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Plastic soil-cement mixtures for isolation barriers

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Б. Чакалова, К. Тодоров – *Пластичный грунтоцемент для изоляционных барьер*. В настоящей статье рассматриваются свойства и технологические характеристики 3-компонентных смесей, состоящих из лесса, портланд-цемента и цеолита, приготовленных при высоком влагосодержании. Предел прочности при одноосном сжатии, коэффициент фильтрации и сорбционная емкость смесей определялись на различные периоды выдерживания образцов. Установлено, что исследуемые смеси являются более подходящими для строительства изоляционных барьеров хранилищ опасных отходов по сравнению со смесями, содержащими только лесс и портланд-цемента.

Abstract. The present paper considers the properties and technological characteristics of ternary mixtures of loess, Portland cement and zeolite prepared at high moisture content. The unconfined compressive strength, permeability and sorption of the mixtures are determined after different periods of curing. It is established that the analysed mixtures are more suitable for the construction of isolation barriers of waste repositories in comparison with mixtures containing only loess and cement.

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Key words: loess soil, soil-cement mixture, non-compacted stabilization, strength behaviour.

Introduction

Loess soils differ from the other Quaternary sediments by their collapsibility and high permeability. For this reason, when facilities for waste disposal are built in them, it is necessary to perform isolation screens (barriers) in order to prevent soil and groundwater pollution.

In general, the engineered barriers applied for the hazardous and household waste isolation could be grouped as follows:

1. Surface (or near surface) barriers
   a. liners
   b. covers (or sealing caps)
2. Subsurface (deep) barriers
   a. Slurry walls
   b. Deep soil mixing
   c. Treatment walls
   d. Grouted walls
   e. Sheet – pile walls.

In Bulgaria barriers against collapsibility and against filtration had been laid by *stiff* or *plastic* soil-cement (Минков, Евстатиев, 1975) for the purposes of irrigation construction. The barriers of stiff soil-cement were built by compacting loess-cement mixtures with optimum moisture content W_{opt} to standard density c_{ds}, and the barriers of plastic soil-cement – by casting without compaction loess-cement mixtures with high moisture content. Plastic soil-cements exhibit a number of advantages (Bell, 1993). They acquire higher strength after longer curing period than the strength of stiff soil-cements. It has been established that the strength of the built barriers of plastic soil-cement increases from 0.7–1.0 MPa on the 28th day to 12–16 MPa after 20-years of curing (Карастанев, 1988). In case of their stationary preparation, good homogenization is achieved and the built barriers are uniform. The plastic soil-cement is easily applied in narrow places with insufficient workspace and on inclined terrains.

It is proved that the addition of chemical activators increases the strength and water impermeability of plastic soil-cements and facilitates the technology of their preparation and casting (Евстатиев, Ангелова, 1993). Natural sorbents (zeolite and bentonite) have been applied for increasing the retention capacity of plastic soil-cements (Антонов, 2002).

The present paper considers the properties and technological characteristics of ternary mixtures of loess, Portland cement and zeolite at high moisture content for the purposes of their application without compaction for isolation barriers of industrial, power generation and household waste repositories.

Initial materials

Typical loess from the region of Kozloduy was applied for the ternary mixtures preparation. This soil variety was used in previous investigations for the preparation of plastic soil-cement mixtures (Чакалова, 2006). According to the classification parameters (Table 1 and 2) it was determined as silty sandy clay (BDS 676) and as "CL-lean clay with sand" (ASTM D2487). The coarse silt (0.1–0.01 mm) predominates in the prevailing silt fraction (Fig. 1). The clayey fraction content with particle size less than 0.005 mm is only 9%, which predetermines the low humus substance content. The chemical composition in weight % is as follows: SiO_2 – 53.9%, Al_2O_3 – 11.3, Fe_2O_3 – 3.8%, TiO_2 – 0.7%, CaO – 3.5%, MgO – 11.0%, Na_2O – 1.5%, K_2O – 1.6% and ignition losses (1000°C) – 13.2%. The $SiO_2 : R_2O_3$ ratio is 3.6. This value is typical for silty loess (Минков, 1968). The total amount of water soluble salts is less than 30%. The water extract is slightly alkaline (pH about 8). According to its classification parameters and substance composition, the used loess is suitable for strengthening with hydraulic binding substances (Евстатиев, 1984).

Portland cement, certified according to BDS EN ISO 9001/2001 and BDS EN ISO 14001/1998 was used as stabilizing substance.

Zeolite from the Beli Plast quarry in the Northeast Rhodopes was added to the loess-cement mixture for increasing its sorption capacity. It contains about 70% of clinoptylolite. According to data of the producer the average chemical composition of the used zeolite in weight % is: SiO_2 – 66.16%, Al_2O_3 – 11.41, Fe_2O_3 – 0.80%, TiO_2 – 0.15%, MnO – 0.06%, CaO – 2.81%, MgO – 0.85%, Na_2O – 0.22%, K_2O – 2.90%, S – 0.03% and ignition losses (1000°C) – 7.49%. The zeolite has higher silicon content and is very resistant in acidic and alkaline solutions. Its ion exchange capacity is more than 100 meq/100 g. The fraction with grain-size less than 0.08 mm was used in the present study.

Methods of investigation

The test specimens for the laboratory investigations were cylinders with a diameter d = 5cm and height h = 10 cm, made of non-compacted mixture of loess, Portland cement and zeolite at high moisture content. The test specimen preparation conforms to the requirements of the standard *JSF T 821 — 1990: Practice for making and Curing Noncompacted Stabilized Soil Specimens.*

A certain amount of water was added to the well homogenized mixture of air-dried loess, Portland cement and zeolite and the formed plastic mass was cast in three equal parts in the cylindrical moulds, the air from each portion being removed by slight shaking (Fig. 2). The cylindrical moulds were kept to the day of testing in water desiccators at a temperature of about 20°C. The prepared ternary mixtures contained 10% of Portland cement and different amount of zeolite – 5, 10, 15 and 20% with respect to the dry weight of loess.

Table 1
Classification parameters of typical loess according to BDS 676

Particle size distribution (%)				Plasticity (%)		
Gravel >4.75 mm	Sand 2-0.1mm	Silt 0.1–0.005mm	Clay <0.005mm	W_P	W_L	I_P
–	4	87	9	17.3	29.4	12.1

Table 2
Classification parameters of typical loess according to ASTM

Particle size distribution (%)			Plasticity (%)		
Gravel >2 mm	Sand 4.75–0.075mm	Silt+clay <0.075 mm	PL	LL	PI
–	16	84	17.3	35.6	18.3

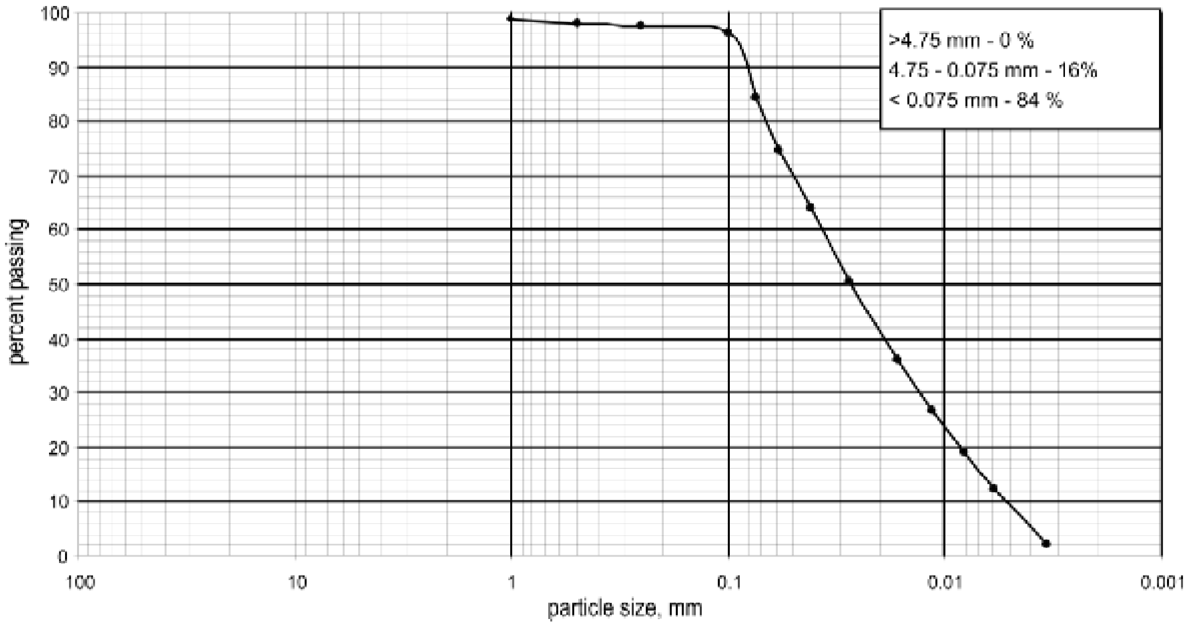

Fig. 1. Particle size distribution of the used loess

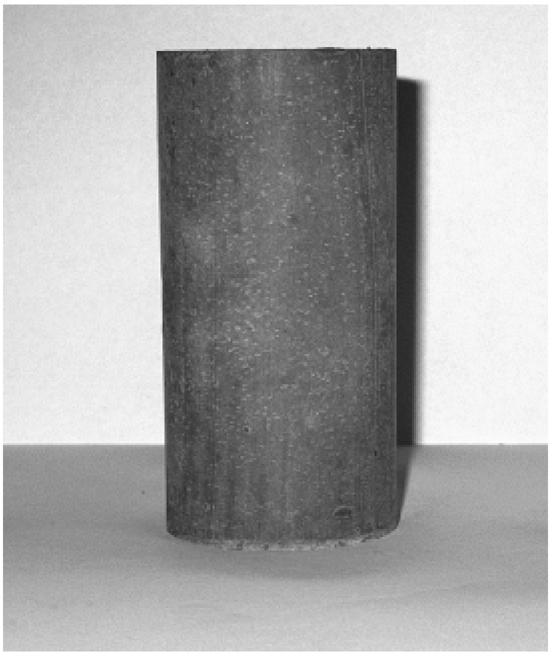

Fig. 2. Test specimens of the plastic ternary mixture after 28 days of curing

The mobility of the mixtures was evaluated by determining their consistency according to the method of Abrams (BDS 7016).

The unmoulded specimens (Fig. 3) were planed and tested after 24 hours of water soaking. The unconfined compressive strength q_u was determined by the specimen fracture using a compression loading machine with a vertical deformation rate of 11.8 mm/h (Fig. 4). The coefficient of permeability k was determined in a filtration apparatus according to the falling head method (Head, 1982). Cylindrical specimens with d = 9.4 cm and h = 10 cm were incorporated in the falling head permeability cell. The

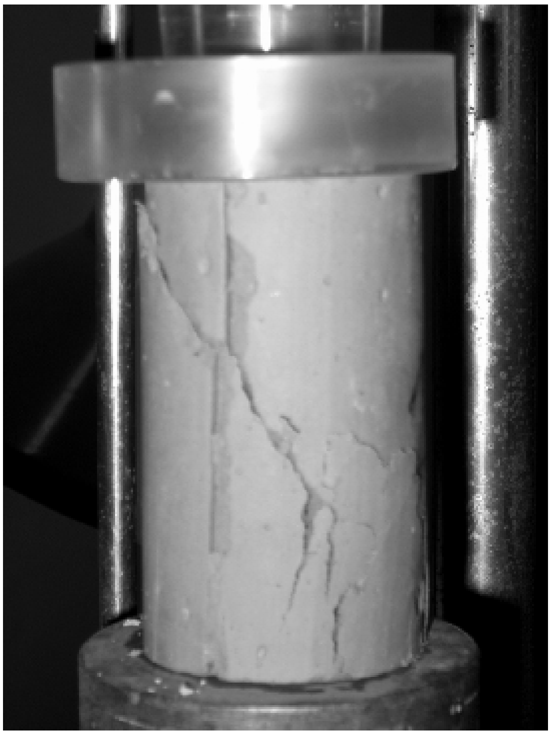

Fig. 3. Determination of unconfined compressive strength by fracture of test specimens using a hydraulic press

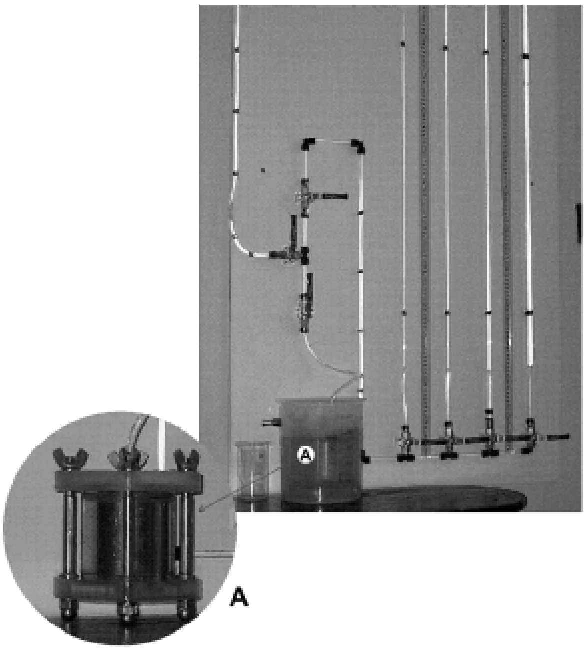

Fig.4. Determination of the coefficient of permeability in a filtration apparatus

strength and permeability values were obtained as average from the testing of three parallel test specimens.

The cation exchange capacity CEC was determined of the loess itselfs and the plastic ternary mixtures by replacing the alkali and earth alkali cations by ammonium ions at pH = 7 and a definite contact time (ON 33.67589-75 "*Zeolites – crushed and ground*").

Results from the investigation

Ternary mixture mobility

The ternary mixtures for practical purposes have to be easily poured and self-compacted without loosing their homogeneity. It is proved that soil-cement mixtures acquire sufficient mobility at moisture content around or a bit higher than the liquid limit of the strengthened soil (Kitazume et al. 2000). The studied ternary mixtures possess high specific surface due to the silt sizes of their ingredients. The high specific surface is a prerequisite for reducing the mixture mobility (Чакалова, 2006). The investigated mixtures acquire plastic consistency for higher moisture contents compared to the loess-cements. The mixture of loess, 10% of Portland cement and 10% of zeolite with a moisture content at about the liquid limit W_L=29.4% (according to BDS) has semi solid consistency and is unsuitable for application (Table 3). The mixture acquires slightly plastic consistency with moisture content a little higher than W_L=35.6% – the liquid limit according to ASTM and is also unsuitable for application. The mixture becomes sufficiently mobile and can be easily poured and self-compacted at a moistire content of 40–41% while it transforms to liquid consistency at moisture content above 44% and becomes susceptible to bleeding (water release) and segregation as a result of the sedimentation processes.

Table 3
Consistency of mixtures (according to BDS 7016) of loess, 10% of Portland cement and 10% of zeolite depending on their moisture content

Moisture content, %	Slump, cm	Consistency according to BDS 7016
30.0	<2	semi solid
37.8	3.5	plastic
39.6	5	plastic
41.4	9	plastic
44.3	>14	liquid

All test specimens for the laboratory investigations were prepared with mixtures with moisture content ranges from 40.5% to 42% – the interval, in which they acquire and preserve plastic consistency.

Unconfined compressive strength

The plastic ternary mixtures of loess, 10% of cement and different amount of zeolite exhibit after 28-day curing higher strength than the strength of the same soil variety with 10% of cement (Table 4). The highest strength was established for the mixtures with 10% of zeolite.

The strength of the mixtures increases significantly after longer curing periods – 90 and 180 days (Table 5).

Kitazume et al, 2000 and Чакалова, 2006 have established that the unconfined compressive strength decreases with increasing the moisture content of the soil-cement mixtures. The strength of the analysed ternary mixtures also decreases with increasing the moisture content. The mixture with 10% of zeolite

Table 4
Unconfined compressive strength of mixtures of loess, 10% of Portland cement and different amount of zeolite after 28-day curing

Zeolite content	Initial moisture content, W_i	Bulk density, ρ	Unconfined compressive strength, q_u
%	%	g/cm³	MPa
0	38.4	1.81	1.28
5	41.2	1.79	1.80
10	41.4	1.78	1.96
15	41.6	1.76	1.63
20	40.5	1.75	1.48

Table 5
Unconfined compressive strength of mixtures of loess, 10% of Portland cement and 10% of zeolite after different periods of curing

Curing period	Initial moisture content, W_i	Bulk density, ρ	Unconfined compressive strength, q_u
days	%	g/cm^3	MPa
28	41.4	1.78	1.96
90	41.4	1.78	2.86
180	41.4	1.78	3.72

and W = 41.4 % exhibit the strength of 1.96 MPa at the 28th day, while these with W = 43.5% show a strength of 1.62 MPa.

Cation exchange capacity

The CEC of the soils and the mixtures based on them is of primary importance for the evaluation of their retention capacity.

The used loess contains relatively low amount of clayey substance. The micaceous minerals predominate in it as in most of the silty and silty-sandy loess varieties in Northwest Bulgaria. Its CEC is 6.83 meq/100g. The mixture of loess and 10% of Portland cement exhibits higher cation exchange capacity — 12.63 meq/100g. CEC increases further with addition of zeolite (Table 6). The mixtures of loess, 10% of Portland cement and 10–20% of zeolite show higherCEC than the illite or kaolinite clays as well as clays containing 35–40% of smectite.

The values of CEC are kept after longer curing periods (Table 6).

Table 6
Cation exchange capacity of plastic mixtures of loess, 10% of Portland cement and different amounts of zeolite after 28 and 90 days of curing

Zeolite content, %	Ion exchange capacity, meq/100g	
	After 28 days	After 90 days
5	16.23	16.25
10	21.67	21.40
15	25.95	25.38
20	30.27	30.88

Permeability

The hydraulic conductivity of silty loess in the natural state is on the average $1.7.10^{-7}$ m/s (Евстатиев, Ангелова, 1993). Strengthened loess possesses significantly higher impermeability. The hydraulic conductivity of loess mixtures with 10% of cement, prepared without compaction at high moisture content, varies from 1.10^{-7} to 1.10^{-9} m/s (Чакалова, 2006). The hydraulic conductivity exhibits still lower values for the plastic mixtures of loess, cement and zeolite (Table 7).

Table 7
Hydraulic conductivity of plastic mixtures of loess, cement and zeolite after 28 days of curing

Zeolite content	Initial moisture content, W_i	Bulk density, ρ	Hydraulic conductivity, k
%	%	g/cm^3	m/s
5	41.2	1.79	$1.43.\ 10^{-9}$
10	41.4	1.78	$7.45.\ 10^{-10}$
15	41.6	1.76	$2.10.\ 10^{-9}$
20	40.5	1.75	$9.80.\ 10^{-11}$

In contrast to the strength, the permeability does not change substantially with increasing the moisture content. The mixture with 10% of zeolite exhibits a hydraulic conductivity of $7.45.10^{-10}$ m/s for W = 41.4% and $6.51.10^{-10}$ m/s – for W = 43.5%.

The results from the performed permeability tests are insufficient for evaluating the effect of zeolite content on water impermeability.

Technological characteristics

The mixtures of silty loess, cement and zeolite at high moisture content are plastic and are easily poured and self-compacted. They are stable due to the silty composition and preserve their initial mobility in the course of up to 60 min. No bleeding and mixture segregation are observed during this period. For this reason the stationary mixture preparation, transport and casting will not create any technological difficulties. The test specimens made of these mixtures have a dense structure and no surface defects, shrinkage and cracking are observed in the hardened mass after 28 days of curing in humid environment. When applying the plastic mixtures it is necessary to ensure preservation of the initial high water content during the early stages of their curing. A good possibility is to cover the casted plastic mixture with a thin PVC cover.

Conclusions

The studied plastic mixtures of loess, Portland cement and zeolite (prepared without compaction at high moisture content) are more suitable for the construction of isolation barriers of waste repositories in the loess terrains in comparison with mixtures containing only loess and cement. As in the case of soil-cements, available and cheap materials are used and the technology of preparation and casting is feasible and easily realized. This type of barriers are not affected by the functions of soil flora and fauna and do not pollute the environment.

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Б. Чакалова, К. Тодоров – Пластични циментопочвени смеси за изолационни бариери. Льосовите почви се отличават от другите кватернерни седименти по своята пропадъчност и голяма водопропускливост. При строителство в тях на хранилища за индустриални, енергийни и битови отпадъци е необходимо да се полагат изолационни екрани, за да не се допусне разпространение на замърсители до подземните води. В настоящата статия се описват свойствата и технологичните характеристики на пластични почвени смеси с високо водно съдържание от льос, портландцимент и зеолит с оглед тяхното използване без уплътняване за изграждане на изолационни екрани. Използван е прахов типичен льос от района на Козлодуй и зеолит (фракция под 0,08 mm) от находище „Бели пласт“ в Североизточните Родопи. Изследвани са тройни смеси от льос, 10% портландцимент и съответно 5, 10, 15 и 20% зеолит спрямо теглото на льоса. Тяхното водно съдържание варира от 40,5% до 42%. Установено е, че при това водно съдържание циментопочвените смеси са достатъчно подвижни, лесно се изсипват (изливат) и самоуплътняват без да загубват своята еднородност. Определени са якостта на едноосен натиск, коефициента на филтрация и йонно-обменния капацитет след различен срок на отлежаване.

Установено е, че пластичните тройни смеси придобиват на 28-я ден якост на едноосен натиск над 1,5 MPa, която значително нараства след по-продължително отлежаване. Техният коефициент на филтрация е под 1.10^{-9} m/s, а йонннообменният им капацитет варира в зависимост от количеството на зеолита от 16,2 до 30,9 meq/100g.

Поради праховия си състав те са устойчиви и запазват своята първоначална подвижност до 60 min. За този период от време не се установява водоотделяне и разслояване на сместа. По тази причина тяхното стационарно приготвяне и полагане няма да създава технологични затруднения. В началните срокове на отлежаване е необходимо да се осигури влажна среда за нормално втвърдяване на смесите, за да не се допусне свиване и напукване на изградения изолационен екран.

В заключение е отбелязано, че смесите от льос, портландцимент и зеолит, приготвени при високи водни съдържания и полагани без уплътнение, са по-подходящи за изграждане на изолационни екрани на повърхностни хранилища за отпадъци, отколкото пластичните циментопочвени смеси. След по-продължително отлежаване те придобиват по-голяма якост и водоплътност, а с добавката на зеолит и по-голяма сорбционна способност. Както при циментопочвите техни предимства пред други изолационни екрани са използването на евтини и достъпни материали и простата и лесно изпълнима технология за приготвяне и полагане. Те не се влияят от дейността на почвената флора и фауна и не замърсяват околната среда.