OBȚINEREA MATERIALOR OPTIME PENTRU CONSTRUIREA TERASAMENTELOR PRIN AMESTEC DE PĂMÂNTURI ARGILOASE CU MATERIALE GRANULARE ŞI DEŞEURI INDUSTRIALE
OPTIMAL MATERIAL FOR EMBANKMENTS: MIXTURE OF CLAYEY SOILS WITH GRANULAR MATERIAL AND INDUSTRIAL WASTE

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For the construction of embankments or compacted cushions, the cheapest solution is to utilize the excavated material from the site or from the vicinity. But when the backfilling material is composed of clayey expansive soil it's use may be impropriate. Expansive soils have a high activity in relation to water and are classified as material "very bad" for the construction of earthworks.

The legislation in force imposes the removal of expansive clays and their replacement with a better material. The high cost of expansive soil replacement has caused the necessity to use a stabilized soil for these constructions.

Cea mai eficientă soluție pentru realizarea terasamentelor sau a pernelor din pământ compactat este aceea de a utiliza materialul din amplasament sau din vecinătatea acestuia. În cazul pământurilor argiloase se recomandă evitarea folosirii acestora ca materiale de adaos pentru terasamente. Aceste pământuri sunt active în raport cu apa încadrându-se în categoria pământurilor cu o calitate "foarte rea" pentru folosirea ca materiale pentru terasamente.

În normele tehnice se recomandă evitarea folosirii pământurilor argiloase la realizarea terasamentelor şi înlocuirea acestora cu materiale inactive în raport cu apa. Înlocuirea pământurilor argiloase impune costuri foarte mari, din acest considerent se impune îmbunătățirea acestor pamânturi dificile cu diverse materiale de adaos.

***Keywords:** compacting (A), composites (B), mechanical properties (C), expansive soils*

1. Introduction

In order to build a compacted cushion made of local materials, the clayey soils are materials available in Romania. But these soils, after compaction, due to the dense state in which it may be, at any increase in the moisture content will result in increases in volume, waving and hence degradation of the construction. Decreasing of the moisture content will be accompanied by reductions in volume (shrinkage), the occurrence of cracks in the compacted material and preferential drainage paths.

The main improvements aimed in the stabilization of expansive soils are: reduction of the swelling pressure, increase of shear strength and reduction of the shrinking-swelling potential.

The principal methods to stabilize clayey soils are classified as follows:

- physical stabilization - achieved by mixing soils with granular materials (non-cohesive);
- chemical stabilization - achieved by mixing soils with various chemical additives as: lime, Portland cement, eco-cement, fly ash, etc..

The paper will describe the laboratory procedure to identify the optimal content of filler material to transform the expansive clay from the site into a proper material for construction.

In situ works performed during a test pad are also described: spreading, mixing and compaction of the materials. As the visual observations and laboratory tests for physical and mechanical parameters confirmed that by the process described above, a quasi-homogeneous mixture was obtained, forming an optimal material for embankments.

2. Theoretical aspects on expansive soil improvement

Soil stabilization is widely used to reduce the damages of civil engineering structures realized from expansive soils or founded on expansive soils; this has been implemented in many parts of the world. Soil stabilization is a frequently studied topic due to mixing problems encountered in field applications. For this reason were developed new equipments and new technologies to achieve soil

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mixtures, the development of this technology is a current concern.

The soil stabilization is used in the construction of: highways and roads (embankments), highways, roads and airports (subgrades), municipal waste landfills, dams of local materials, embankments for dykes.

Because each soil acts differently, depending on its mineralogical and granulometric composition, there is no 'recipe' for the improvement of clayey soils and for this reason soil stabilization is a topical issue intensively studied.

2.1. Improvement methods

According to the scientific paper, the expansive clayey soils are stabilized successfully (Figure 1) by one of the following methods:

Physical stabilization is done by the modification of the grain size distribution of a soil by mixing it with another soil, generally a non-cohesive soil such as: sand, gravel, slag (industrial waste), mineral mining waste etc [1]. This method of stabilization showed a decrease in the optimum moisture content and an increase in the maximum dry density.

Chemical stabilization is done by altering the clay structure by mixing it with some chemical materials such as: lime, cement, fly ash, etc.

- ***Lime*** stabilization refers to stabilization of the soils by the addition of burned limestone product (calcium oxide). Lime is the most effective and widely used chemical additive for expansive soils [1-3], because after adding the lime to a clay soil, many chemical reactions such as cation exchange, flocculation-agglomeration, lime carbonation and pozzolanic reaction occur [2].

The pH test is very important in lime stabilization [5]; the lowest percent of lime which gives a pH value of 12.4 at 25°C is that required to stabilize the soil.

- ***Cement*** stabilization develops from the cementations bonds between the calcium silicate (three-calcium silicate) and aluminate hydration products of cement and the soil particles. When cement is added to clayey soils in the presence of water, a number of reaction occur leading to the modification of soil properties. These reactions include cation exchange, flocculation, carbonation and pozzolanic reaction. The cation exchange takes place between the cations associated with the surfaces of the electrically charged clay particles and calcium cation of the cement. The effect of cation exchange and attraction causes clay particles to become close to each other; this process is called flocculation. Flocculation is primarily responsible for the modification of the engineering properties of clayey soils [2, 3].

Lime and cement stabilization reduce the plasticity (decrease the liquid limit and the plasticity index) and the maximum dry density and increase the optimum moisture content, shrinkage and plastic limit.

Fly ash is produced during the combustion of ground or subbituminous coals, exhibiting self-cementing characteristics that can be adapted to a wide range of stabilization applications. Applications for fly ash treatment can be divided into several categories: drying soils to facilitate compaction, treatment of soils to reduce swelling pressure, and stabilization to improve engineering properties of a material such as increased strength, durability or stability. The reduction of

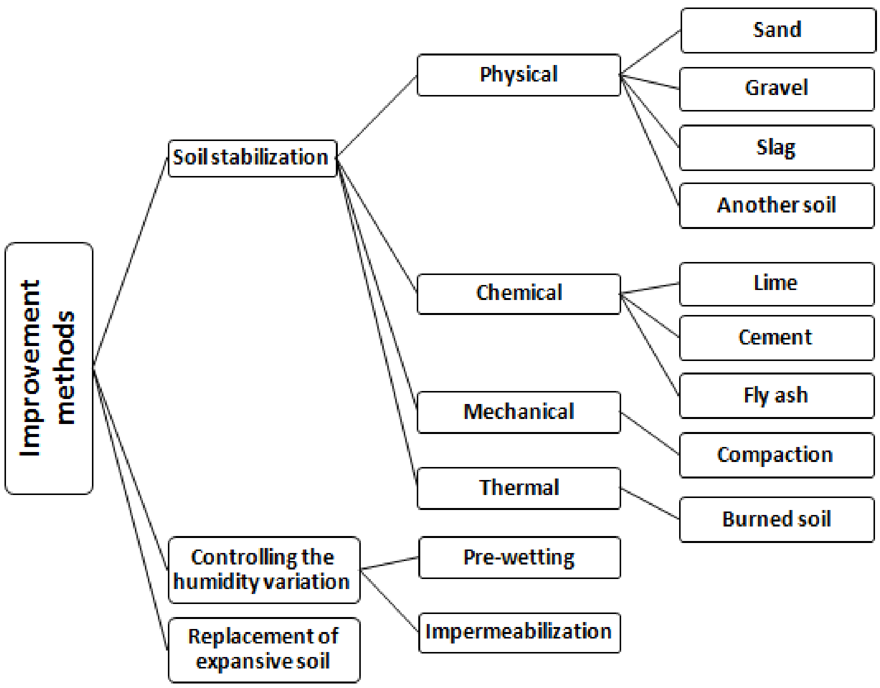


Fig. 1 - Improvement methods for expansive clayey soils / *Metode de îmbunătățire a pământurilor argiloase.*

swelling pressure by adding fly ash is comparable to lime and cement stabilization. This reduction based on the amount of CaO and SiO_2, appears to be a result of bonding of the soil particles by the cementations products formed during hydration of the fly ash in addition to flocculation of the clay minerals [2]. The use of fly ashes as stabilizing materials can be economical in industrial regions where this waste by-product is produced.

A comparison between the above mentioned methods is presented (Figure 2):

- in the case of physical stabilization, based on the compaction test, the optimal parameters of compaction showed a decrease in the optimum moisture content and an increase in the maximum dry density;
- in the case of chemical stabilization, based on the compaction test, the optimal parameters of compaction showed a decrease in the maximum dry density and an increase in the optimum moisture content.

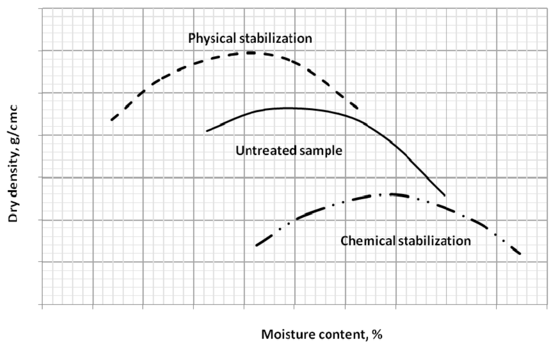


Fig. 2 - The effect of the physical and chemical stabilization on the compaction characteristics [4]/ *Influența stabilizării fizice şi chimice asupra caracteristicilor de compactare.*

2.2. Case studies in Romania

In Romania, in order to reuse the expansive clayey soils as filler materials the stages for the determination of optimal material for embankments are presented in the figure below (Figure 3).

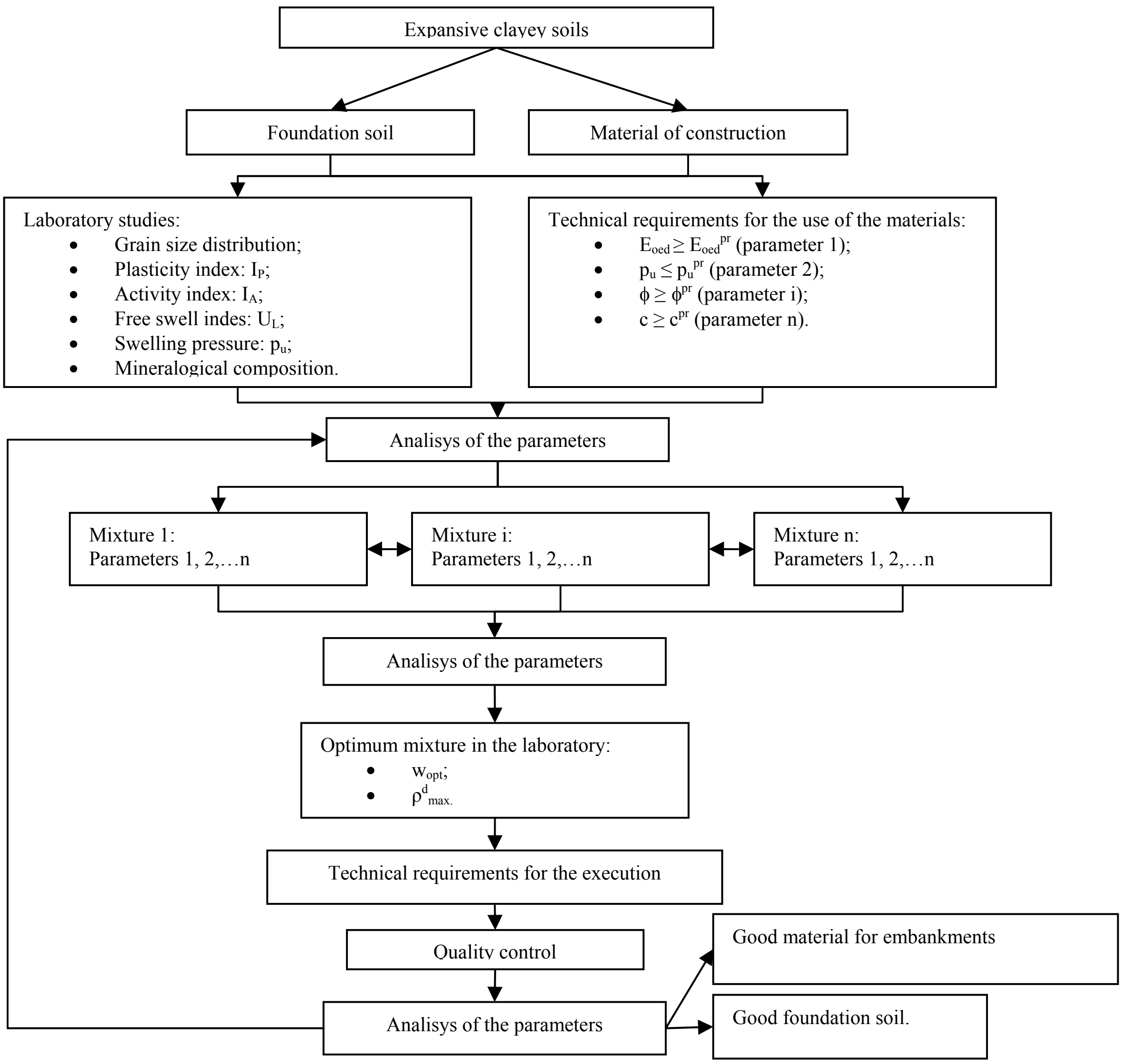


Fig. 3 - Stages for the determination of optimal material for embankments [5] / *Etape de îmbunătățire a pământurilor cu umflări şi contracții mari pentru terasamente şi ca teren de fundare.*

3. Experimental research on soil stabilization

The paper presents two case studies of physical stabilisation, the laboratory and in situ tests results of the experiments resulted.

3.1. Embankments of stabilized expansive clay for a landfill

The design and execution of a municipal solid waste landfill involves important earthworks - excavations and fillings – for the construction of the perimetral embankments and sorting platform. To achieve the perimetral embankments it was analyzed geological and topographical data on the site and to identify the soil properties used in this study it was executed 21 geotechnical boreholes uniformly distributed on the surface of the site [6].

The site is approximately 19.5 ha and the level difference ranges from 265 m to 315 m nMN. The natural ground slope is 1:7...1:8 on the north – south line. Initially, the site was not affected by the phenomena of loss of stability. For building of sorting platform it is necessary to undertake excavations and reshape the slopes to 1:2 or 1:3.

Initial tests of the study consisted in defining geotechnical properties of these soils. Grain size distribution, plastic limits, natural water content, swelling pressure, oedometric modulus and shear strength test were conducted on natural soil.

According to STAS 1913/5-85 analyzed soils are clayey soil with the grain size distribution composed from clay 55-80 %, silt 20-45 % and sand 1-20 % (Figure 4). Determining the plastic and liquid limits it can be seen that the plastic index shows values between 26.7 – 57.2 %, this index ranks the analyzed soils in the category of very active clays. The oedometer compressibility tests have been performed for samples initially saturated to determine the swelling pressure, this swelling pressure recorded values of 40…200 kPa.

The shearing resistance parameters have been determined in consolidated-undrained (CU) and consolidate-drained (CD) conditions performed for samples with natural humidity and for samples initially saturated. Table 1 shows the variation of the shear strength parameters.

In order to determine the optimal parameters of compaction and the mechanical characteristics on compacted samples have been performed Standard Proctor test on average samples obtained from the site (Table 2). The high values of the swelling pressure obtained for compacted samples at optimum moisture content do not recommend the use of these materials for the construction of embankments; these soils are classified as material "very bad" for the construction of earthworks [7] (Figure 5).

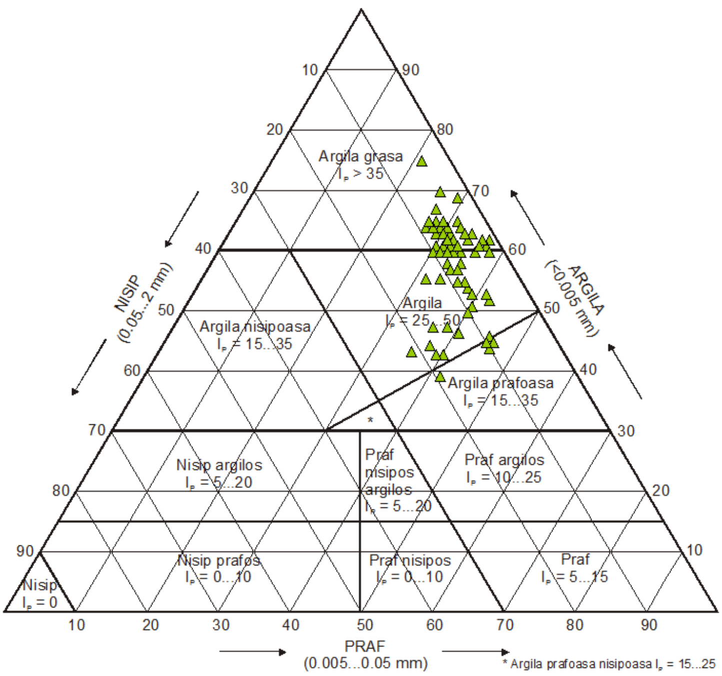


Fig. 4 - Presentation in ternary diagram of the analyzed soils / *Reprezentarea în diagramă ternară a pământurilor analizate.*

Table 1

Shearing resistance parameters [5,6] / *Parametrii rezistenței la forfecare*

Parameter / Shearing type - *Parametrii / Tipul de forfecare*	CU	CUsat	CD	CDsat
Internal friction angle / *Unghiul de frecare internă*, Φ [°]	11 ÷ 29	19 ÷ 28	19 ÷ 30	17 ÷ 23
Cohesion / *Coeziunea*, c [kPa]	59 ÷ 160	23 ÷ 81	33 ÷ 80	25 ÷ 55

Table 2

Optimal parameters of compaction and mechanical characteristics of the compacted soils [3, 6] / *Caracteristicile optime de compactare şi caracteristicile mecanice ale probelor compactate*

Material / characteristics of the compacted samples / *Materialul / Caracteristicile probelor compactate*	Optimum parameters of compaction *Caracteristicile optime de compactare*		Compressibility characteristics *Caracteristicile de compresibilitate*		Shearing characteristics *Parametrii rezistenței de forfecare*	
	ρ_d^{max} [g/cm^3]	w_{opt} [%]	$E_{oed200\text{-}300}$ [kPa]	p_{umfl} [kPa]	Φ [°]	c [kPa]
Natural clay / *Argila naturală*	1.47 – 1.60	18.5 - 20	10000 - 12381	95 - 170	17 - 20	45 - 47

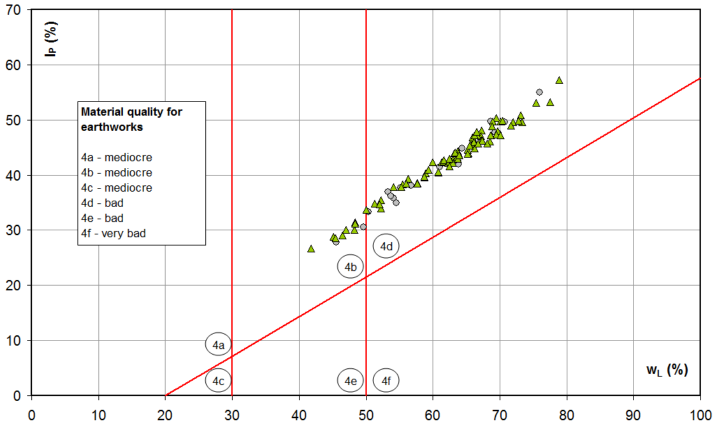
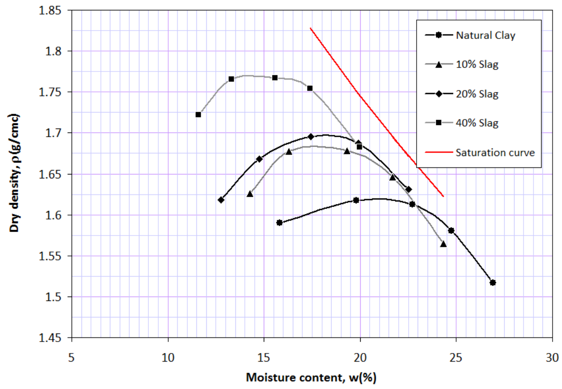


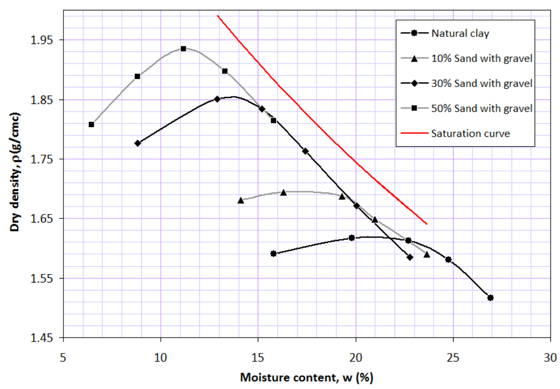
Fig. 5 - The classification of analyzed soils according to STAS 2914-84 / *Clasificarea pământurilor conform STAS 2914-84.*

In order to reuse these materials as filling materials we desensitized these soils in relation to water by adding granular material. There was proposed an experimental program that consisted in the determination: of the compaction characteristics, of the swelling pressure and the compressibility and consolidation parameters (determination of the permeability coefficient) and of the shearing resistance parameters in CUsat conditions on samples around the optimal compaction parameters.

In order to stabilize the expansive clay, by mixing with a non-cohesive material, was proposed three types of granular materials: S - slag (foundry sand), SG – sand with gravel and G - gravel.

Based on compaction tests (normal Proctor test), performed for the natural clay samples and for the mixtures with granular materials, optimal parameters of compaction have shown a decrease of the optimal moisture content and an increase of the dry density with the increasing the percentage of granular material (Figure 6).





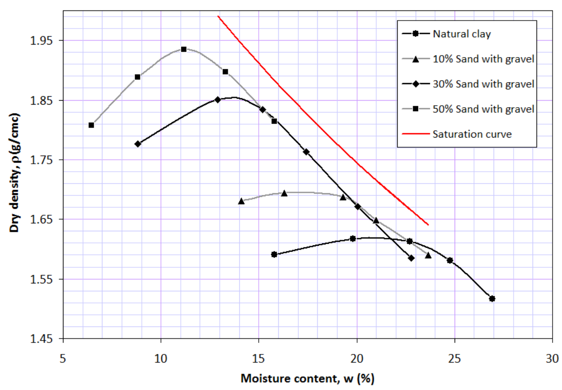


Fig. 6 - Compaction curves for mixtures with granular materials (slag, sand with gravel and gravel) [5, 6]

The laboratory tests revealed as optimal mixtures, in relation to the natural sample, the following mixtures: 40% slag, 50% sand with gravel and 30% gravel (Table 3) / *Curbe de compactare pentru amestecurile dintre argilă cu materiale granulare (zgură, balast şi petriş). Pe baza încercărilor de laborator s-au determinat amestecurile optime de material pentru corpul terasamentelor: 40% zgură, 50% balast şi 30% pietriş.*

Table 3

Soil characteristics of optimal mixtures with granular materials [5, 6, 8] / *Caracteristicile amestecurilor optime cu materiale granulare*

Material / Characteristics of the compacted samples *Materialul / Caracteristicile probelor compactate*	Optimal parameters of compaction *Caracteristicile optime de compactare*		Permeability coefficient *Coeficientul de permeabilitate*	Compressibility characteristics *Caracteristicile de compresibilitate*		Shearing characteristics *Parametrii rezistenței de forfecare*	
	ρ_d^{max} [g/cm3]	w_{opt} [%]	k [cm/s]	$E_{oed200-300}$ [kPa]	p_{umfl} [kPa]	Φ [°]	c [kPa]
Natural clay / *Argila naturală* (C)	1.62	21.0	$8.22 \cdot 10^{-9}$	8403	200	24	43
60% C + 40% S	1.77	14.5	$7.63 \cdot 10^{-9}$	11905	110	27	35
50% A + 50% SG	1.93	11.2	$1.07 \cdot 10^{-8}$	11111	110	33	17
70% A + 30% G	1.87	11.9	$4.89 \cdot 10^{-8}$	7380	75	*25	*35

The variation of stress-strain curve can be seen in Figure 7. Due to the high value of oedometric modulus and to the values of the swelling pressure, the mixtures with 40% slag and 50% sand with gravel fit perfectly as filling materials; these materials shows the smallest values of the oedometric modulus due to the smoothest load slope. Even if the smallest value of the swelling pressure is registered for the mixture with 30% gravel, this material is considered improper due to the value of the oedometric modulus.

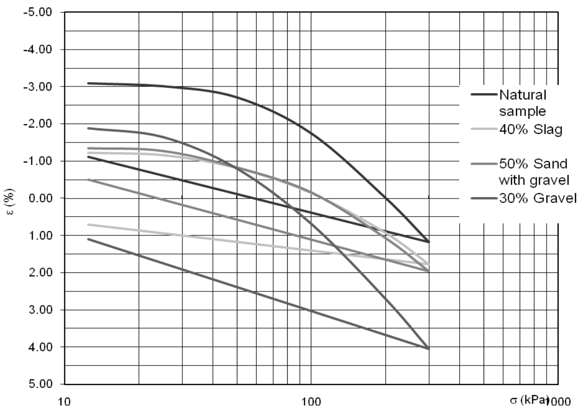


Fig. 7 - Stress-strain curve of optimum mixtures with granular materials / *Curbe de compresiune-tasare pentru amestecurile optime cu materiale granulare.*

According to the laboratory tests were established the variation diagrams regarding the swelling potential and the swelling pressure depending on the moisture content difference towards the optimum moisture content of compaction. From the mixture between 90% natural clay and 10% slag, from Figure 8, results the fact that the initial swelling and the swelling pressure register very high values, even higher than the values registered for the natural clay, behaviour justified by the fact that the compaction effect is higher than the desensitization effect (ρ_d^{max} increases from 1.62 g/cm^3 to 1.68 g/cm^3). Such diagrams constitute a solid support for the determination of the technological solution of soil stabilization with inactive materials [6].

A material resulted from the mixture of two soils does not have the behaviour of a natural material. A soil mixture identified in the ternary diagram as being sandy clay does not behave as a natural soil identified in the ternary diagram as sandy clay. For example, the mixture of 60% clay and 40% slag (identified in the ternary diagram as being sandy clay) developed a swelling pressure of 110-120 kPa, while in general, a natural material with the same grain size distribution is not active in contact with water [6].

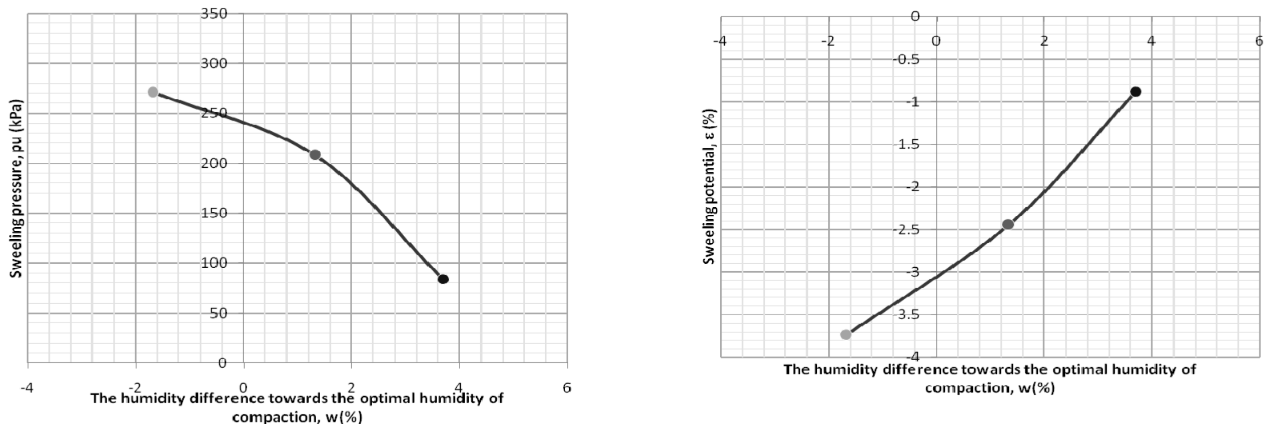


Fig. 8 - Swelling potential and swelling pressure variation in regard to the moisture content difference towards the optimum moisture content of compaction / *Variația presiunii de umflare şi a umflării specifice în funcție de diferența de umiditate a probei analizate şi umiditatea optimă de compactare* [6].

In order to develop some reduced swelling pressures, in the case of desensitization with granular material, is recommended that the moisture content of the used material should have a 1...3 % higher level than the optimum moisture content of compaction ($w = w_{oc} + 1...3$ %).

3.2. Embankments of stabilized expansive clay for a highway

For the construction of the embankments required for the 'Autostrada Transilvania' Project it was intended to use the existing materials, the excavated materials from the site or from the vicinity. Based on the geological and archive information, these materials are susceptible to be expansive soils.

In order to identify the activity in relation to water of these soils it was performed a series of initial tests such as: grain size distribution, plastic limits, natural water content, swelling pressure, oedometric modulus and shear strength tests. These tests were carried out for a test pad which was constructed at 25+400 km.

These materials have the following physical and mechanical properties according to the Romanian standards in force:

- grain size distribution: clay: 52%, silt: 46%, sand: 2%;
- plastic limit: $w_P = 15.3\%$;
- liquid limit: $w_L = 57.52\%$;
- plasticity index: $I_P = 42.22\%$ ⇒ very active soil;
- clay percentage 2μm: 44% ⇒ very active soil;
- activity index: $I_A = 0.96$ ⇒ low activity soil;
- compaction parameters:
  - optimum moisture content for compaction: $w_{opt} = 17.6$ %;
  - maximum dry density: $\rho_d^{max} = 16.9$ kN/m^3;
- mechanical characteristics obtained on compacted samples with the optimum moisture content for compaction:
  - swelling pressure, $p_u = 220$ kPa ⇒ very active soil;
  - edometric compressibility modulus, $M_{200\text{-}300} = 9901$ kPa;
  - internal friction angle tested in CU_{sat} conditions: $\rho = 16.4°$;
  - cohesion tested in CU_{sat} conditions: $c = 92.1$ kPa.

From the analysis of the above listed tests, it results that the material used on the test pad falls into the category of very active soils (expansive soils); especially due to the very high swelling pressure value and it cannot be used as a fill material in his natural state.

It was proposed as a solution for the stabilization of the clay used on the test pad to use a mix of 80% clay and 20% ballast. In laboratory conditions, this mix was achieved with granular material with a maximum grain size of 3.5 mm in order to be able to perform oedometer compressibility tests in order to determine the swelling pressure, which is an extremely important value for determining the optimum percentage of the mix.

The mechanical properties obtained for the 80% clay and 20% ballast mix the following:

- Optimum compaction parameters:
  - Optimum moisture content for compaction: $w_{opt} = 15.6$ %
  - Maximum dry volumetric weight: $\rho_d^{max} = 17.7$ kN/m^3
- Mechanical characteristics obtained on a compacted sample with the optimum moisture content for compaction:
  - Swelling pressure, $p_u = 132$ kPa ⇒ active soil;
  - Oedometric compressibility modulus, $E_{oed200\text{-}300} = 15038$ kPa;
  - Internal friction angle tested in CU_{sat} conditions: $\rho = 27.1°$;
  - Cohesion tested in CU_{sat} conditions: $c = 47.7$ kPa;

It is observed that although the material has a lower swelling pressure, it still remains active in relation to water and the compressibility characteristics are improved, as the mix has a medium compressibility ($E_{oed200\text{-}300} = 15038$ kPa), as compared to the high compressibility of the natural clay ($E_{oed200\text{-}300} = 9901$ kPa).

Based on the laboratory test results obtained for the 80% clay – 20% ballast mix, it was decided to determine the mechanical characteristics for a mix of 70% clay and 30% ballast.

In Table 4 are presented the characteristics of the clay used on the trial section, with the natural composition and mixed with ballast in proportions of 20% and 30%.

Table 4

Soil characteristics of optimal mixtures with ballast / *Caracteristicile amestecurilor optime de argilă cu balast*

Characteristics *Caracteristici*	100% clay / *100% argila*	80% clay – 20% ballast *80% argila – 20% balast*	70% clay – 30% ballast *70% argila – 30% balast*
w_{opt} (%)	17.5	15.6	15.2
γ_d^{max} (kN/m^3)	16.9	17.7	17.9
p_u (kPa)	220	132	88
$E_{oed200\text{-}300}$ (kPa)	9901	15038	13333
φ_{CUsat} (°)	16.4	27.1	25.4
c_{CUsat} (kPa)	92.1	47.7	42.3
$CBR_{2.54}$ (%)	11.68	12.6	13.47
$CBR_{5.08}$ (%)	9.4	9.67	10.75

The main characteristic used to establish the optimum ballast content of the clay used on the trial section is the swelling pressure. It shows a quite linear variation according to the percentage of ballast used in the mix (Figure 9). The objective value was established based on the minimum vertical pressure on the embankment material estimated to approximately 60kPa and taking into account the motorway structure and the operation load. To this pressure, the 70% clay and 30% ballast mix, tested by the oedometer, has a specific swelling of approx. 0.4%.

Analyzing the results obtained for the three materials, it is estimated that the clay used on the trial section, with an addition of minimum 30% of ballast, records acceptable values for swelling pressure and the obtained mix can be used as embankment fill material.

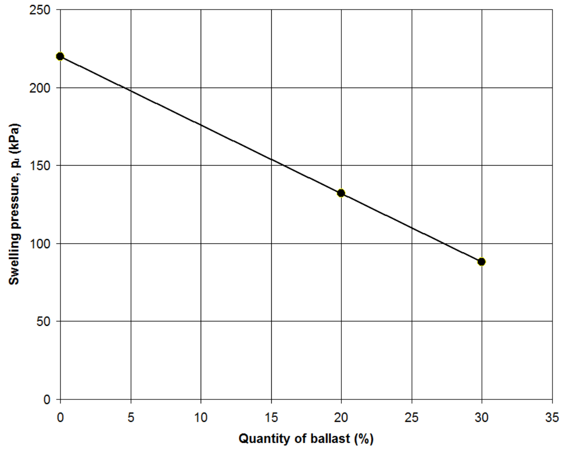


Fig.9 - The variation of the swelling pressure according to the percentage of ballast from the mixture / *Variația presiunii de umflare în funcție de procentul de balast.*

The quality of the material obtained at site was checked on a test pad. The purpose was to obtain a homogenous mix of 80% clay and 20% ballast. The execution stages were (Photo 1... Photo 9):

- Spreading of the clay material;
- Crumbling of the clay material (eliminate clay boulders);
- Levelling with the grader to achieve a layer of 27 cm;
- Spreading of the ballast material;
- Levelling with the grader to achieve a layer of 5 cm;
- Vertical mixing of the materials with CAT RM-350B;
- Levelling with the grader;
- Compacting with the sheep foot roller – 4 passes;
- Compacting with the drum cylinder compactor – 4 passes

The most important equipment to achieve the mix is the CAT Rm-350B mixer. This machine is equipped with a lobe rotor which penetrates below the surface level, on a width of 50cm. The mixing is made vertically. A scheme of the mixing chamber, extracted from the technical data sheet of the equipment is presented in Figure 10.

Photo 1

Photo 2

Photo 3

Photo 4

Photo 5

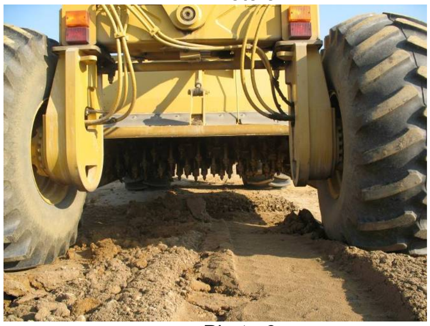


Photo 6

Photo 7

Photo 8

Photo 9

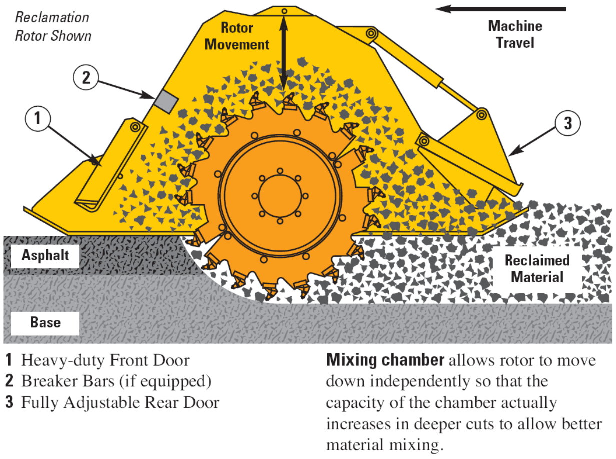


Fig. 10 - The mixer rotor and the sketch of the mixing process / *Schema rotorul mixerului şi obţinerea amestecului.*

Three layers were placed on the test pad to check the homogeneity of the mix, including at the interface between two successive layers. After compaction, a trench was executed where the quality of the mix was checked visually and the material was sampled to a depth range of 20 cm in order to determine the gradation (Photo 10...Photo 15). The results for the distribution of the solid particles according to grain size and the obtained mix are presented in Table 5.

Table 5

The distribution of the granular materials / *Distribuţia materialelor granulare.*

	Natural clay *Proba naturală de argilă*	Sample 1 / *Proba 1* 0.00…0.20m		Sample 2 / *Proba 2* 0.20…0.40m		Sample 3 / *Proba 3* 0.40…0.60m		Sample 4 / *Proba 4* 0.60…0.80m	
			Difference / *Diferenţa*		Difference / *Diferenţa*		Difference / *Diferenţa*		Difference / *Diferenţa*
Clay / *Argila*	52	41	-9	47	-5	45	-7	44	-8
Silt / *Praf*	46	33	-13	34	-12	38	-8	36	-10
Sand / *Nisip*	2	15	+13	11	+9	9	+7	11	+9
Gravel / *Pietriş*		11	+11	8	+8	8	+8	9	+9
Percentage of granular material / *Procentul de material granular*			23%		17%		15%		18%

Photo 10

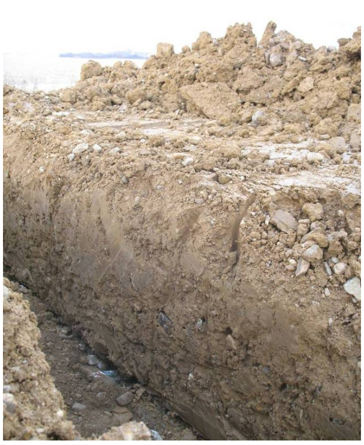


Photo 11

Photo 12


Photo 13


Photo 14


Photo 15

The first column shows the percentages for the three granulometric fractions, clay, silt and sand. For each of the four samples taken in situ, the percentages of clay, silt, sand and gravel determined by laboratory tests are presented in the first column and the difference from the natural material is shown in the second column. The percentages of clay and silt showed a decrease because of the additional sand and gravel. The percentage of coarse material from the mix is determined as an average of the decreasing and increasing percentages of material. This percentage varies between 15 and 23%, with an average value of 18%.

Both the visual observations and the laboratory tests confirm that a quasi-homogenous mix of clay with ballast is obtained with the above described technological process, applied on the test pad section. The achieved compaction degree was higher than 98%.

For embankment fill material, samples taken from 23 sources were analyzed. The purpose is to establish the optimum ballast percentage per groups of materials, especially the ones which are more active in relation to water.

In Figure 11 these materials are presented in the ternary diagram. It is observed that they are grouped in 3 zones, named groups and marked as A, B and C. All the samples recorded values of the free swell greater than 70, according to STAS 2914-88, from this result that all the materials fall into in the category 4d (bad quality materials for earthworks).

The materials from **group A** are type of silty clays with clay percentage less than 40%.

Materials of **group B** are type of sandy clay with:

- Clay percentage with $x_{2\mu}$ = 30 ÷ 33 – active soil;
- Plasticity index I_P = 27.9 ÷ 33.1 % – active soil;
- Activity index I_A = 0.93 ÷ 1 – low activity – active soil.

The soils from group A and group B, based on the analysis of the physical characteristics, it is estimated that they are not active in relation with water; respectively they do not record any significant volume variations at variations of humidity. The behaviour in relation with water shall be checked by compaction of a sample and

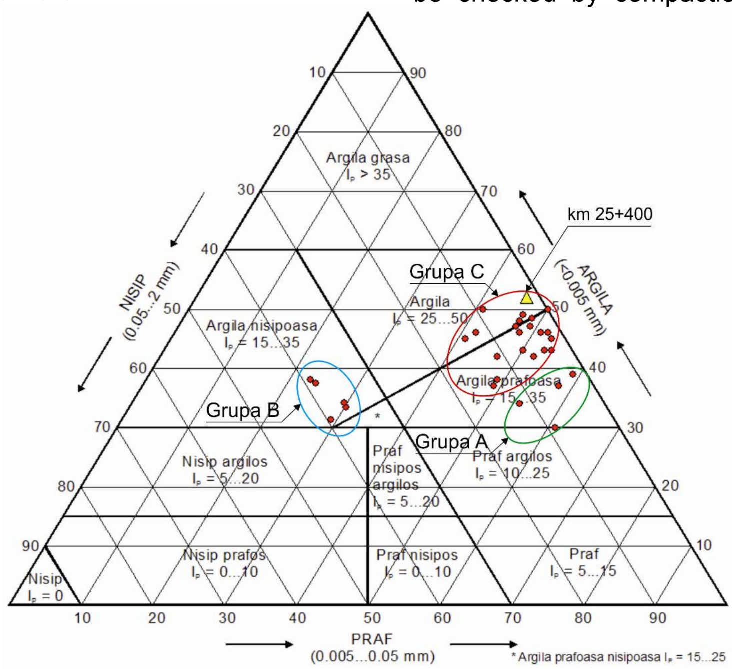


Fig. 11 - Presentation in ternary diagram of the cohesive materials from the 23 sources / *Reprezentarea în diagrama ternară a materialelor coezive din cele 23 de surse.*

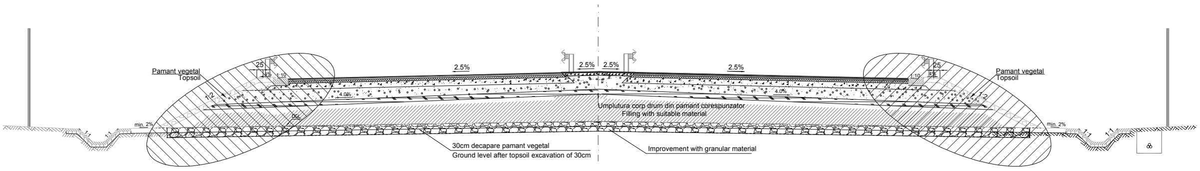


Fig.12 - Embankment cross section indicating the zones subjected to variations of humidity and temperature / *Secțiune transversală prin rambleu cu indicarea zonelor supuse la variații de umiditate şi temperatură.*

determining the swelling pressure on a sample compacted to the optimum moisture content for compaction.

Materials of **group C** are type of clay – silty clay with:

- Clay percentage with $x_{2\mu}$ = 35 ÷ 42 – active – very active soil
- Plasticity index I_P = 28 ÷ 41 % – active – very active soil
- Activity index I_A = 0.7 ÷ 0.95 – low activity soil
- Free swelling U_L = 95 ÷ 118 % – low activity soil

The material used for the test pad section and laboratory analysis for the mix is classified as belonging to the same group. The solution requiring using additional ballast is maintained for these materials.

Figure 12 shows a typical embankment cross section. On the set up ground level, there is a layer of compacted granular material, followed by the embankment body consisting of the material which is the subject of this study. The road structure with a thickness of 95 cm is on top of this layer.

The permeable layer on the bottom of the embankment, executed with gradients which drain the water out of the embankment reservation, limit the possibility of humidity increase in the embankment body if the source were underground water.

The road structure and especially the sealing provided by the asphalt layer limit the possibility of humidity increase in the embankment body if the source were precipitation water.

The zones susceptible of being subject to variations of humidity and temperature are in the area of the embankment slopes, highlighted in Figure 12. These are the areas where it is needed to use a fill material which does not have volume variations at variation of humidity. In the embankment slope body**,** the used material must correspond in terms of mechanical characteristics.

Considering the laboratory test results for embankment slope area, on a thickness up to the frost depth (Min 80 cm), it is recommended to use a mixture with a minimum ballast percentage of 30%. In the embankment slope body, it is possible to reduce the ballast percentage until reaching similar compressibility characteristics, respectively down to a minimum percentage of 15%.

4. Conclusions

Based on the compaction tests, it was revealed that the optimum moisture content decreases and the maximum dry density increases in the case of physical stabilization; while in the case of chemical stabilization, the optimum moisture content increases and the maximum dry density decreases.

In order to develop some reduced swelling pressures, in the case of desensitization with granular materials, it is recommended to assure some compaction degrees of 95-98% to moisture content with 1...3% higher than the optimum moisture content of compaction.

Based on the laboratory systematic tests, can be established diagrams of variation of swelling potential and the swelling pressure depending on the moisture content difference in regard to the optimum moisture content of compaction; such diagrams constitute a solid support for the determination of the technological solution of soil stabilization with inactive materials

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