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Analyse de la corrélation entre l'indice modifié de compression secondaire et primaire sur l'exemple des vieux déchets municipaux en Serbie

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ABSTRACT: The paper presents the results related to the determination of the index of primary and maximum and minimum indices of secondary compression, i.e. modified primary and secondary compression indices (C_c, C_c', $C_\alpha'_{min}$, $C_\alpha'_{max}$), obtained by laboratory testing of artificially prepared municipal waste samples (three series of 9 samples in total) in an oedometer apparatus with a diameter of 20 cm. 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 the other that is still in use (city landfill in Novi Sad). The duration of the test of the first series was 74 days, the second series 161 days and the third series 147 days. From the results it was possible to present the relationship of these indices and the initial void ratio as well as the influence of normal stresses on the ratio of modified secondary and primary compression indices ($C_\alpha'_{max}/C_c'$ and $C_\alpha'_{min}/C_c'$). The established relation can be useful for obtaining the secondary compression index for a significantly shorter duration of the experiment, since a time of 15 min has been adopted for the completion of the primary compression.

RÉSUMÉ: L'article présente les résultats liés à la détermination de l'indice des indices primaire et maximum et minimum de compression secondaire, c'est-à-dire des indices de compression primaire et secondaire modifiés (C_c, C_c', $C_\alpha'_{min}$, $C_\alpha'_{max}$), obtenus par analyse en laboratoire d'échantillons préparés artificiellement de déchets municipaux (trois séries sur un total de 9 échantillons) dans un appareil oedomètre d'un diamètre de 20 cm. D'anciens déchets municipaux ont été utilisés, qui provenaient de deux décharges en Serbie, l'une qui n'est plus utilisée (Ada Huja à Belgrade) et l'autre qui est toujours utilisée (décharge municipale de Novi Sad). La durée du test de la première série était de 74 jours, de la deuxième série de 161 jours et la troisième série 147 jours. À partir des résultats, il a été possible de présenter la relation entre ces indices et le coefficient de porosité initial ainsi que l'influence des contraintes normales sur le rapport des indices de compression secondaire et primaire modifiés ($C_\alpha'_{max}/C_c'$ and $C_\alpha'_{min}/C_c'$). La relation établie peut être utile pour obtenir l'indice de compression secondaire pour une durée significativement plus courte de l'expérience, car un temps de 15 min a été adopté pour l'achèvement de la compression primaire.

KEYWORDS: municipal solid waste; secondary compression index; ratio of modified secondary and primary compression index.

1 INTRODUCTION

Determining numerical indicators of mechanical behaviour of municipal waste is quite complex, and the main reasons for this are: variable and heterogeneous composition of waste which is porous and mostly unsaturated, difficult taking and testing of representative samples, lack of generally accepted sampling and testing methodology, pronounced changes in properties depending on time i.e. stage of waste decomposition, etc.

When it comes to determining the deformable characteristics of municipal solid waste - MSW, there are different approaches. The very data on the different approaches indicate that certain problems remained unsolved, because the mechanical behaviour of municipal waste is still not fully understood. According to some authors, the behaviour of waste should be considered within the special discipline "waste mechanics", and the term "waste geotechnics" is also mentioned (Dixon, Russel & Jones 2005), so as a rule, laboratory tests are performed based on basic methods and concepts developed for soil. For these reasons appropriate geotechnical classification systems are proposed, which include key factors influencing the mechanical behaviour and physical properties of municipal waste. The aim is to include as many components in the waste as possible in the classification system and to select indicators that need to be described and examined in practice. Some of the systems of geotechnical classification of municipal waste also provide information on the compressibility and degradability of components, thus enabling the comparison of different wastes. (Rakić et al. 2020). 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 most usually used laboratory test 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 (Rakić et al. 2015).

2 SAMPLE SELECTION 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 (Figure 1).

Figure 1. Analysed municipal waste from exploration boreholes and exploration pits.

After drying at 60°C, the mass of extracted waste groups were measured to define the mass percentage in relation to the total sample mass. 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" (EC, 2004). After defining the composition, sorting of waste was performed according to the partially modified procedure presented in Figure 2 (Rakić 2013).

Figure 2. The applied procedure of municipal waste classification.

The results indicate that it is old waste, which contains a significant percentage of unclassified and soil material (Table 1). 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 (Rakić et al. 2013).

Table 1. Composition of analysed municipal waste.

Type and denotation of waste by S.W.A. tool catalogue	Mass (%)	
	Landfill Ada Huja, Belgrade	Landfill 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

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≥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 < 8 cm. 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 raising the support in the cylinder, i.e. moving the lower surface for the load (Figure 3).

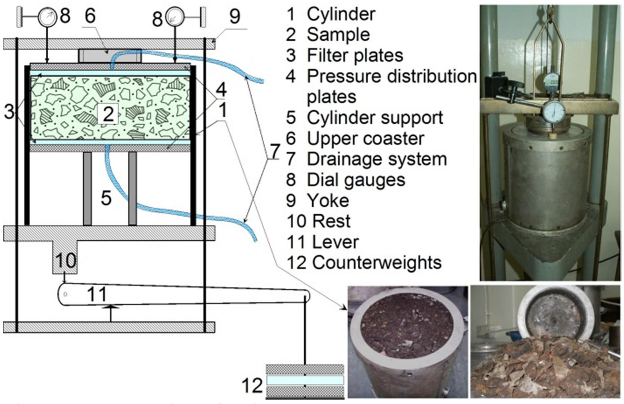

Figure 3. Construction of oedometer apparatus

In this way samples were formed in three series (A, B and C). The waste from the landfill Ada Huja (age over 40 years) was used for the series A (4 samples), and the waste from the landfill in Novi Sad (age about 20 years) was used for the series B (4 samples). One sample was formed for the series C from mixed waste from two landfills (Ada Huja and Novi Sad). For all three series, samples were formed with different unit weights and with natural moistures (Table 2), which are typical for most landfills which contain a higher percentage of soil (Zekkos et al. 2006).

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
C	U-9	30.8	10.0	2.05	1.676

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). Also, specific gravity was determined by laboratory test using completely 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 obtained specific gravity values ranged from G_s = 1.977 to 2.390, and the highest values were obtained for waste samples with the highest soil material content, 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 – 150 kPa (100 kPa for series B) which were constantly maintained. Sample U-9 was loaded with three vertical stress levels: 11 – 32 – 53 kPa. Total duration of the test for samples of the series A was 74 days, for samples of the series B was 161 days, and series C 146 days. Load durations differed from grade to grade and from sample to sample, and ranged from a minimum of 3 days for the series A (σ'_v =10 kPa), to a maximum of 83 days for the sample of the series C (σ'_v =53 kPa, Figure 4). At the end of the last load level, short-term unloadings were performed for 10 min, as follows: 50 - 30 - 10 - 0 kPa, or: 32 - 11 - 0 kPa for sample U-9.

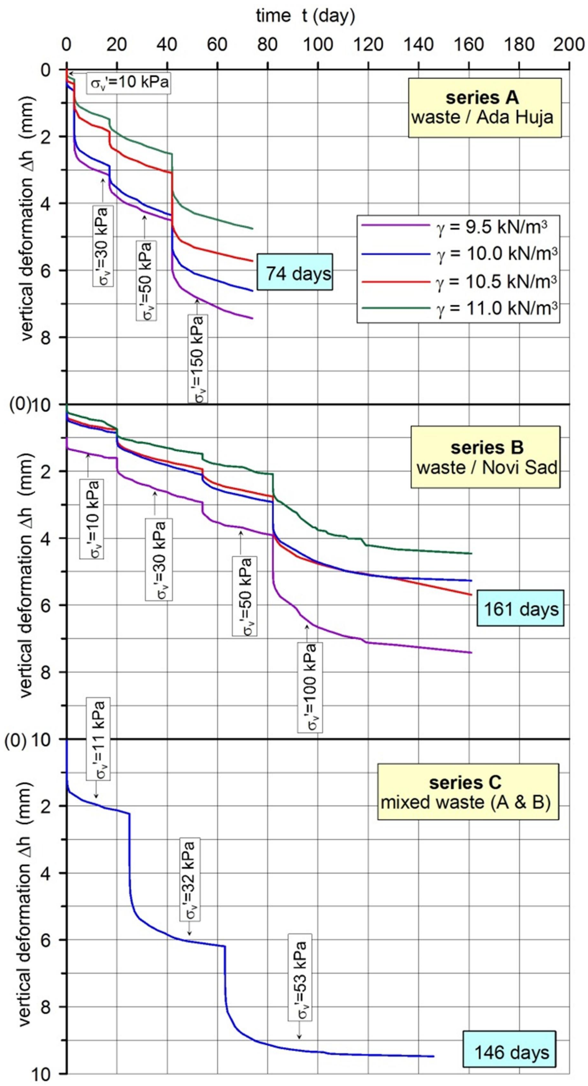

Figure 4. Time-deformation diagrams for samples of the series A, B and C.

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 5, 6 and 7). 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.

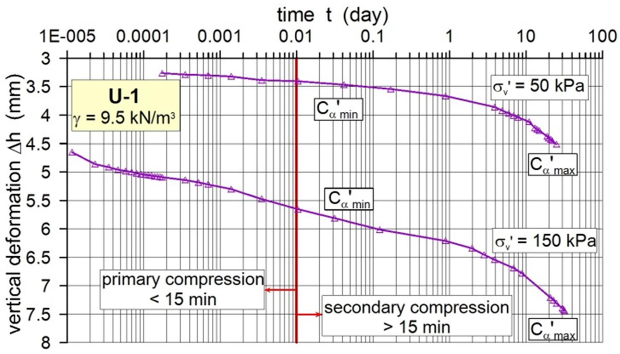

Figure 5. Compressibility diagram for loading level $\square_1$' = 50 and 150 kPa (samples of series A)

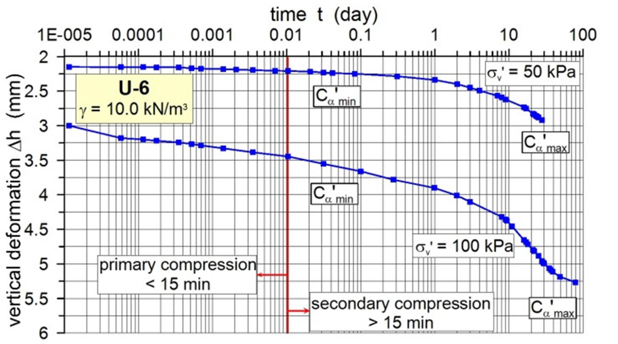

Figure 6. Compressibility diagram for loading level σ_1' = 50 and 100 kPa (samples of series B)

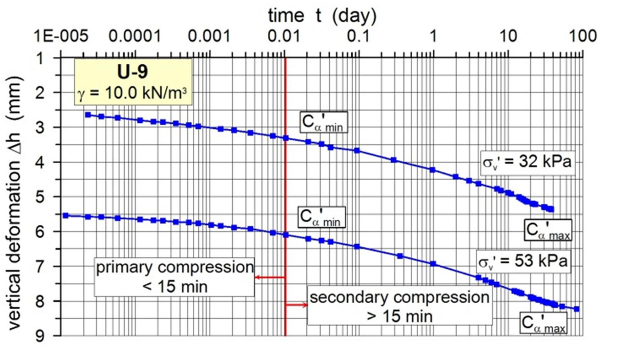

Figure 7. Compressibility diagram for loading level σ_1' = 32 and 53 kPa (samples of series C)

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).

3.1 *Dependence of index and modified index of primary and secondary compression (C_c, C_c', C_α, C_α') on void ratio*

Values of modified primary and secondary compression index are cumulatively presented in Figures 8 and 9. 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 are 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 determined from 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 (Bjarnagard & Edgers, 1990).

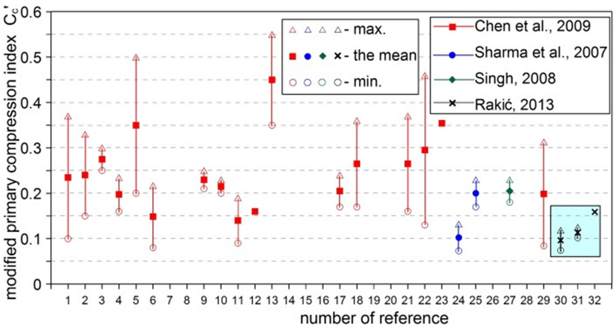

Figure 8. Display of modified primary compression index

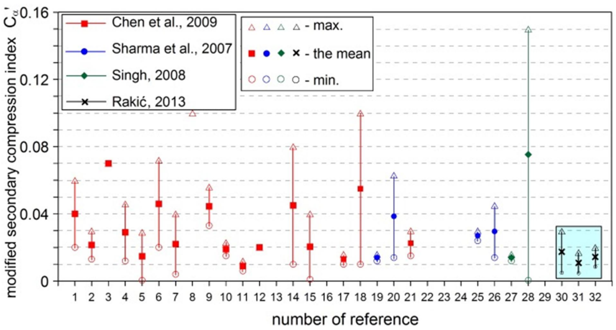

Figure 9. Display of modified secondary compression index

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 from a small number of samples (Singh, 2008: 4 samples), and others from over 30 samples (Chen et al. 2009: 31 samples). The apparatuses 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 10. It can be seen that the obtained values of the primary compression index fit well in the boundary value interval proposed by Sowers.

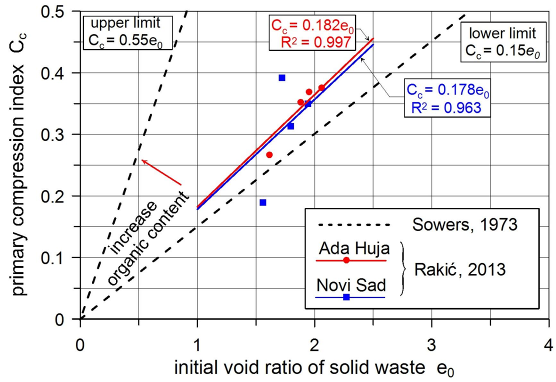

Figure 10. Relationship of the primary compression index and initial void ratio

Established relationship between the primary compression index and initial void ration approximately corresponds to the lower limit ($C_c = 0.178e_0$ to $C_c = 0.182e_0$). 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

$$C_c = 0.18e_0 \tag{1}$$

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 11.

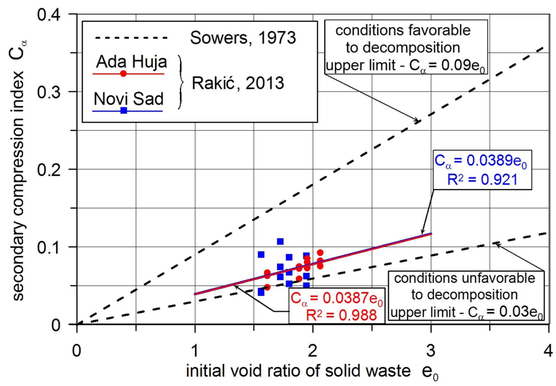

Figure 11. Relationship of the maximum secondary compression index and initial void ratio

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

$$C_{\alpha\,max} = 0.0388e_0 \tag{2}$$

Similar analysis was performed for the minimum secondary compression index (Figure 12).

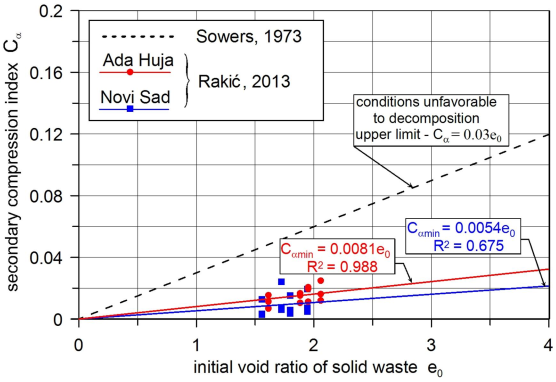

Figure 12. Relationship of the minimum secondary compression index and initial void ratio.

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

$$C_{\alpha\,min} = 0.0068e_0 \tag{3}$$

3.2 *Ratio of modified secondary and primary compression index*

Several authors (Mesri and Castro, 1987) have analysed the relationship between the secondary and primary compression index for different types of geomaterials, but not for municipal waste. They concluded that for materials with a predominant fibrous structure (e.g. peat) this ratio has the highest value, which is around 0.07. The lowest value of the ratio of secondary and primary compression was obtained for granular materials and is around 0.01.

Determining the compressibility parameters of municipal waste requires long-term laboratory tests. Since the primary compression in municipal waste lasts significantly shorter, compared to the secondary (in this paper, the primary compression duration of about 15 min is adopted), by establishing the relationship between these two parameters, the test time could be significantly shortened.

For all tested samples, and depending on the value of normal stresses, the minimum $C_\alpha'_{min}$ and maximum $C_\alpha'_{max}$ were calculated. As the values of the modified primary compression index C_c' were determined for all tested samples, it made it possible to establish their correlation depending on the applied vertical stresses (σ' = 30, 50, 100-150 kPa).

When it comes to the maximum ratios of the modified secondary and primary compression index, the general conclusion is that it increases as vertical stresses increase. A similar conclusion can be reached when analysing the values for the minimum ratios of the modified secondary and primary compression index.

In Figures 13 and 14 these relationships are presented, noting that for clarity of results, they are given in the form of logarithmic diagrams. In this way, the law has been established according to which, with the increase of vertical stresses, the relationship between the modified indices of secondary and primary compression increases.

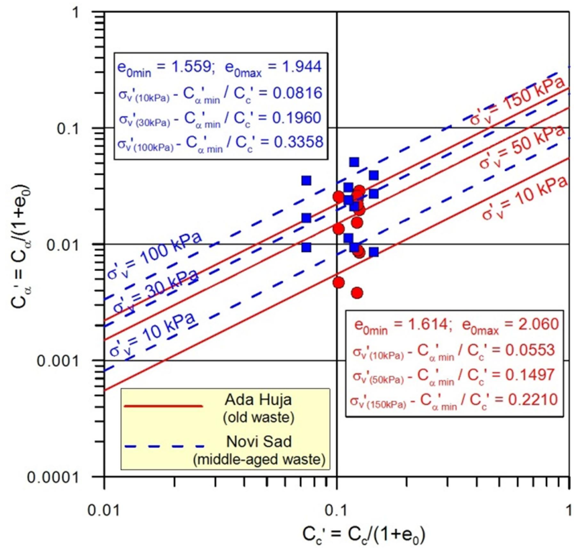

Figure 13. Effect of normal stresses on the ratio of the maximum modified indices of secondary and primary compression.

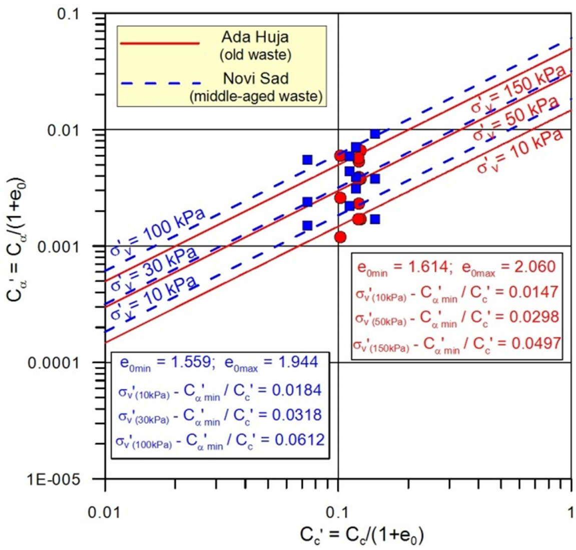

Figure 14. Effect of normal stresses on the ratio of minimum modified indices of secondary and primary compression.

4 CONCLUSION

Unlike natural soil, where the main component of settlement is primary compression, in municipal waste the main component of total settlement is secondary compression. Therefore, in landfill settlement analyses, the secondary compression index and the modified secondary compression index (C_α, C_α'), determined from the settlement diagram, are of special importance. These diagrams for the early period of time, as a rule, show a slight slope, but due to the pronounced decomposition of waste, the slope increases significantly with time, so the minimum and maximum values of the modified secondary compression index ($C_{\alpha}'_{min}$, $C_{\alpha}'_{max}$) are determined for municipal waste. For these reasons, it is necessary to conduct long-term experiments that can take several months. The tests presented in the paper (performed in a period of 74 - 161 days depending on the series of tests), allowed to establish a correlation between the modified index of primary and min and max modified secondary compression indices. The results are presented graphically in the form of logarithmic diagrams, which can be useful for obtaining the approximate values of the indices $C_{\alpha}'_{min}$ and $C_{\alpha}'_{max}$, for a significantly shorter duration of the experiment.

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5 REFERENCES

Babu G.L.S., Reddy K.R. and ChoukseyS.K. 2010. Constitutive model for municipal solid waste incorporating mechanical creep and biodegradation-induced compression, *Waste Management* 30, 11-22.

Bjarnagard A.B. and Edgers L. 1990. Settlement of municipal solid waste landfills, *Proceedings, 13 Annual Madison Waste Conference,* 192-205.

Chen Y.M., Zhan TL.T., Wei H.Y. and Ke H. 2009. Aging and compressibility of municipal solid wastes, *Waste Management* 29, 86-95.

Dixon N., Russell D and Jones V. 2005. Engineering properties of municipal solid waste, *Geotextiles and Geomembranes* 23, 205-233.

European Commission. 2004. Methodology for the Analysis of Solid Waste (SWA-Tool), User Version, Project: SWA–Tool, Development of a Methodological Tool to Enhance the Precision & Comparability of Solid Waste Analysis Data, Program: 5th Framework Program, EU Austria, 57.

Fassett J.B., Leonards G.A. and Reppeto P.C. 1994. Geotechnical properties of municipal solid wastes and their use in landfill design. *Proceedings of the WasteTech '94* (Eds: National Solid Waste Management Association), 1-31. Silver Springs, Maryland.

Gabr M.A. and Valero S.N. 1995. Geotechnical properties of municipal solid waste, *Geotechnical Testing Journal*, ASTM 18, 241-254.

Gasparini P.A., Saetti G.F. and Marastoni M. 1995. Experimental research on MSW compaction degree and its change with time. *Proceedings of the 5th International Landfill Symposium, Sardinia '95,* S. Margherita di Pula, Cagliari, Italy, 833-842.

Grisolia M. and Napoleoni X. 1996. Geotechnical characterization of municipal solid waste: choice of design parameters. *Proceedings of the Second International Congress on Environmental Geotechnics,*V.2, 641-646.

Hossain S.M. and Gabr M.A. 2005. Prediction of municipal solid waste landfill settlement with leachate recirculation. *Proceedings of the Geo-Frontiers Congress 2005,* Publisher: ASCE*,* 168*, 50.* Austin, Texas.

Huat B.K. 2004. Organic and peat soils engineering. University Putra Malaysia Press, Serdang.

Landva A.O., Valsangkar A.J. and Pelkey S.G. 2000. Lateral earth pressure at rest and compressability of municipal solid waste. *Canadian Geotechnical Journal* 37, 1157-1165.

Machado S.L., Carvalho M.F. and Vilar O.M. 2002. Constitutive model for municipal solid waste. *Journal of Geotechnical and Geoenvironmental Engineering* 128, 940-951.

Marques A.C.M., Filz G.M. and Vilar O.M. 2003. Composite compressibility model for municipal solid waste, *Journal of Geotechnical and Geoenvironment Engineering* 129*,* 372-378.

Mesri G.M. and Castro A. 1987. C_{α}/C_c Concept and K_0 During Secondary Compression, *Journal of Geotechnical Engineering,* Volume 113*,* Issue 3, 230-247.

Rakić D., Čaki L. and Ljubojev M. 2011. Deformable characteristics of the old municipal solid waste sites with Ada Huja, Belgrade – Serbia. *Technics Technologies Education Management – TTEM* 6, 52-60.

Rakić D. 2013. Constitutive relations of landfill municipal waste in Serbia (in Serbian), Ph.D. thesis, *University of Belgrade, Faculty of Mininag and Geology, Department of Geotechnics,* Belgrade, 458.

Rakić D., Čaki L. and Ćorić S. 2013. Shear strength of municipal waste materials from two landfills in Serbia, *Proceedings of the International Symposium: Coupled Phenomena in Environmental Geotechnics*, 347-354. CRC Press/Balkema, Taylor & Francis Group, London.

Rakić D., Čaki L., Hadži-Niković G., Basarić I. 2015. Compresibillity parameters of old municipal waste from two landfills in Serbia, *Proceedings of the XVI European Conference of Soil Mechanics and Geotechnical Engineering- ECSMGE*, Geotechnical Engineering for Infrastructure and Development, 2741-2746.

Rakić D., Basarić I., Čaki L., Ćorić S. 2020. Contribution to the geotechnical classification of municipal waste landfills in Serbia, *Environmental Geotechnics,* Vol. 7, Issue 7, 501-511.

Reddy K.R., Gangathulasi J., Hettiarachchi H. and Bogner J. 2008. Geotechnical properties of municipal solid waste subjected to leachate recirculation, *Geotechnical Special Publication, ASCE* 177*,* 144-151.

Sharma H.D. and De A. 2007. Municipal solid waste landfill settlement: postclosure perspectives, *Journal of Geotechnical and Geoinveronmental Engineering* 133*,* 619-629.

Sharma H.D., Dukes M.T. and Olsen D.M. 1990. Field measurements of dynamic moduli and Poisson's ratios of refuse and underliyng soils at a landfill site, *Geotechniques of waste fills – theory and practice*, 57-70. ASTM International, STP 1070.

Singh M.K. 2008. Characterization of stress-deformation behaviour of municipal solid waste. Ph.D. thesis. University of Saskatchewan, Saskatoon, SK, Canada, 292.

Skempton A.W. and Petley J. 1970. Ignition loss and other properties of peats and clays from Avonmouth, King's Lynn, and Cranberry Moss, *Geotechnique* 20, 343-356.

Sowers G.F. 1973. Settlement of waste disposal fills. *Proceedings of the Eighth International Conference on Soil Mechanics and Foundation Engineering*, 207-210. Vol. 2.2, Session 4, Moscow, USSR.

Vilar O.M. and Carvalho M.F. 2004. Mechanical properties of municipal solid waste, *Journal of Testing and Evaluation* 32, 1-12.

Zekkos D.P., Bray J.D., Kavazanjian E., Matasovic N., Rathje E.M., Riemer M.F. and Stokoe K.H. 2006. Unit weight of municipal solid waste. *Journal of Geotechnical and Geoenvironmental Engineering* 132, 1250-1261.