod)

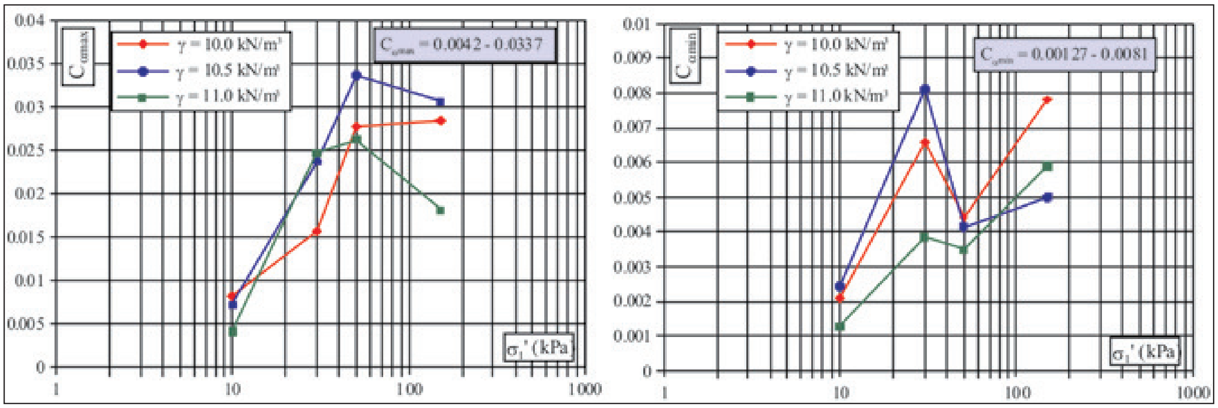

Fig. 8. Secondary compression dependency on unit weight and consolidation stresses

Table 1. Published refuse compressibility parameters (Complied from Fasset 1994[10], Landva 2000 [13], and Rakić [16])

Reference	primary compression index C_c	secondary compression index C_a
Sowers, 1973	0.1-0.41	0.02-0.07
Zoino, 1974	0.15-0.33	0.013-0.03
Converse, 1975	0.25-0.3	0.7
Chang and Hannon, 1976	-	0.013
Rao et al, 1977	0.16-0.235	0.012-0.046
York et al, 1977	0.08-0.21	0.02-0.04
Landva et al, 1984	0.2-0.5	0.0005-0.029
Burlingame, 1985	0.15-0.35	0.04
Oweis and Khera, 1986	0.08-0.217	-
Bjarngard and Edgers, 1990	-	0.004-0.04
Lukas, 1992	-	0.001-0.024
Wall and Zeiss, 1995	0.21-0.25	0.035-0.056
Gabr and Valero, 1995	0.2-0.23	0.015-0.023
Boutwell and Fiore, 1995	0.09-0.19	0.006-0.012
Stulgis et al, 1995	0.16	0.02
Green and Jamenjad, 1997	-	0.01-0.08
Landva et al, 2000	0.17-0.24	0.01-0.016
D. Rakić et al, 2010 - Present study	**0.279-0.463**	**0.0042-0.0337**

showing deformation as a function of square root of time i.e. $\Delta\varepsilon = f(\sqrt{t})$ was used (Fig. 7). Based on this, a compression diagram corresponding to the initial phase was constructed and it was used to determine primary compression index C_c and primary compression coefficient C_c'.

Calculated values of secondary compression index are within $C_{\alpha min}$=0.00127-0.0081, and $C_{\alpha max}$ = 0.0042 - 0.0337 intervals (Fig. 8).

Results obtained have shown relatively good coincidence with average values of these parameters found in literature and which are typical for waste older than 10 years (Table 1) [4], [10], [11], [12], [14], [15].

Obtained values primary compression index are in the interval of C_c = 0.279-0.463. This parameter has also shown relatively good coincidence with average values published in well-known international literature (Table 1).

6. Conclusion

This paper has shown that regardless of extensive heterogeneousness of municipal solid waste, conventional methods of testing and research which are normally used during the soil testing, can be used during municipal solid waste testing as well. Based on those tests, its settlement can also be calculated. However, during these tests, it is necessary to pay particular attention to the representativeness of the samples which need to be in accordance with the observance ratio.

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