СПИСАНИЕ НА БЪЛГАРСКОТО ГЕОЛОГИЧЕСКО ДРУЖЕСТВО, год. 81, кн. 3, 2020, с. 230–232
REVIEW OF THE BULGARIAN GEOLOGICAL SOCIETY, vol. 81, part 3, 2020, p. 230–232

Национална конференция с международно участие „ГЕОНАУКИ 2020“
National Conference with international participation "GEOSCIENCES 2020"

Ultrasonic velocities and elastic parameters of plastic soil-cement

Ултразвукови скорости и еластични параметри на пластична циментопочва

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Keywords: loess-cement, ultrasonic velocities, elastic parameters.

Introduction

Plastic soil-cement is a mixture of soil and cement prepared at water content W much higher than the optimum one W_{opt}, usually at or slightly above liquid limit W_L of soil. Recently extensive investigations of plastic loess cement mixtures have been performed for assessment of various options for their using as engineering barriers in safe waste disposal. In this connection binary (loess-cement) and ternary (loess-cement/zeolite) mixtures were analyzed. In the current paper laboratory determination of pulse velocities and ultrasonic elastic parameters of plastic soil cement prepared by these mixtures is described.

While data for the ultrasonic elastic constants of compacted loess-cement have existed (Karastanev, 1989; Antonov, 2013), these parameters of the plastic loess-cement have not been estimated so far. Besides laboratory measurement of the pulse velocities of compression waves V_p and shear waves V_s in plastic loess-cement and the determination of ultrasonic elastic parameters, the other aim of the investigation is to evaluate the role of zeolite on the elastic properties of that stabilized soil.

Materials and methods

Specimen preparation

The specimens for the presented investigation were made by loess soil with the following classification properties: liquid limit W_L=36.2% and plasticity index I_P=18.3% defined by BDS EN ISO 17892–12:2007. According to European Soil Classification System (BDS EN ISO 14688) the loess soil is classified as CIM – medium plasticity clay (Tchakalova, 2019).

Two types of the plastic soil-cement samples were prepared as follows:

- LC type – prepared by mixing of loess with 10% Portland cement CEM II with respect to the weight of dry loess soil at W=40%;
- ZLC type – prepared by adding 10% zeolite to LC with respect to the weight of dry loess soil, i.e. mixing of loess soil with 10% zeolite and 10% Portland cement CEM II at W=40%.

All samples were made by procedure following the JGS 0821–2000 – standard of the Japanese Geotechnical Society. Prior to the preparation of specimens, the loess was initially sifted through a No. 10 sieve, well homogenized and then oven-dried at 110 °C. The respective additives – cement (for the LC type samples) and cement and zeolite (for ZLC type) were thoroughly mixed with the dry loess, then the certain amount of water was added and the mixture was stirred again. Immediately after thoroughly mixing, the loess-cement/zeolite slurry was poured into cylindrical plastic moulds (with a diameter D=50 mm) in three layers. In order to remove air bubbles from the mixture, each layer was tapped 25 times against a rigid surface. The specimens were then sealed and stored in a curing chamber at a relative humidity of 95% and a temperature of 20 °C. After respective curing of 7, 14, 28 and 90-days, the samples were taken out of the moulds, then cut to form specimens with an approximate 50 mm height and smoothed to have plain and parallel end surfaces. The sample height, diameter and weight were measured so that the density to be determined.

Ultrasonic pulse velocity test

After expiring of the respective curing period the specimens were immersed in water for 4 hours

Fig. 1. Ultrasonic testing for determination of the dynamic elastic parameters

prior to testing. The test was conducted according to ASTM D 2845–08 by a V–Meter Mark III ultrasonic device with excitation of ultrasonic pulses (Fig. 1). The resonance frequency of the transducers was f=50 kHz. So the requirement of the standard that $D \geq 5 \times V/f$, where V is pulse propagation velocity (compression or shear) in *m/s*; f is in *Hz,* was fulfilled. The values of V_p and V_s were measured. The ultrasonic elastic parameters – elastic modulus E_d, Poisson's ratio μ_d, shear modulus G_d and bulk deformation modulus K_d were calculated following the respective relationships according to ASTM D 2845–08.

Results and discussion

The determined ultrasonic elastic parameters obtained by the measured pulse velocities are presented in the Table 1.

The results show that the velocities of the longitudinal waves and transverse waves of both types of samples LC and ZLC are very similar and generally increase with increase of the curing age. When compared with the loess-cement samples at the early aging zeolite-containing samples show slightly higher V_s. On the 7th curing day the zeolite-containing samples are classified as very stiff clay (type B according to BDS EN 1998–1:2004/AC:2017), while the loess-cement samples are classified as stiff clay (type C). Most likely this is due to that zeolite activity in the early stage of hydration is based mainly on the large surface area of the particles (Snellings et al., 2010). In the later curing periods, chemical reactions occur between the products of the hydration of cement and the soluble SiO_2 and at the age of 14 days and after, the V_p and V_s values get closer to each other and according to Eurocode 8 both types of plastic soil-cement are classified as very stiff clay (type B) after 14 and 28 days and as rock-like geological formation (type A) after 90 days.

Conclusions

Ultrasonic elastic parameters of two types of plastic soil-cement: loess-cement and loess-cement/zeolite, were determined by laboratory measurements of the pulse velocities. Based on the experimental results, it can be concluded that:

Table 1. Ultarsinic elastic parameters of plastic loess-cement

Parameter / Sample ID	V_p [m/s]	V_s [m/s]	ρ [g/cm³]	E_d [GPa]	G_d [GPa]	μ_d [–]	K_d [GPa]	Ground type according to Eurocode 8
			7-days curing					
LC	1227	318	1.81	0.54	0.18	0.46	2.48	C
ZLC	1235	411	1.76	0.85	0.30	0.44	2.29	B
			14-days curing					
LC	1648	500	1.81	1.31	0.45	0.45	4.31	B
ZLC	1648	523	1.76	1.39	0.48	0.44	4.14	B
			28-days curing					
LC	1570	747	1.81	2.73	1.01	0.35	3.11	B
	1671	714	1.76	2.49	0.90	0,39	3.72	B
			90-days curing					
LC	1880	827	1.81	3.42	1.24	0.38	4.75	A
ZLC	1811	883	1.76	3.69	1.37	0.34	3.94	A

- plastic loess-cement after 90 curing days exhibits very high elastic parameters and classifies as rock-like material according to Eurocode 8;
- addition of zeolite does not indicate negative impact on the elastic parameters of the plastic loess-cement. Thus, the well-known benefits of the zeolite such as improvement of the microstructure and the cation exchange capacity, reduction the risk from alkali–silica reaction and sulfate attack, etc., (Caputo et al., 2008) can be successfully used as additive in the plastic loess-cement without worsening of its deformability characteristics.

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