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SOIL STABILIZATION BY MEANS OF »LENDUR EH« UREAFORMALDEHYDE RESIN

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Geomechanical behaviour of soil is determined by its physical and chemical properties. Sometimes geomechanical properties do not meet conditions reguired and improvements are necessary. Improvements can be made applying various soil stabilization methods depending on required conditions, type and properties of soil, and the material used for stabilization. Polymers can also be used for stabilization. In some cases ureaformaldehyde resins are used.

The properties of a soil sample and ureaformaldehyde resin were determined. Several samples of soil and resin mixed in different ratios were prepared. Investigations of diffferent parametres show that the resin significantly improves geomechanical soil properties. As a relult the ureaformaldehyde resin applied in the tests can used for stabilization.

Ključne riječi: Tlo, Stabilizacija, Tvrdnjenje, Ureaformaldehidna smola, Polimer

Geomehanička svojstva tla određena su njegovim fizikalnim i kemijskim svojstvima. U pojedinim slučajevima geomehanička svojstva tla ne zadovoljavaju potrebne kriterije te je svojstva tla potrebno poboljšati.

Stabilizacija tla, kojom se poboljšavaju geomehanička svojstva, može se izvesti na više načina, zavisno o traženim uvjetima, vrsti i svojstvima tla te upotrijebljenom materijalu. Između ostalog, stabilizacija se može izvesti i polimerima. U pojedinim slučajevima mogu se za stabilizaciju upotrijebiti i ureaformaldehidne smole.

Određenom uzorku tla UF smole ispitana su svojstva na temelju kojih je pripravljen niz uzoraka smjese tla i smole u različitim omjerima. Ispitivanjem različitih parametara ustanovljeno je da dodatak UF smole bitno poboljšava geomehanička svojstva na temelju čega se zaključuje da upotrijebljeni tip UF smole može služiti za stabilizaciju tla.

Introduction

Geomechanical soil properties are governed by its physical and chemical characteristics. When geomechanical properties do not meet the conditions required for building improvements are necessary.

Stabilization of soil means limitization or removal of an unacceptable soil property. In other words, stabilization improves geomechanical properties of soil.

Certain soils, e.g. uniformly graded sand, have no coherence between particles, have a low bearing capacity and cannot resist mechanical influences. They have a high permeability and are easily eroded by water and wind. In their natural conditions such soils are unstable.

Water has strong effects on clay particles which have powerful cohesion forces. In dry conditions, clay has great strength and high bearing capacity. When saturated, it becomes plastic, even slurry, and may loose its bearing capacity. Such soil is unfit for construction purposes.

Between the two types of soils there are soils with various transitional properties, though many of them are unstable. Since these are unsuitable for building, various methods for their improvement have been developed. These include ways for unstable materials to become resistant to mechanical, weather and – possibly – chemical influences. Stabilization can produce new materials of better properties which then significantly effect building qualities. Besides, soil stabilization may lead to more economical designs and rational construction consuming less time and money. This can have important positive economic results (Babić, 1977).

Stabilization is, generally, carried out in two ways. In some cases they can be combined together.

In physical and mechanical method stbailization means greater density of soil. This is achieved by punding or rolling, and in some cases even the energy of explosion can be used. The holes in soil become smaller, and this makes it more compact. The result is a greater bearing capacity. Various methods with effects to the depth of about fifteen metres are applied in building roads, water plants and irrigation systems.

Another method is physical and chemical. Soil particles are combined together by means of different mixtures which can react chemically. The mixtures are introduced into soil by mixing, watering or injection. Such mixtures are usually liquid. They fill in the pores, cement particles together, and soil becomes more compact and less permeable. This kind of stabilization generally costs more than the mechanical one. Yet, it can be used for both materials and conditions for which the first one cannot. Chemical stabilization is applied for all kinds of low and high rise buildings, water constructions, airports, etc. Its effects are good both at soil surface and in great depths (Ibragimov, 1980).

There are several chemical ways of soil stabilization (Adamovich, 1980, a) Reference is made to some. Large part of chemical stabilization is based on the reactions of changes of ions of clay minerals. Lime or gypsum are usualy used for this purpose (Brandl, 1981; Joshi et al., 1981; Wagner et al., 1981). The solutions of multivalence cations (Matsuo and Kamon, 1981) and, sometimes, electrochemical methods (Katti et al., 1981; Brosh et al., 1983) are also used. The method of sillicatization by injection of sillicates solution, single or double component, alone or in mixtures with cement and bentonite (Coumulos and Korialos, 1983; Widing, 1983; Chi and Yang, 1985), and solutions of phosphoric acid (Evans and Bell, 1983) are also used. Cement suspensions, specially with addition of bentonites, are widely applied.

Polymers can also be used in soil stabilization. This is done by introducing liquid polymers, i.e. prepolymers, into soil pores where they harden through polymerization. If a polymer is to be used for soil stabilization, it must meet the following criteria: it must be adhesive. i.e. capable of binding with soil particles with the assistance of water; it must be sufficiently cohesive, i.e. its internal strength must be adequate; it must polymerize at normal or lowered temperatures and higher humidity, and within the time required during the process of polymerization bind large quantities of water; when applied it must have low viscosity.

In stabilization of soil, polycondensational polymers are more adequate than polyadditional. Polyadditional monomers or prepolymers ar more sensitive to all that that prevents chains to become larger and interrupts the process of polymerization without creating possibilities for polymerization reactions to start again after being stoped once. Precondensates of condensational polymers, are relatively insusceptible to impurities, the process of polymerization can be interrupted and started anew. They are easily prepared, and are always less expensive.

In spite of being relatively expensive for soil stabilization, polymers have already found wide application. Among them, ureaformaldehyde, rezorcynformaldehyde, fenolformaldehyde and furan resins as well as polyacryllates, polyurethans and some others are most commonly used (Kolesnikov and Muljukov, 1983; Hewlett and Hutchinson, 1983; Evangelista et al., 1983; Perez and Krizek, 1985; Mihalj and Čvokić, 1984).

Application of Ureaformaldehyde Resins for Soil Stabilization

Of all the polymers used in soil stabilization ureaformaldehyde resins are the most popular because of their low prices. Combining of UF resins with soil particles is thought to be possible due to the creation of hydrogen bonds between free hydroxyl groups of soil alluminosyllicates with CO groups of ureaformaldehyde resin (Egadzaj et al., 1986).

UF resins are applied for stabilization of a sand soil having a specific permeability coefficient, where K_{10} is between 1.2 x 10^{-6} ms^{-1} and 3.50 x 10^{-4} ms^{-1}. The resin is applied onto the soil either by spraying or injecting, depending on whether surface or deep soil strata are to be stabilized. Every soil stabilization carried out by means of ureaformaldehyde resins usually has two aims: increased soil strength or, more often, decreased permeability.

A mixture of water solution of resin and catalyst is injected into soil. Sometimes these can be forced into soil separately. If this happens, then resin water solution is applied before the catalyst.

Condensation time depends, of course, upon the acidity and temperature of solution. However, clay and carbonates existing in the soil may also have an effect on this for they can consume some acid from the catalyst. In such a case either gelatinization period becomes longer or resin is inadequately hard. To prevent this, and if the soil has between one and three per cent of clay particles, a pretreatment of soil using between three and five per cent solution of chloride acid is necessary. If carbonates make more than three per cent of the soil, it is pretreated with the solution of oxalic acid.

Laboratory and in situ tests of the durability of sands stabilized with UF resins in acid, base and salty solutions during six years have made it possible to determine the limit of solution aggressiveness depending on the degree of acidity. The solutions of acids with pH$<$3 and bases with pH$>$13 have been found to be aggressive against stabilized soil. For the pH of water in normal conditions is usually between 6 and 8, the soil can be considered practically permanently stabilized (Adamovitch, 1980.b).

The shortcoming of UF resins is that they are brittle, and this makes them less usable, specially in places where a higher degree of elasticity is needed. Such places are, for example, the joints between concrete buildings with differential settlements, which nevertheless must be impervious. For this purpose success was achievedwith the application of UF resins with synthetic chloropren and divinyllstiren latexes plus oxalic acid as hardening material. After the resin gels in both cases had been hardenend, they were elastic enough and had satisfactory strength and impermeability (Ibragimov, 1978).

Tested materials

The application of UF resins is basically limited to soils with the permeability coefficient K_{10} between 10^{-6} ms^{-1} and 10^{-4} ms^{-1} . Unified classification classifies it as sand. This was the reason why sand was chosen for investigation. Stabilization was carried out using different UF resins produced in Yugoslavia. All tests of sand and UF resins properties were performed in relation with current standards (JUS).

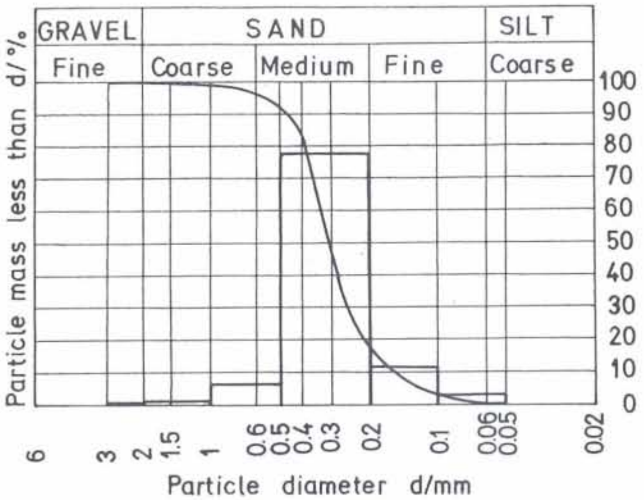

Fig. 1. Grain size distribution of sand sample shown by means of histogram and cumulative curve.

Sl. 1. Granulometrijski sastav uzorka pijeska prikazan pomoću histograma i kumulativne krivulje.

Soil – Sand

The sample of soil used for the tests was made of washed and dried grey sand of the left bank of the river Drava, north of Varaždin. The sand was kept in room conditions, practically dry, the humidity being 0.05 percent.

The gradation of the test sample was determined in the standard way. This and the histogram of grain size distribution are shown in Fig. 1. It is seen that the sample was uniformly graded sand (SU), the fraction content mostly between 0.5 and 0.2 mm. The biggest particle was 3 mm in diametre. The majority of particles were compact having sharp edges. Only a small portion of particles were platy shaped.

The chemical content of the sand was as follows:

SiO_2	82.3	per cent
Al_2O_3	4.06	,,
Fe_2O_3	2.16	,,
CaO	4.54	,,
MgO	0.67	,,
MnO	0.32	,,
K_2O	0.59	,,
Na_2O	0.48	,,
SO_3	0.04	,,
Ignition loss	4.43	,,
Humidity	0.38	,,
	99.97	per cent

Calcium carbonate content was determined in the standard way according to Scheibler, and was 2.97 per cent.

Minerlogically, the sample consisted mainly of quartz. Also present were muscovite, biotite, amphybolle, magnetite, hematite, dolomite, calcite, plus other minerals in small quantities.

The permeability coefficient was determined in the usual way in edometre applying the mthod of lowering the water pressure. The changes of permeability coefficient K_{10} against different vertical sample loads are shown in Fig 2.

The determination of whether the sample was acid or base was necessary because the reaction of its surroundings has a significant influence on the speed of hardening of UF resin. Sand suspension had a pH value of 7.7 – weakly base – so that a too fast gelling was impossible.

Optimal water content, Wopt, at which maximal density can be achieved, was determined in the usual way according to Proctor, and it was Wopt = 4.1 per cent.

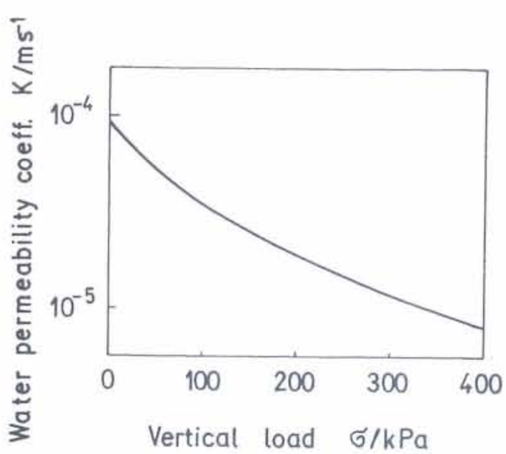

Fig. 2. Changes in permeability coefficient K/ms^{-1} under different vertical loads σ/kPa.

Sl.2. Promjene koeficijenta vodopropusnosti K/ms^{-1} uz različita vertikalna opterećenja uzorka σ/kPa.

The determination of sand sample compressibility for various vertical loads was carried out in oedometre using standard procedures. The samples were soaked into water, the load being 50 kPa. Compressibility modulus are plotted in Fig. 3. Absolute porosity, n = 0.4624, and relative porosity, e = 0.8601, were determined together with the compressibility. The density of the sample was found to be ϱ = 2663 kg/m^3.

The shear strength of the sample was determined by direct shear tests with certain degree of deforma-

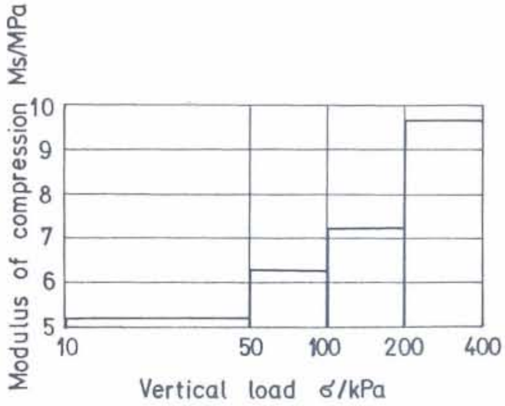

Fig. 3. Moduli of compression Ms/Mpa for various vertical loads σ/kPa.

Sl. 3. Moduli stišljivosti Ms/Mpa za različita vertikalna opterećenja σ/kPa.

tions and applying standard procedures. The angle of internal friction was $\varphi = 29.2°$, and cohesion C = 0. These values are typical for this kind of soil.

Ureaformaldehyde resin

The sample of the ureaformaldehyde resin used in the tests was produced by INA – NAFTA – Lendava. Its commercial name is Lendur EH, and it is primarily used as a cold glue for wood (ljepilo UF JUS H–K2.032).

The following properties of the sample tested using standard methods were found:

– dry substance	64 per cent
– gel time	30 to 40 mins (15° to 25°)
– viscosity	1060 m Pas (20°C)
– pH	8.1
– free formaldehyde	2.8 per cent
– solvent water	

For the resin to become hard, five per cent of the hardening material–catalyst per resin quantity were added. The contact used was a 20 per cent water solution of amonium chloride NH_4 Cl. The pH value of such water solution was 6.6.

Preparation of Stabilized Soil Sample

In order to prepare a sample, certain quantity of sand was measured and the UF resin was added according to a specific percentage. Proportional quantity of contact material was added to the resin. The resin and the contact were mixed with the sand and left to gel, i.e. harden in special moulds. Gel time for the mixture of sand and resin was a little longer than for the resin itself, in sand between ten and fifteen minutes. The samples were usually tested twenty–four hours after complete hardening.

The mixing ratios for sand and resin were chosen to correspond with some characteristic properties of the sand sample. So, for example, the smallest quantity of the added resin corresponded with the optimal water content and was four per cent. The greatest amount of the resin added was based on the absolute porosity of the sand, so that it was forty per cent. These samples represented sand saturated with the resin. Between these two extreme quantities of the resin added, other samples were prepared and tested containing twenty per cent of the resin added to the mass of sand. This was done for an easier investigation of the soil properties with gradual addition of the UF resin.

Two sets of samples were prepared and tested parallelly. One set contained the original sample of the UF resin, and the other had resin containing fifty per cent of water. In other words, the resin was diluted with water in the ratio 2:1. This caused the viscosity of the resin to be lowered on 115.4 m Pas (20°C), and gel period was about thirty per cent longer than the gel period of the original resin. The resin diluted in such a way was then added to the sand in the same quantities as the resin which remained pure. The diluted samples were prepared and tested to determine several different things. These included the possibility of achieving satisfactory stabilization in cases when the resin mixes with ground waters. Improvements in the application of the resin and its subsequent penetration into the holes and pores of the soil as well as filling them due to lower viscosity were also tested. The tests included ways of lowering the consumption of the resin, which would then decrease the cost of stabilization.

Investigation of Samples

Shrinkage and Swelling

The UH resin became practically hard within twenty–four hours. Polycondensation and cross–linking, however, continued for some time, so that hardness increased with time, yet with the loss of viscosity. In pure UF resins, which have no additives to increase their viscosity, fractures appear relatively often, and this decreases the strength of polycondensates. During condenzation and hardening the resin attracts large quantities of water. If the condensed resin is exposed in the air, the water will slowly evaporate. This causes shrinkage of hardened resin. The application of UF resin to soil surface during dry summer months may possibly have the same effect. In order to see if this happens, the samples of sand containing resin were tested. Fig. 4 shows relative shrinkage of the sand sample with fourty per cent of resin in relation with the decrease of the volume to total volume. The shrinkage was observed for thirty days. It was rapid during first five days, when it practically stopped. After thirty days of drying, the dried and shrinked sample was soaked into water and left to swell. Relative swelling in thirty days is also shown in Fig. 4. During first five days the sample swelled slowly. Then, between the fifth and twentieth days the swelling was quick, and after thirty days it is insignificant. Generally, no significant swellings were observed.

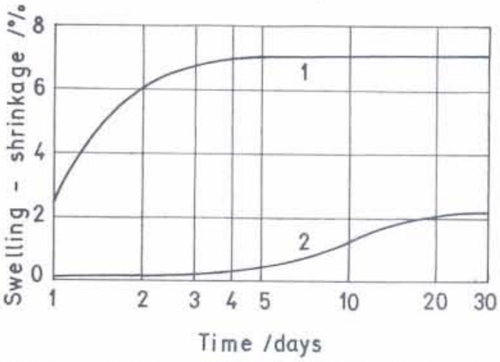

Fig. 4. Relative shrinkage (1) and swelling (2) of sand sample with 40 per cent of resine in relation with time

Sl. 4. Relativno stezanje (1) i bubrenje (2) uzorka pijeska s 40% smole u zavisnosti od vremena.

Permeability

The permeability of the samples of sand having different quantities of UF resin as regards water was tested in the same way as that of pure sand.

As little as four per cent of the UF resin were enough for the sample to stay impervious for fourteen days, so that it can be considered practically impervious. This particularly applies for the samples with larger quantities of the resin.

Compressibility

The compressibility was tested on the samples with various resin contents and under various vertical loads. From the beginning of the tests the samples were in water to simulate the worst natural conditions during investigation. The results are shown in Fig. 5. The compressibility module increases multiply with addition of resin. Thus sand – as medially compressible soil – with addition of the UF resins becomes a soil with low compressibility.

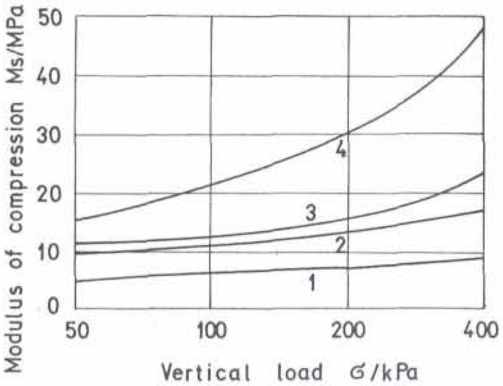

Fig. 5. Moduli of compression for samples with different UF resine contents. (1) sand, (2) sand with 4 per cent of resine, (3) sand with 20 per cent of resine, (4) sand with 40 per cent of resine.

Sl. 5. Moduli stišljivosti uzoraka s različitim dodacima UF smole; 1–pijesak; 2–pijesak s 4% smole; 3–pijesak s 20%smole; 4–pijesak s 40% smole

Load Strength

The load strength of the samples with different UF resin contents was determined in standard ways using the unconfined compression of standard–size samples to failure. All samples developed very irregular failure areas without clearly marked failure planes. The samples with fourty per cent of diluted resin could not be adequately prepared for testing. The results are shown in Fig. 6.

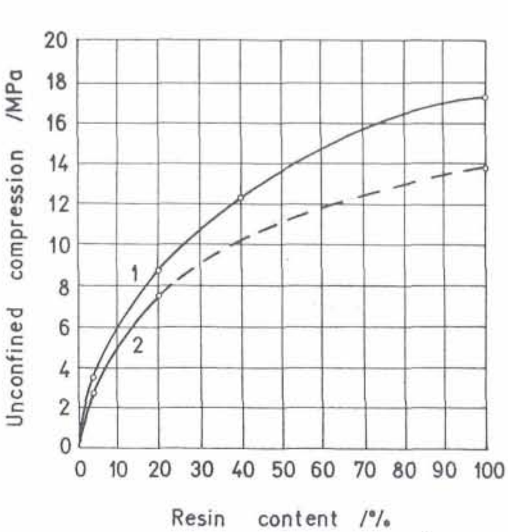

Fig 6. Unconfined compression and resine content ratio. (1) sand with resine, (2) sand with diluted resine.

Sl. 6. Jednoosna tlačna čvrstoća u zavisnosti o količini smole. 1–pijesak sa smolom; 2–pijesak s razrijeđenom smolom.

Direct Shearing

Tests with direct shearing of the sand samples having various quantities of UF resin gave values for the angle of internal friction φ and cohesion C. Figs. 7 and 8 show comparisons of the resultst obtained for the angle of internal friction and cohesion of the samples with various UF resin contents.

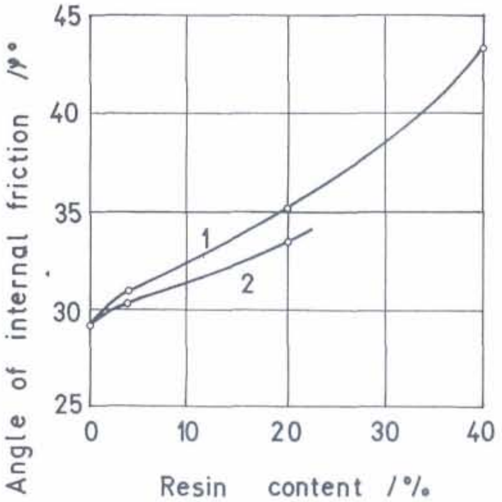

Fig. 7. Change of angel of internal friction φ for sample with addition of UF resine. (1) sand with resine, (2) sand with diluted resine.

Sl. 7. Promjena kuta unutarnjeg trenja φ uzoraka dodatkom UF smole. 1–pijesak sa smolom; 2–pijesak s razrijeđenom smolom.

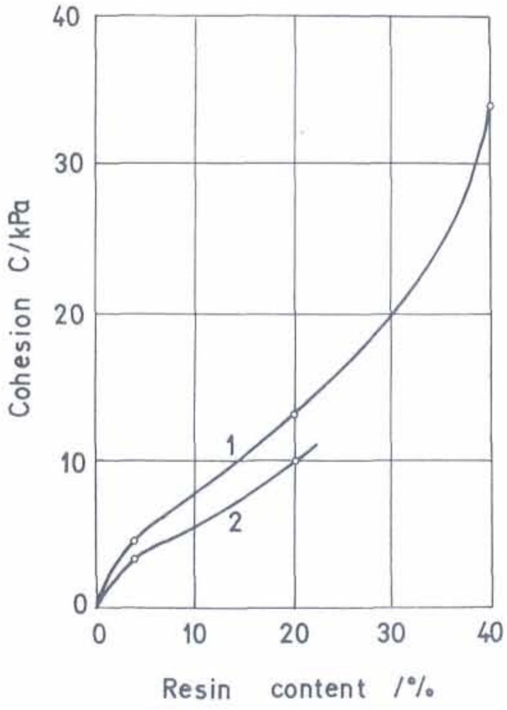

Fig. 8. Change of cohesion C for sample with addition of UF resine. (1) sand with resine, (2) sand with diluted resine.

Sl. 8. Promjena kohezije C uzoraka dodatkom UF smole. 1–pijesak sa smolom; 2–pijesak s razrijeđenom smolom.

Rapid increase in cohesion and the angle of internal friction are observed with gradual addition of the resin, and geomechanical properties are outstandingly improved.

Discussion of Results

In the descussion of the results we start from the fact that the original test material represents a non–coherent soil, i.e. sand, which has no cohesion, and is relatively highly permeably. It is compressible and has a relatively low bearing capacity. In cases when it is necessary for the sand to become impervious or more compact, it must and can be stabilized. The success of the stabilization is valued by comparing the properties of the samples with and without added UF resin.

The permeability of the sample used in the tests is considerably high. However, even a small quantity of the resin can make the sample practically impervious. This suggests that such stabilizration can successfully solve the problems due to increased permeability.

The increase of the compressibility module with addition of the UF resin is caused by a multi–decrease in compressibility. Simultaneously, UF resin increases the load strength. All this suggests that the stabilization of soil with the UF resin increases the baering capacity of the stabilized soil. In other words, structures erected on the soils stabilized in this way may be expected to settle less.

The increased cohesion and angle of internal friction due to the added UF resin suggest that the originally incoherent material is now after stabilization similar in properties to monoliths. The result of this is, no doubt, a higher bearing capacity.

The danger of fractures appearing on the surface of the soil stabilized with the UF resin due to shrinkage as a result of evaporation is minimal. Minimal is also the danger of enormous swelling. Subsurface drying of the stabilized soil is practically impossible, for it is prevented by natural humidity of sand or sandy soil. Particularly, if stabilization is performed under ground wate level.

Tests with sand samples containing diluted resin have produced values for certain parametres which are, understandably, lower than those obtained for pure resin. However, the samples show considerable improvements of their properties compared to the original material. The application of diluted resins, specially in cases when lower viscosity is required, may give effective results.

Generally, the Lendur EH type of UF resin has been found to stabilize certain soil types. Yet, for practical puproses, this still needs confirmation in corresponding samples of the soil with a specific type resin and in the conditions that would correspond to the location and methods of application.

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Stabilizacija tla pomoću ureaformaldehidne smole »Lendur EH«

M. Levačić i M. Bravar

Geomehanička svojstva tla određena su njegovim fizikalnim i kemijskim svojstvima. U pojedinim slučajevima geomehanička svojstva ne zadovoljavaju potrebne uvjete pa ih je potrebno poboljšati.

Stabilizacija tla, kojom se poboljšavaju geomehanička svojstva, može se izvesti na više načina, zavisno o traženim uvjetima, vrsti i svojstvima tla te upotrijebljenom materijalu. Između ostalog, stabilizacija se može izvesti i polimerima. U pojedinim slučajevima mogu se za stabilizaciju upotrijebiti i ureaformaldehidne smole.

Određenom uzorku tla i UF smole ispitana su svojstva na temelju kojih je pripravljen niz uzoraka smjese tla i smole u različitim omjerima. Ispitivanjem različitih parametara ustanovljeno je da dodatak UF smole bitno poboljšava geomehanička svojstva na temelju čega se zaključuje da upotrijebljeni tip UF smole može služiti za stabilizaciju tla.