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Compressibility parameters of old municipal waste from two landfills in Serbia

Paramètres de Compresibillity de vieux déchets municipaux de deux décharges en Serbie

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ABSTRACT In this paper, results related to the determination of the minimum and maximum secondary compression index ($C_{\alpha min}$, $C_{\alpha max}$), i.e. the modified secondary compression index ($C'_{\alpha min}$, $C'_{\alpha max}$), obtained from laboratory tests of municipal waste samples using the oedometer apparatus with diameter of 20 cm, are presented. The dependences of these indices and the initial void ratio arealso presented and compared with the proposed intervals of Sowers (1973). All tests were performed on artificially prepared samples with respect to the recommendations related to the dimensions of used devices and the size of the largest fractions in sample (EN 1997-1, 2007). For the sample formation, old municipal waste was used, which was taken from two landfills in Serbia: one that is no longer in use (Ada Huja in Belgrade) and another that is still in use (landfill in Novi Sad).

RÉSUMÉ Dans ce papier, les résultats liés à la détermination du nombre minimal et maximal indice de compression secondaire ($C_{\alpha min}$, $C_{\alpha max}$), c'est à dire l'indice de compression secondaire modifié ($C'_{\alpha min}$, $C'_{\alpha max}$) obtenues à partir des essais en laboratoire d'échantillons de déchets municipaux dans l'appareil de œdomètre d'un diamètre de 20 cm, seront présentés. Les dépendances de ces indices et le taux de vide initial seront présentés et seront comparés avec les intervalles proposes par Sowers (1973). Tous les tests ont été effectués sur des échantillons préparés artificiellement ce qui concerne les recommandations relatives aux dimensions des appareils utilisés et de la taille des plus grandes fractions de l'échantillon (EN 1997-2, ASTM 2007-a, 2007-b). Pour la formation de l'échantillon, le vieux déchets municipaux a été utilisé, qui a été prise à partir de deux sites d'enfouissement en Serbie, qui n'est plus en usage (Ada Huja à Belgrade) et l'autre qui est encore en usage (décharge à NoviSad).

1 INTRODUCTION

In order to perform modelling and numerical simulation of long-term settlement of municipal waste, the parameters of compressibility and consolidation are of the highest importance. Since municipal waste is extremely heterogeneous and anisotropic, the determination of these parameters is much more difficult than in soils. However, the classical theories of soil mechanics, related to compressibility, are usually applied to municipal waste (with many limitations), so we use the same parameters for description of its behaviour. Unlike the native soil, where the settlement is mostly done during the initial compression and primary consolidation, at the municipal waste site the major component of settlement is secondary compression and it can be said that it proceeds during the entire existence of the landfill.

For the determination of compressibility parameters of municipal solid waste, the laboratory test most usually used is the one-dimensional test with oedometer apparatus (Gabr& Valero 1995; Landva et al. 2000; Vilar&Carvalho 2004; Reddy et al. 2008; Chen et al. 2009). Besides laboratory tests, the monitoring of waste settlements is performed at landfills (Sharma et al. 1990; Grisolia&Napoleoni 1996; Gasparini et al. 1995; Machado et al. 2002). Test results are usually presented according to the compressibility parameters: primary compression index C_c and secondary compression index C_α. According to Fassett et al. (1994) parameters C_c and C_α depend on the values adopted for e_0. But the determination of the void ratio of municipal solid waste is quite complex. Therefore, some researchers (Vilar&Carvalho 2004; Hossain &Gabr 2005; Gabr& Valero 1995) assumed the initial value of the void ratio e_0, in order to calculate values C_c and C_α. Therefore the modified index of primary C_c' and the modified index of secondary compression C_α' are more often used, because they are expressed by axial deformation. Furthermore C_α' depends on the stress level and time interval as well on the choice of the beginning time of the secondary compression.

2 SAMPLE PREPARATION AND TESTING PROCEDURE

Laboratory tests were performed on municipal solid wastes of different ages, which were taken from two landfills in Serbia (active landfill in Novi Sad and closed landfill Ada Huja in Belgrade) by exploratory drilling and by digging of exploratory pits. In accordance with the SWA-Tool (European Commission 2004), sorting and classification were performed, based on which the composition of the tested municipal solid waste was defined (Table 1).

Table 1. Composition of analysed municipal waste

Kind and denotation of waste by S.W.A. tool catalogue	Mass (%)	
	Landfill Ada Huja, Belgrade	Landfill for Novi Sad
Wood – W2	1.0	2.9
Paper and cardboard–PC3	3.7	4.2
Plastics – PL4	5.6	6.4
Glass – G5	4.9	6.3
Textiles – T6	2.3	1.8
Metals – M7	1.9	2.4
Complex products – C9	1.1	1.3
Soil – IN10 01	34.1	29.4
Ceramics – IN10 02	6.1	5.3
Unclassified (fine) – F12	39.3	40.0

The results show that it is old waste, which contains a significant percentage of unclassified and soil material. This is typical for landfills in Serbia which have been in existence for over 30 years and where the biodegradation process is at an advanced stage (Rakic et al. 2013). Tests were performed on artificially prepared samples, taking into account humidity, compaction, percentage content and form of individual waste components. The material was previously homogenised, mixed and fragmented in order to ensure an adequate ratio of particle size distribution, i.e. ratio of the characteristic apparatus dimension (L) and size of fractions (d), $L/d \geq 5$. Maximum particle size of prepared samples was 4 cm; the smaller mass part of plastic fractions (< 7%) contained elongated one-dimensional particles with a length < 8cm. According to these conditions and characteristics of municipal solid waste, tests were carried out using an oedometer apparatus with diameter of Ø20 cm and height of 20 cm (Rakić et al. 2011). Samples with height of 8 cm were installed in it, by rising the support in the cylinder, i.e. moving the lower surface for the load (Figure 1).

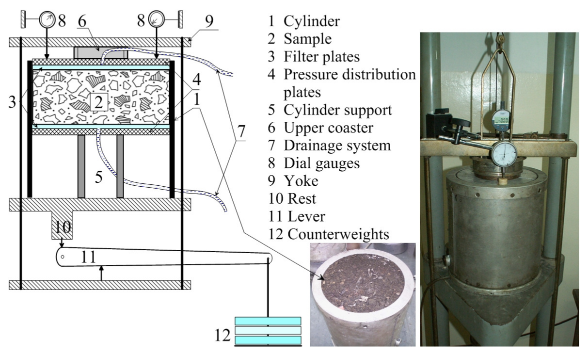

Figure 1. Construction of oedometer apparatus

Two series of four samples (A and B) were formed. The waste from the landfill Ada Huja (age over 40 years) was used for the series A, and the waste from the landfill in Novi Sad (age about 20 years) was used for the series B. For both series, samples were formed with different unit weights and with natural moistures (Table 2), which are typical of most landfills which contain a higher percentage of soil (Zekkos et al. 2006).

For the determination of the void ratio e_0, the specific gravities G_s were adopted which were determined by using the expression which contains content of organic substances (Skempton & Petley 1970; Huat 2004). The obtained values were in range of $G_s = 1.98 – 2.39$, and the average values were adopted depending on the location.

For all samples, loads were applied stepwise and the following values of vertical stresses were selected: 10 – 30 – 50 – 100(150) kPa which were constantly maintained. Total duration of the test for samples of the series A was 74 days and for samples of the series B was 161 days. Load durations differed from grade to grade and from sample to sample (Figure 2), and ranged from a minimum of 3 days for the series A (σ'_v =10 kPa), to a maximum of 79 days for the sample of the series B (σ'_v =100 kPa). During the test, samples were not further moistened.

Table 2. Identification and classification data for test samples

Series	Sample labels	*w* (%)	γ (kN/m^3)	G_s	e_0
A	U-1	27.5	9.5	2.20	1.952
	U-2	39.1	10.0		2.060
	U-3	37.5	10.5		1.882
	U-4	30.7	11.0		1.614
B	U-5	39.9	9.5	2.00	1.944
	U-6	39.9	10.0		1.798
	U-7	42.9	10.5		1.722
	U-8	40.7	11.0		1.559

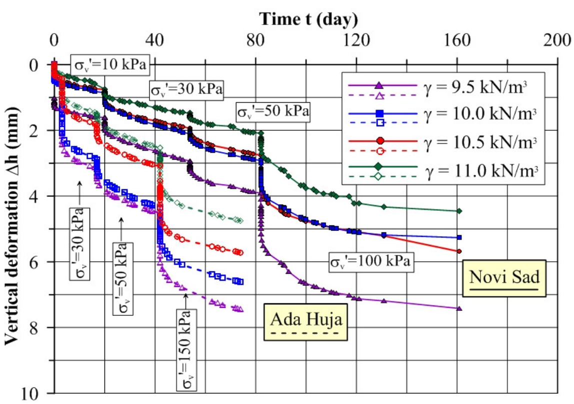

Figure 2. Relationship ofthe time-strain for samplesof the series Aand B

3 TEST RESULTS

During the testing, data on the time settlement were collected. Results show that in the early period of time, most of the curves have a relatively slow trend, which significantly increases with time (Figures 3 and 4). Significantly higher inclination at an advanced phase of compression is attributed to the higher waste decomposition and the gradual weakening of the solid skeleton which at a certain point cannot resist its own weight and leads to deterioration and collapse. Increase of pores and frequent collapses during the waste degradation are some of the main factors that influence the secondary compression.

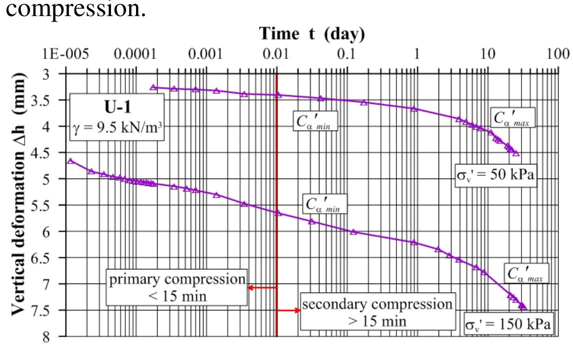

Figure 3. Compressibility diagram for loading level σ_1' = 50 and 150 kPa (samples of series A)

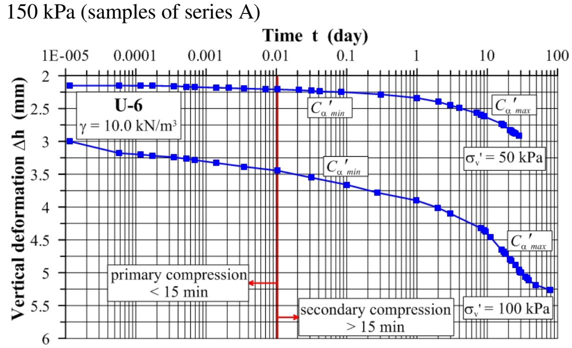

Figure 4. Compressibility diagram for loading level σ_1' = 50 and 100 kPa (samples of series B)

It is evident that the transition from primary to secondary compression is not clearly defined. The secondary compression index is calculated according to the adopted period of 15 min for the beginning of secondary compression. It should be noted that other researchers have made similar assumptions on both the duration of primary and the beginning of secondary compression (Landva et al. 2000; Hossain &Gabr 2005; Singh 2008).

Values of modified primary and secondary compression index are cumulatively presented in Figures 5 and 6. Those values were presented by about 30 authors (including values obtained in this research). Numerical values related to the index or modified secondary compression index, which is obtained from the steeper part of the time-settlement curve and basically presents their maximum values, are mostly given in the literature. Index and modified index of secondary compression were determined for all load steps, particularly for less steep and steeper parts of the curve. Considering the nature of deformations, its minimal values $C_{\alpha min}$ and $C_{\alpha}'_{min}$ were determinedfrom the less steep part of the diagram, while from the steeper part of the diagram (which generally begins after 1 to 5 days), the maximal values $C_{\alpha max}$ and $C_{\alpha}'_{max}$ were determined.

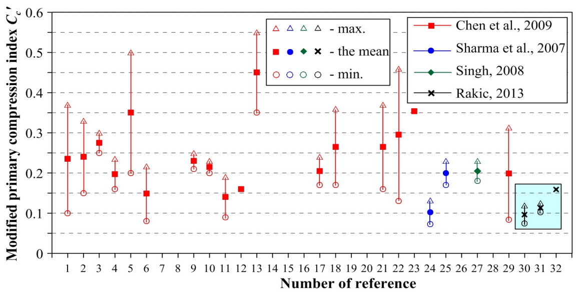

Figure 5. Display of modified primary compression index

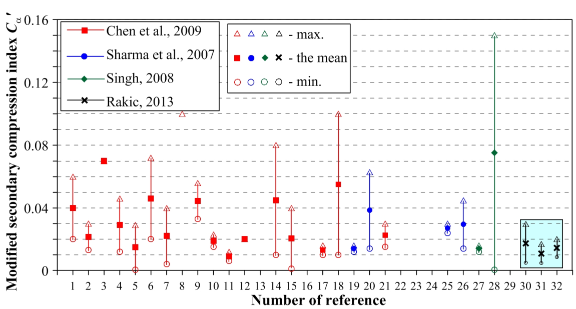

Figure 6. Display of modified secondary compression index

It can be noted that the values vary a lot and that most authors give quite wide intervals. One of the reasons for such pronounced result dispersion could be the method of sample preparation, i.e. different initial values of void ratio and bulk density, but also the use of different normal stress values during the test. Also, the authors utilised different methodologies during the test performance. Thus the individuals performed short-term tests and the loads lasted from several hours to several days during one stage (Chen et al. 2009; Babu et al. 2010). In contrast, in some cases, time per one load stage was several months (Hossain &Gabr 2005; Singh, 2008), and up to one year (Marques et al. 2003). On the other hand, some results were obtained froma small number of samples (Singh, 2008: 4 samples), and others from over 30 samples (Chen et al. 2009: 31 samples). The apparatus with which the tests were performed were different, because besides the conventional oedometer apparatus, a special apparatus was used which included the ability to simulate the long biodegradation process.

The correlation relationships related to the primary compression index can be found very rarely in the literature. A frequently used relationship is the one proposed by Sowers (1973), which refers to the relationship of the primary compression index and initial void ratio. The results that he obtained show that C_c ranges from $0.15e_0$ in municipal solid waste with low content of organic substances to $0.55e_0$ in municipal solid waste with high content of organic substances. It is characteristic that the index values are higher if the presence of wood, bushes and cans is higher, while the lower values are the consequence of the presence of stiffer material.

The results of the study are presented in Figure 7. It can be seen that the obtained values of the primary compression index fit well in the boundary value interval proposed by Sowers.

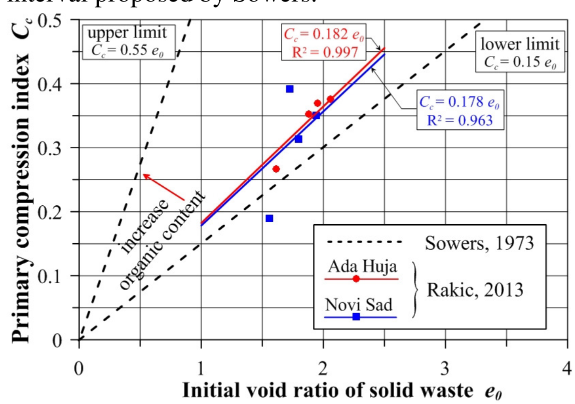

Figure 7. Relationship of the primarycompressionindexand initial void ratio

Established relationship between the primary compression index and initial void ration approximately corresponds to the lower limit ($C_c = 0.178\ e_0$ to $C_c = 0.182\ e_0$). The obtained results lead to the general conclusion that the tested waste contains less organic substances. Considering that the established relationships are very similar, regardless of the sample location, it can be concluded that the waste age and its composition do not have a large influence on the primary compression index. Therefore, the following relationship is recommended for municipal solid waste in Serbia:

$$C_c = 0.18 \cdot e_0$$

Sowers (1973) also defined, based on field monitoring, the relationship of secondary compression index and initial void ratio. When it comes to waste for which the conditions of decomposition (decay) are unfovarable, C_α is about $0.03e_0$; otherwise, when the conditions of waste decomposition are favorable (warm and humid conditions), its value increases and C_α is about $0.09e_0$. The values of the secondary compression index, obtained from the laboratory tests of the municipal solid waste from the mentioned landfills, are cumulatively presented in Figure 8.

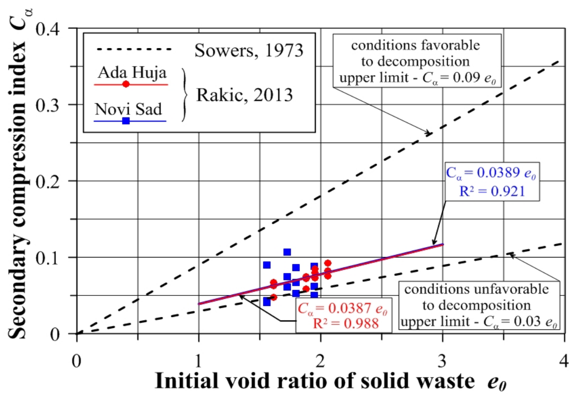

Figure 8. Relationship of the maximum secondary compression index and initial void ratio

As in the previous case, the correlation relationship between the maximum secondary compression index and initial void ratio approximately corresponds to the lower proposed limit, with values $C_\alpha = 0.0387e_0$, and $C_\alpha = 0.0389e_0$. These values lead to the general conclusion that the conditions for the further waste degradation and its decomposition are mainly unfavourable. Additionally, it can be concluded that due to approximately similar composition of the tested municipal solid waste (Table 1), its age did not have a major influence on the secondary compression index value, because a nearly identical correlation relationship was established for the waste from the landfill Ada Huja and from the landfill in Novi Sad. Therefore, the following relationship is recommended for municipal solid waste in Serbia:

$$C_{\alpha\,max} = 0.0388 \cdot e_0$$

Similar analysis was performed for the minimum secondary compression index (Figure 9).

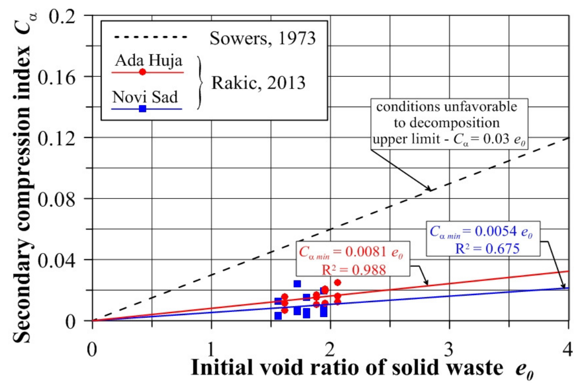

Figure 9. Relationship of the minimum secondary compression index and initial void ratio

Unlike the maximum secondary compression index, here the correlation relationship was conditioned by the waste age. However, due to simplification, in this case the averaged value of the minimum secondary compression index for the municipal solid waste in Serbia is also recommended:

$$C_{\alpha\,min} = 0.0068 \cdot e_0$$

4 CONCLUSION

In this paper the values of primary and secondary compression index of municipal solid waste from the older landfills in Serbia was presented. Those values are in range that can be found in the world literature. However, it does not mean that they can always be taken from the literature data without previous knowledge of methods and procedures for their determination. For the older municipal solid waste from the landfills in Serbia, recommended relationships of these indexes and initial void ration fit in with Sowers' intervals quite well. In both cases these values approximately correspond to the lower limits: for the primary index as well as the maximum secondary compression index. In this paper the relationship of the minimum secondary compression index and void ratio is also suggested. Unlike the primary compression index, where it was concluded that the waste age had no significant influence, for the secondary compression index it was concluded that the correlation relationship is conditioned by the waste age.

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