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Stabilization of fine-grained soils with fly ash

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Preliminary report

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Stabilization of fine-grained soils with fly ash

Results of laboratory research focusing on soil stabilization, using fly ash without activators, are presented in the paper. Two types of fine-grained soils were tested: low to medium plasticity clay and very expansive, medium to high plasticity clay. Soil-fly ash mixtures were prepared at optimum fly ash contents (15 and 20 %). The effects of fly ash on the soil plasticity, moisture-density relationship, unconfined compressive strength, shear strength parameters, CBR (California Bearing Ratio) values, deformation parameters, and swell potential, were evaluated. Results obtained show that the use uf fly ash can significantly contribute to the improvement of soil properties.

Key words:

soil stabilization, fly ash, fine-grained soil, shear strength, CBR

Prethodno priopćenje

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Stabilizacija sitnozrnatog tla letećim pepelom

U radu su prikazani rezultati laboratorijskog ispitivanja stabilizacije tla letećim pepelom bez primjene aktivatora. Ispitivane su dvije vrste sitnozrnatog tla: glina niske do srednje plastičnosti te vrlo ekspanzivna glina srednje do visoke plastičnosti. Mješavine tla i letećeg pepela su pripremljene s optimalnom količinom pepela (15 i 20 %). Ispitivan je utjecaj letećeg pepela na plastičnost tla, odnos vlage i gustoće, jednoosnu tlačnu čvrstoću, vrijednosti parametara posmične čvrstoće, vrijednosti CBR-a (California Bearing Ratio-CBR), deformacije i potencijal bujanja. Dobiveni rezultati pokazuju da primjena letećeg pepela može značajno poboljšati svojstva tla.

Ključne riječi:

stabilizacija tla, leteći pepeo, sitnozrnato tlo, posmična čvrstoća, CBR

Vorherige Mitteilung

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Stabilisierung feinkörniger Böden mittels Flugasche

In dieser Arbeit sind Resultate von Laborversuchen zur Bodenstabilisierung mittels Flugasche ohne Anwendung von Aktivatoren dargestellt. Zwei Typen feinkörnigen Bodens wurden getestet: Ton niedriger bis mittlerer Plastizität und sehr expansiver Ton mittlerer bis hoher Plastizität. Bodenmischungen mit einem optimalen Anteil an Flugasche (15 und 20 %) wurden vorbereitet. Der Einfluss von Flugasche auf die Plastizität des Bodens, das Verhältnis von Feuchte und Dichte, die einachsige Druckfestigkeit, die Schubfestigkeitsparameter, die Werte des CBR (California Bearing Ratio-CBR), die Verformung und das Schwellungspotenzial wurden erforscht. Die Resultate zeigen, dass Flugasche die Bodeneigenschaften bedeutend verbessern kann.

Schlüsselwörter:

Bodenstabilisierung, Flugasche, feinkörniger Boden, Scherfestigkeit, CBR

1. Introduction

Fly ash produced by burning pulverized coal in power plants is a fine grained material that is carried off in the flue gas and collected by means of electrostatic precipitators or mechanical collection devices (cyclones). In recent decades, fly ash has been widely used in construction industry. The majority of this use concerns production of concrete, concrete products, grout (about 46 %), other structural fills and embankments (22 %), waste and soil stabilization (~10 %). According to [1], 43.5 % of the 130 million tons of the coal ash produced in 2011 was beneficially used in the USA, while over 90 % of the total coal combustion products (17.7 million tons in 2008) were used in the EU [2]. In Serbia, approximately 7 million tons of fly ash and slag are produced every year, of which only 3 % is used in cement industry. The remaining products (about 300 million tons so far) are disposed in landfills, taking up an area of approximately 1600 hectares [3, 4].

Fly ashes from Serbian power plants have pozzolanic properties and, because of low concentrations of calcium compounds (less than 10 % CaO), they are devoid of self–cementing characteristics. These ashes belong toclass Faccording to ASTM C 618 [4]. According to European Standard EN 197-1, these ashes are classified as siliceous (type V) ashes.

Studies on the use of fly ash for soil stabilization have so far been conducted by a number of researches. Many scientific results have shown that the self-cementing fly ash is an effective and economical stabilizing agent for a wide variety of construction applications [5-13]. Benefits of using the self-cementing fly ash include: drying of soil, reduction of shrink/swell potential, and increase in strength or subgrade capacity [5, 9, 11]. Although the non self-cementing fly ash should be used in soil stabilization applications with the addition of a cementitious agent such as lime, lime kiln dust, cement, or cement kiln dust [14], some researchers have shown that this flyash can effectively improve some engineering properties of soil even without activators [15-19].

This study is aimed at investigating effectiveness of stabilizing soft fine-grained soils by means of non self-cementing fly ashes without activators. This paper presents results of the fly ash soil stabilization laboratory research performed by the authors in 2012-2014 in the Laboratory for Soil Mechanics of the Faculty of Civil Engineering in Belgrade, as a part of the research project funded by the State Electric Company of Serbia. Materials used for implementation of the experimental research program include: fly ash from thermal power plants "Kolubara" (KOL-FA) and "Kostolac" (KOS-FA), and clay from the Kalenić Regional Waste Management Centre (soil A) and the Košava Wind Park Project (soil B).

2. Testing materials

2.1. Fly ash

Fly ash samples were directly collected from electrostatic precipitators. Chemical composition of thefly ashes was determined at the Faculty of Physical Chemistry in Belgrade (Table 1). The chemical composition is in line with published results [20]. Because the SiO_2+Al_2O_3+Fe_2O_3 content is above 70 % and sulfur trioxide (SO_3) content is less than (KOS-FA) or close to 5 % (KOL-FA), this fly ashcan be categorized intoclass F according to ASTM C 618.

2.2. Soils

Soils used for this study are fine grained soils, predominantly clays.

Soil A was collected at the borrow pits located close to the site of the future Kalenić Waste Management Centre near the "Kolubara" Power Plant. According to its mineral composition, this soil consists of quartz, muscovite and soft minerals of montm or illonite (testing conducted at the Faculty of Physical Chemistry, Belgrade). According to USCS, this soil, known as alevrite, is medium to high plasticity clay (CI/CH), with swell potential.

Soil B was collected at the site of the future Košava Wind Parknear Vršac in Vojvodina. The soil consists of Quaternary loess sediments, which have same mineral composition as loess, but with the loess structure altered – the soil is devoid of collapse potential. According to USCS, this soil can be classified as the low to medium plasticity clay (CL/CI).

3. Testing methods

Improvement level of the fly ash treated soils is dependent on: soil properties, fly ash addition ratio, delay time, and moisture content at the time of compaction [14]. An optimum percentage of fly ash must be used for successful soil stabilization so that preconditions can be created for all chemical reactions and change of microstructure in soil. Published papers have shown that an optimum ash content ranges from 10 to 30 %, depending on the type of soil and ash. To enable comparison of different fly ash-soil mixtures, testing samples were prepared under the same conditions, by compaction at optimum moisture content according to the Standard Proctor compaction test, with the compaction effort of 600 kNm/m^3. The following procedure

Table 1. Chemical composition of fly ash [%]

Fly ash	SiO_2	Al_2O_3	Fe_2O_3	ReactiveCaO	MgO	K_2O	Na_2O	TiO_2	SO_3	P_2O_5
KOL-FA	50.21	23.83	9.89	4.79	3.12	0.44	0.35	0.54	5.24	0.06
KOS-FA	56.38	17.57	10.39	7.46	2.13	0.57	0.38	0.52	0.95	0.025

Note: Values may not be entirely representative of the tested material as over time the chemical content of the coal used in the power plants may have changed.

was used for the preparation of mixture samples: a pre-weigh edquantity of dried soil and fly ash was mixed thoroughly to produce a homogeneous fly ash-soil mixture. Then the required quantity of water was added and, after mixing, the mixture was compacted without delay. The soil-fly ash specimens were extruded and sealed using a plastic wrap. Prior to testing, samples were left to cure in desiccators at 25°C. According to [6, 21], the compaction should start immediately after the mixing process and finish within a maximum of 2 hours. Stabilization effects can be negatively influenced by late compaction. During the hydration process, fly ash cements particles are included in the mixture, and more energy is required for successful compaction. A smaller strength gain, and sometimes loss of strength after late compaction, is explained by the loss of hydration products, and by the loss of connections between cemented particles [6]. Samples were tested two hours after compaction (t = 0), as well as at 7 and 28 days. All tests were performed on two or three specimens.
The following laboratory methods, based on SRPS (former JUS) standards, were used to determine physical and mechanical properties of the soil, ash and mixtures: The grain size analysis was performed on the fly ash and soil according to SRPS U.B1.018 (2005). Atterberg limits were determined for soil and mixtures using SRPS U.B1.020 (1980). The specific gravity of fly ash and soil was determined according to SRPS U.B1.014 (1988). The compaction of soil, ash and mixtures was conducted in accordance with SRPS U.B1.038 (1997). Unconfined compression (UCS) tests were carried out according to SRPS U.B1.029 (1996) on samples 38 mm in diameter and 76 mm in height. One dimensional consolidation tests were conducted according to SRPS U.B1.032 (1969) on samples 70 mm in diameter and 20 mm in height. The specimens were soaked for 24 hours before compression, and were then loaded incrementally to a maximum vertical stress of 400 kPa. Direct shear tests were performed according to SRPS U.B1.028 (1996) on samples with square base 60x60 mm, 30 mm in height. Prior to shear, saturated specimens were consolidated by applying vertical stresses of 100, 200, and 400 kPa. The strain controlled equipment was used in these tests. California bearing ratio (CBR) tests were performed according to SRPS U.B1.042 (1997) on fully soaked samples.

4. Test results and discussion

4.1. Optimum fly ash content

The increased soil strength is the main indicator of successful soil stabilization. In previous studies [5, 6, 8, 10, 13], the strength gain of treated soil was determined by uniaxial compression test or CBR test. In order to determine an optimum fly ash content, UCS tests were performed on fly ash-soil mixtures with different fly ash-soil ratios – 10/15/20/25 %. The highest UCS increase was achieved for the following fly ash content (Table 2):

Table 2. Optimum fly ash content for different mixtures

Fly ash	Soil A	Soli B
KOL-FA	15 %	15 %
KOS-FA	20 %	15 %

The optimum fly ash content from Table 2 was used for the direct shear, CBR and compression tests.

4.2. Specific gravity

Specific gravity values for fly ashes and soils are summarized in Table 3. The narrow range in specific gravity of fly ashes (2.11-2.22) can be attributed to similar iron and silica oxide contents.

Table 3. Specific gravity of fly ash and soil

Material / Spec. gravity	KOL-FA	KOS-FA	Soil A	Soil B
G_s	2,11	2,22	2,67	2,74

4.3. Grain size distribution

The grain size distribution for the fly ashes and soils is shown in Figure 1. The fly ashes are mostly silt to fine sand sizes, while the soils, according to USCS, are predominantly clay.

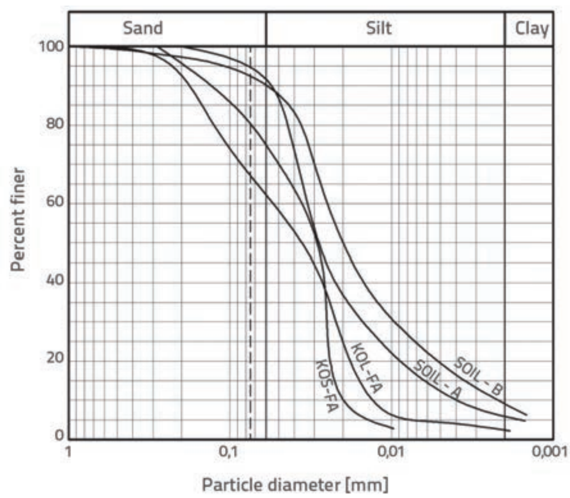

Figure 1. Grain size distribution curves

4.4. Soil plasticity

Fly ash particles are generally larger than clay particles. In most cases of high plasticity clay stabilization, the fly ash decreases plasticity of treated soil. Many studies have shown that plasticity of treated soil decreases with an

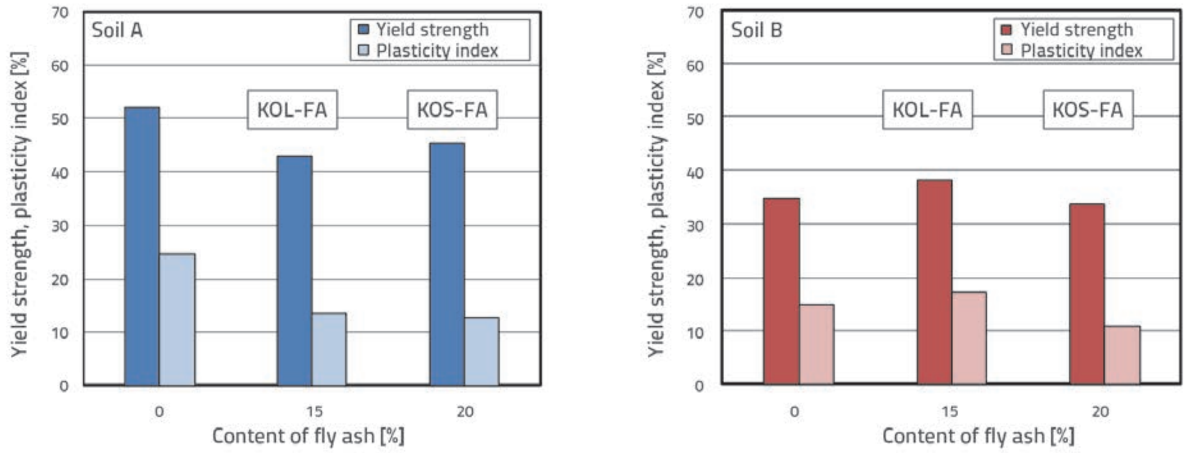

Figure 2. Variation in Atterberg limits for mixtures at t=0 (for optimum fly ash content)

increase in fly ash content [5, 7, 11, 16]. In case of medium to high plasticity soil (soil A), it has been observed that the addition of fly ashes results in a lower liquid limit and plasticity index, which is not the case for low plasticity soil (soil B), as shown in Figure 2.

4.5. Compaction

Standard Proctor test results (Figure 3) show that the maximum dry density decreases and the optimum moisture content increases with an increase in fly ash content (for both soil types

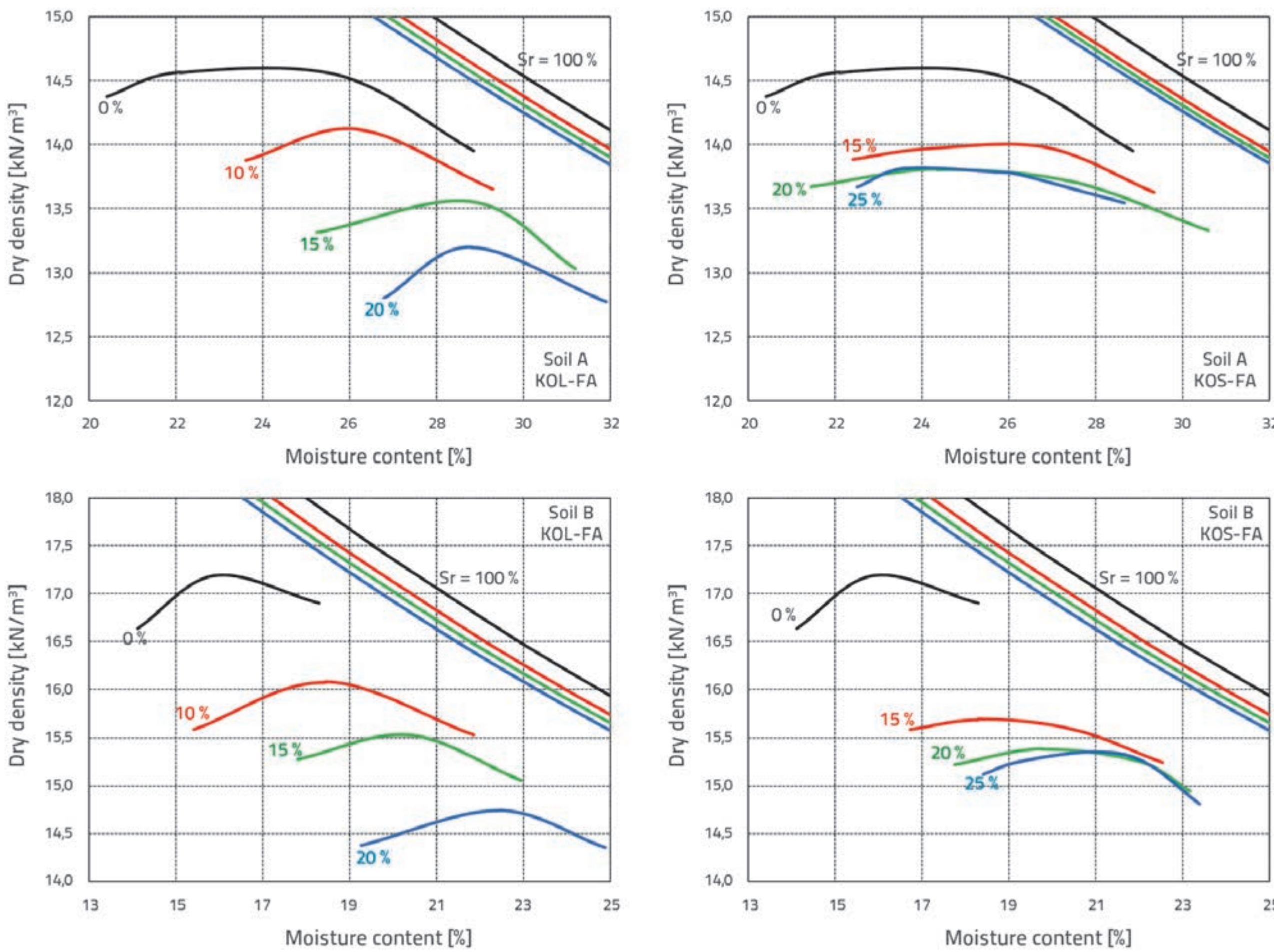

Figure 3. Moisture-density relationship of fly ash-soil mixtures

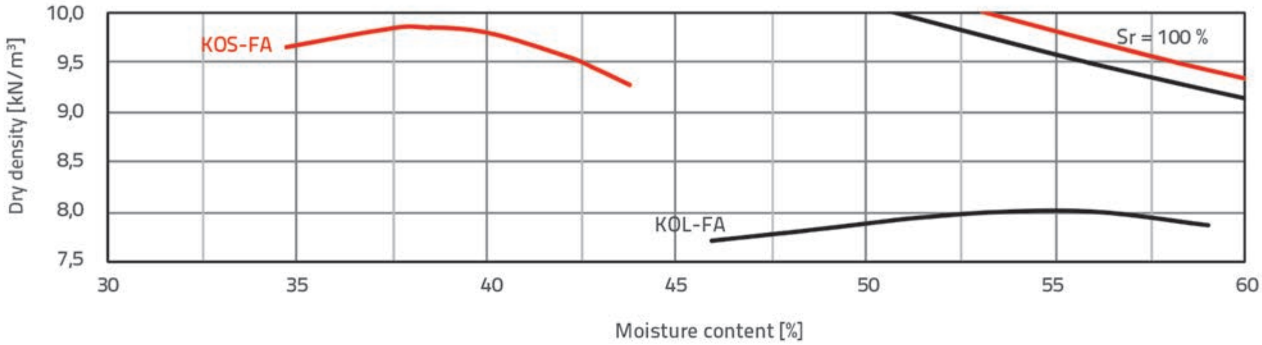

Figure 4. Moisture-density relationship of fly ashes

and ashes).The decrease in maximum dry density is associated with the fact that the specific gravity of the fly ashes is lower compared to that of the soil. Proctor compaction curves of fly ashes under study are shown in Figure 4.

4.6. Unconfined compressive strength (UCS)

The UCS test results are shown in Figure 5. Fly ashes have a very low UCS (up to 90 kPa). UCS was increased up to 20 % for soil A and up to 50 % for soil B, depending on elapsed time. The strength gain isnot significant, because the UCS of the fly ash used is very low.

4.7. Shear strength parameters in terms of effective stresses

Shear strength parameters in terms of effective stresses were determined using the direct shear test. The results obtained

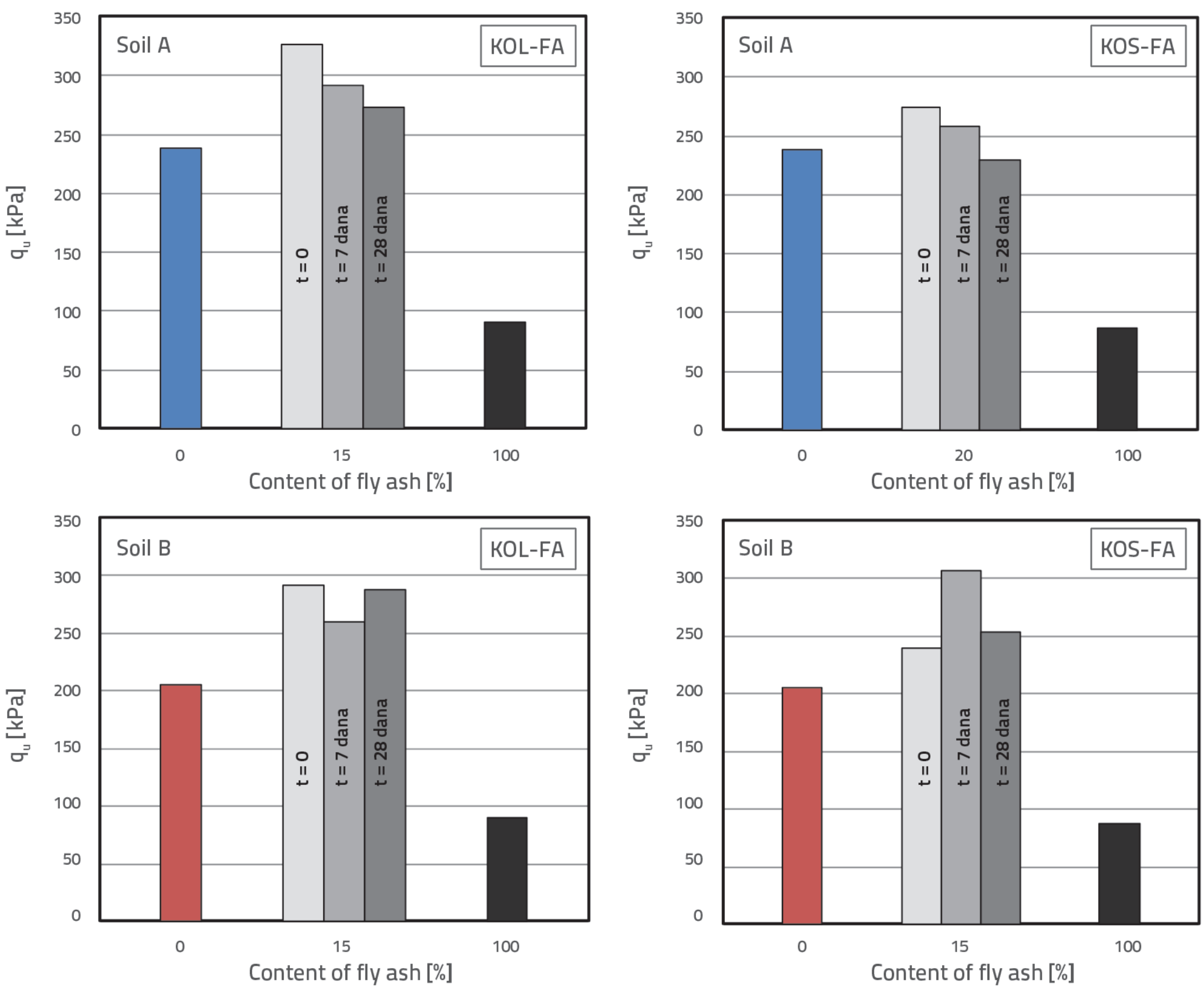

Figure 5. UCS of fly ash-soil mixtures for optimum fly ash content

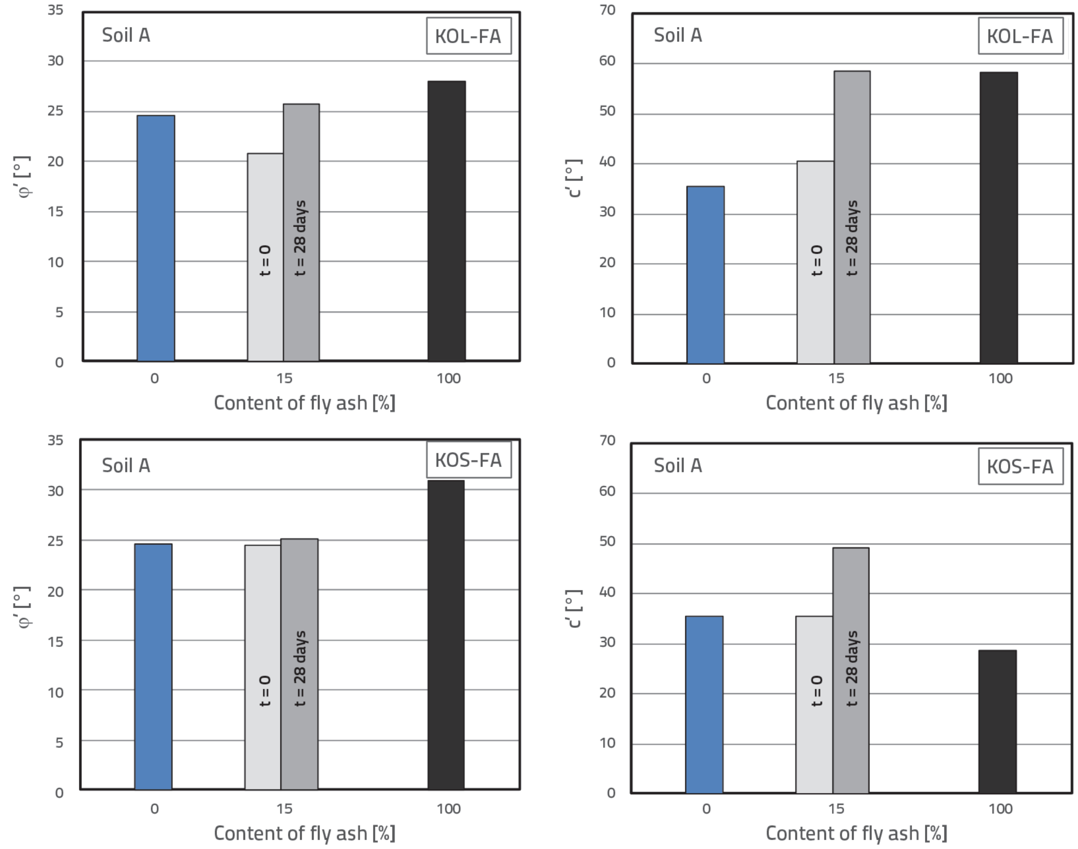

Figure 6. Variation in shear strength parameters for soil A

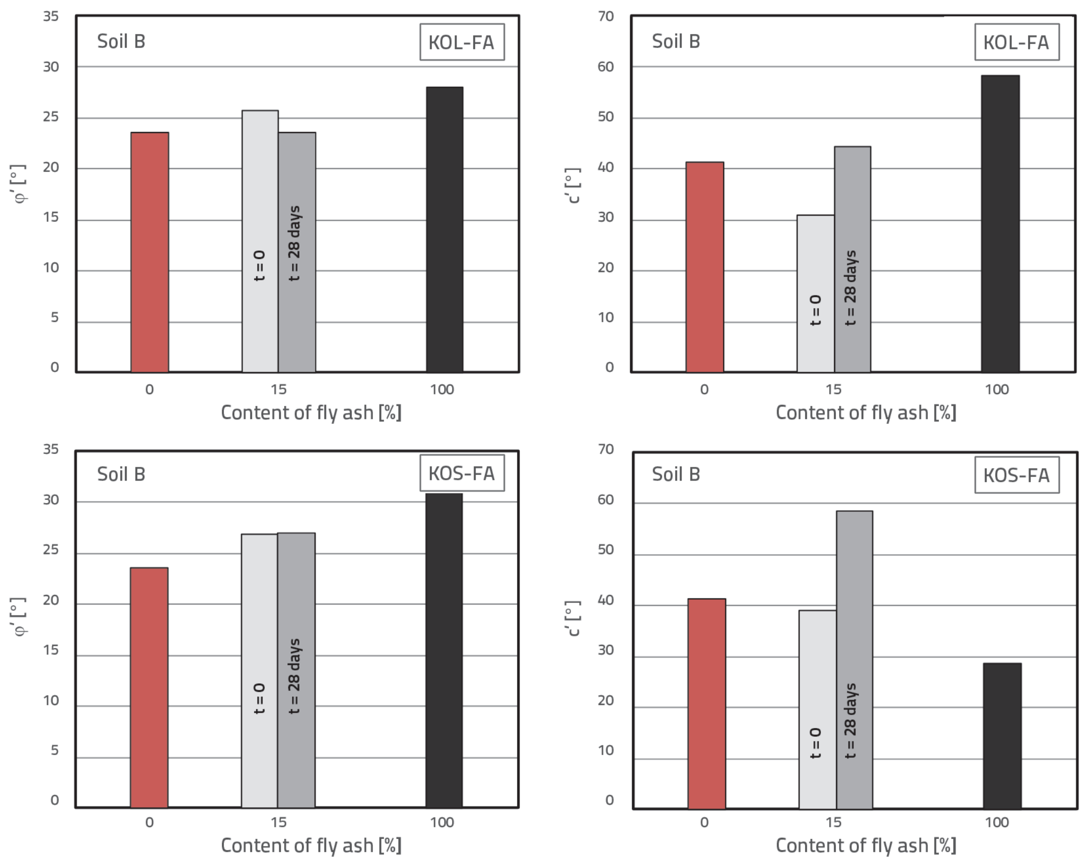

Figure 7. Variation in shear strength parameters for soil B

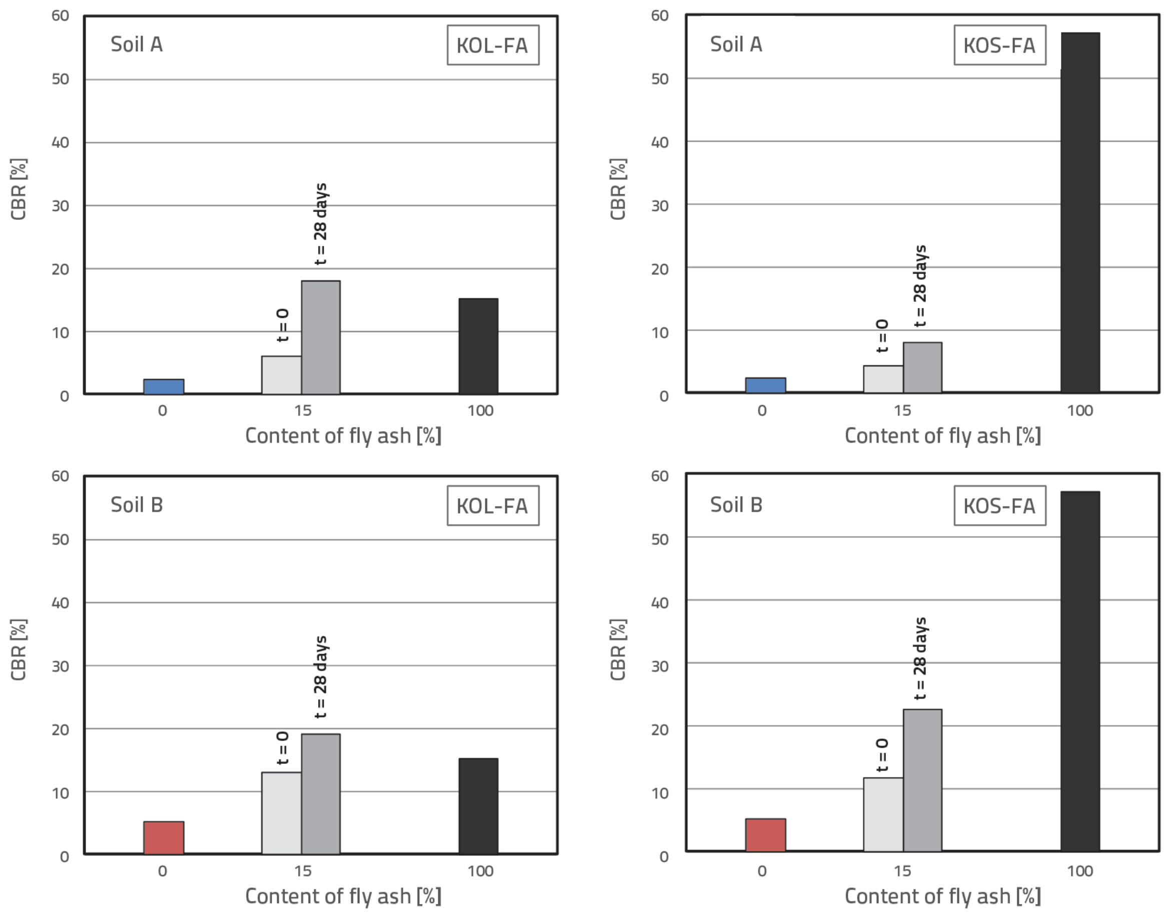

Figure 8. CBR values for soil A and soli B

(Figure 6 and Figure 7) show that the friction angle after 28 days does not substantially change with the addition of fly ash, for both types of soil and ash. On the other side, the cohesion increases with time for all tested mixtures, which is an indication that a slow pozzolanic reaction occurred due to presence of reactive CaO.

4.8. California bearing ratio (CBR)

It is known that clays are generally characterized by low CBR values, which makes them unsuitable for road subgrade construction. CBR tests were conducted on mixtures with an optimum fly ash content from Table 2.The results obtained showed significant gain compared to CBR values for base soils A and B. In case of soil types A and B, CBR values increased by 300-800 % and 360-420 %, respectively (depending on elapsed time). This is especially important for soil A, because it makes it usable for road construction (CBR value increased from 2 to 18). Also, this is the main stabilization effect for soil B. CBR values are shown in Figure 8, and are in line with results presented in [8, 9, 12, 13, 22].

4.9. Deformation parameters

The compressibility modulus for both soil types increases with the addition of fly ash (Figure 9 and Figure 10). The modulus increase is around 15-35 % and 30-50 % for KOL-FA and KOS-FA, respectively. In this case, the influence of time was not taken into account, and fairly small changes in the modulus are due to the fact that compacted samples were not completely identical. These changes are in the domain of scattering of results.

4.10. Swell potential

Although strength and deformation parameters for soil A can be considered acceptable, this soil showed a significant swell potential, which makes it unusable for most engineering purposes. The swell potential of soil A is mostly associated with the presence of expansive mineral montm or illonite, despite the relatively low Atterberg limits for expansive soil [23]. The addition of fly ash can reduce swelling of the soil treated, and this effect increases with an increase in the fly ash content [5, 7, 11, 16, 24, 25]. According to [5], fly ash acts as a mechanical stabilizer by replacing some of the volume held by clay particles.

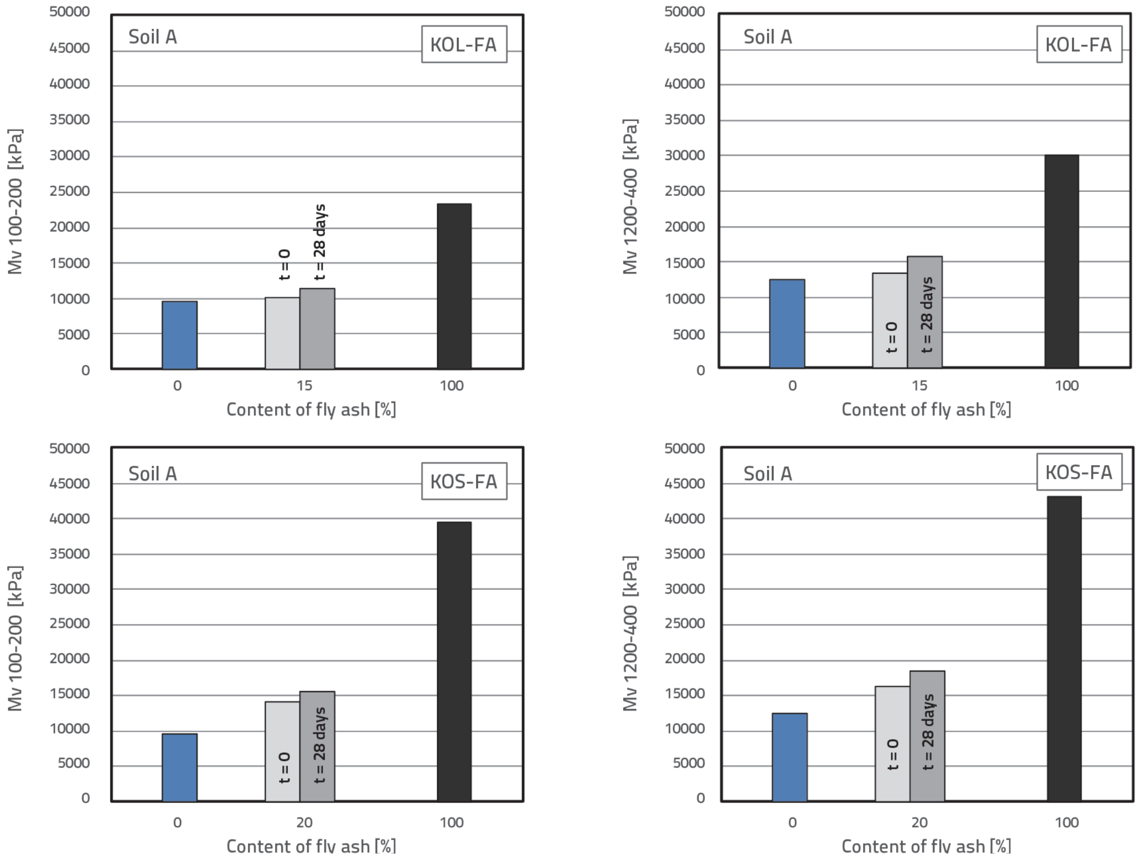

Figure 9. Compressibility modulus for soil A

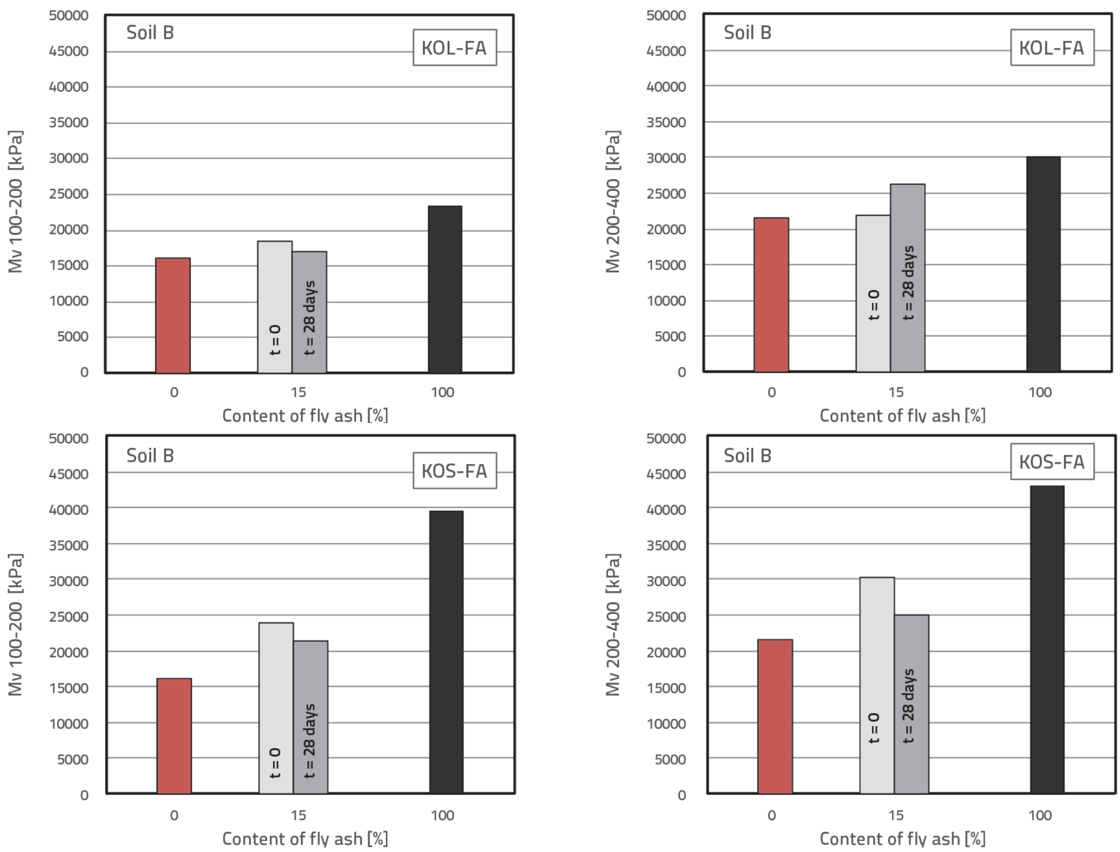

Figure 10. Compressibility modulus for soil B

In this research, a significant decrease of swell deformation, from ε = 8.6 % to ε = 0-1.8 % was obtained for soil A with the addition of an optimum fly ash content (15 % KOL-FA, 20 % KOS-FA). Soil B is not an expansive soil.

5. Conclusions

Although the non self-cementing fly ash is most commonly used for soil stabilization with the addition of lime or cement, laboratory tests performed in this study have shown that fly ashes from power plants Kolubara and Kostolac can effectively be used for soil stabilization without activators. Soil–fly ash mixtures were prepared at optimum fly ash contents (15 and 20 %), with the specimens compacted at an optimum water content. The addition of KOL-FA and KOS-FA decreased plasticity of the medium to high plasticity clay. There was no significant effect on the friction angle, while cohesion was increased. CBR values significantly increased for both soil types. This is especially important for the medium to high plasticity clay (soil A), because it makes it usable for road construction. Also, this is the main stabilization effect for the low to medium plasticity clay (soil B).The compressibility modulus was not significantly changed. The swell potential of the very expansive soil A was successfully reduced with the 15-20 % of fly ash addition.

Despite positive effects shown in the paper, the universally applicable principle of soil stabilization using fly ash cannot easily be defined. Detailed laboratory investigations must be conducted, with appropriate types of ash and soil, as this is the only way to precisely determine an optimum ash content, strength gain, and technology-related operations. This kind of research is very important in Serbia, bearing in mind that an annual production of fly ash to be disposed in landfills averages at approximately 7 million tons.

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