Proceedings of the XVII ECSMGE-2019
Geotechnical Engineering foundation of the future
ISBN 978-9935-9436-1-3

doi: 10.32075/17ECSMGE-2019-0993

XVII European Conference
ECSMGE 2019
Reykjavik
on Soil Mechanics
and Geotechnical Engineering

Soil-mix compacted cushion for rising ground level and distributing loads on a highly compressible foundation soil

Coussin compacté en terre améliorée par mélange requis pour l'élévation du niveau du sol et la répartition des charges sur un terrain de fondation très compressible

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ABSTRACT: Building in floodplains is possible by increasing of the ground level so as to exceed the quote of flooding level imposed by hydrological studies. The geotechnical study showed that the foundation soil consists in layers of very difficult soil characterized by highly compressible soils and expansive soils. In order to build the compacted cushion, it has been proposed to use as filling material a soil identified as a silty clay (si.Cl) which develop a swelling pressure of 120 kPa. To reduce the activity in ratio to water of the si.Cl material, were proposed three mixtures: two with hydraulic binders (based on lime and cement) and one with natural granular materials (sand). Optimum percentages of filler material were determined in the laboratory on samples compacted by the normal Proctor test, so that the resulting mixtures to have reduced the swelling pressure, to record a lower compressibility and to increase the shear strength parameters. After the laboratory tests, in-situ trial pads were performed for the above mentioned optimal mixtures.

RÉSUMÉ: Construire dans les plaines inondables n'est possible que lorsque le niveau du sol est élevé pour dépasser le taux d'inondation requis par les études hydrologiques, Sur un tel emplacement l'étude géotechnique a montré que le terrain de fondation est constitué de couches de sol difficile caractérisées par des terrains très compressibles, des argiles présentant des gonflements et des contractions importants. Afin de construire le coussin compacté, il a été proposé d'utiliser comme matériau de remplissage un sol identifié comme une argile limoneuse (si.Cl) qui développe au contact de l'eau une pression de gonflement de 120 kPa. Afin de réduire l'activité en rapport avec l'eau du matériau si.Cl, trois mélanges ont été proposés: deux avec des liants hydrauliques (à base de chaux et de ciment) et un avec des matériaux granulaires naturels (sable). Les pourcentages optimaux de matériau de remplissage ont été déterminés en laboratoire sur des échantillons compactés par le test Proctor, de sorte que les mélanges résultants aient réduit la pression de gonflement, enregistré une compressibilité inférieure et augmenté les paramètres de résistance au cisaillement. Après les tests de laboratoire, un polygone expérimental a été créé où des essais in situ ont été menés pour les mélanges susmentionnés. Sur la base des résultats, le mélange optimal a été choisi.

Keywords: Compacted cushion; soil-mix; hidraulic binders; test pads.

1 INTRODUCTION

The need to achieve large volumes of controlled compacted earthworks (dams, pavements for road foundations, industrial platforms, harbors and airport platforms) involves the use of various local soils wich often have inadequate geotechnical properties. In order to be used as building materials, these soils must be improved by various methods in order to ensure the quality required in the technical project.

The paper presents the technical solution taken into account for the construction of an industrial platform located in a flooded area of the Danube meadow from Romania.

In terms of protection from flooding has become mandatory to upraise the ground level with minimum 2 m by making a compacted soil cushion on which all technological objects will be founded.

Compaction is one important action applied on geomaterials (soils, rock, mixtures of soil and rocks, stabilised soils and unbound and bounded granular materials) by different technologies to achieve design target values assuring the desired performance of earth structures and structural layers in pavement and railways structures (Gomez Correia, 2018).

Considering the large volume of fillings required for the construction of this industrial platform of 5 ha, the available source of the soils in the area consists in a difficult foundation soil, which is caracterised as a swelling – shrinking clay, which is similar to the natural foundation soil: **silty clay (si.Cl)**.

In order to improve the **si.Cl** material; laboratory and field investigations were performed on three mixtures: a fine-medium sand (**S**) and two types of **hydraulic binders** (**C** and **D**). On the basis of these mixtures the final solution was established.

2 SOIL MIXTURES

The choice of soil improvement methods must take into account the following factors: the aim of the proposed work, the properties of the improved soil, the geotechnical characteristics (physical and mechanical) required for the project, the technologies pf execution (Figure 1).

Clayey soils are often problematic for infrastructure works. In general, if the geotechnical properties of the existing soil are inappropiate, it is either replaced with a suitable fill material or improved on-site via various methods. Quicklime is frequently used to dry wet soils at construction sites and also, reducing construction time and providing an improved working platform. An even more significant use of lime is in the improvement and stabilization of soil beneath road and similar construction projects. Lime can substantially increase the stability, improves plasticity and compaction properties and load-bearing characteristics of the subgrade and lower fill layers (Kavak et all, 2014).

Considering that regardless the type of mixing, putting into operation is achieved by compacting and, as a first step, it is necessary to determine in the laboratory the optimal compaction characteristics of the proposed mixtures and then, based on the compacted samples, to determine the mechanical characteristics and to verify the moisture-sensitivity of the compacted material.

3 THE OPTIMAL SOIL-MIXING FROM THE LABORATORY TESTS

3.1 Characteristics of the natural soil

From the granulometric point of view, the available material is a brownish Silty clay (**si.Cl**) with the following characteristics: Clay ($d < 0.002$ mm) – 24%, Silt ($0.002 < d < 0.063$ mm) and Sand – 20% ($0.063 < d < 20$ mm).

According to the technical norms in force (NP 126-2012) and to the physical characteristics of the si.Cl, it was characterized as a **less active** to **active** in relation to water (w_P = 21.79 %, w_L =

47.12 %, I_P = 25.34 %, $A_{2\mu}$ = 25 %, U_L = 55 %, I_A = 1.0).

These parameters determined in the laboratory reflects only the nature of the material, which, after compaction, will reach damping states with different moisture contents (generally at a smaller porosity) and the material may have the behavior of a swelling – shrinkage clay.

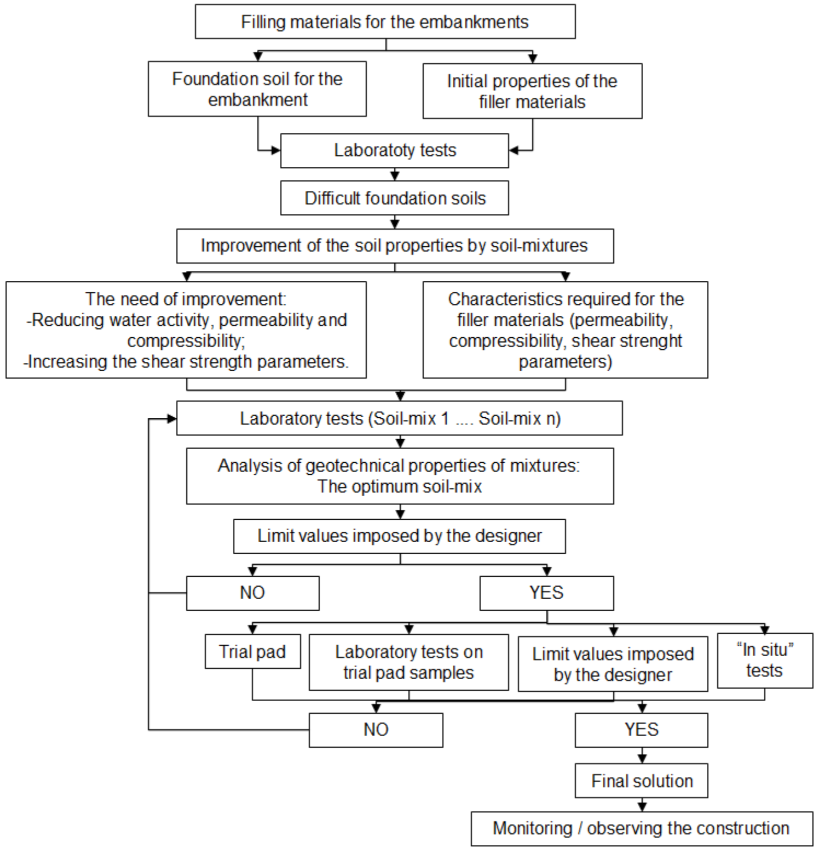


Figure 1. The soil improvement solution

In order to caracterize the swelling – shrinkage behavior, the essential geotechnical parameter is the sweeling pressure, determined on compacted samples by oedometric tests.

The optimum parameters determined by the Standard Proctor test are:

- w_{oc} = 18 %;
- ρ_d^{max} = 1.71 g/cm^3.

The synthesis of the oedometric compressibility tests on the compacted samples is presented in Figure 2.

The shear strenght parameters determined on initially saturated compacted samples in consolidated – undrained conditions are:

- internal friction angle: ϕ = 17.53°;
- cohesion: c = 74.49 kPa.

Table 1. Compaction characteristics of the si.Cl

		p_{umfl} (kPa)	$E_{oed200\text{-}300}$ (kPa)
Compacted samples	w_{oc}-3%	180	7905
	w_{oc}	60	9709
	w_{oc}+3%	55	9259
Foundati on soil	x_{kinf}	4	5382
	x_{ksup}	36	7318
	x_{med}	20	6382

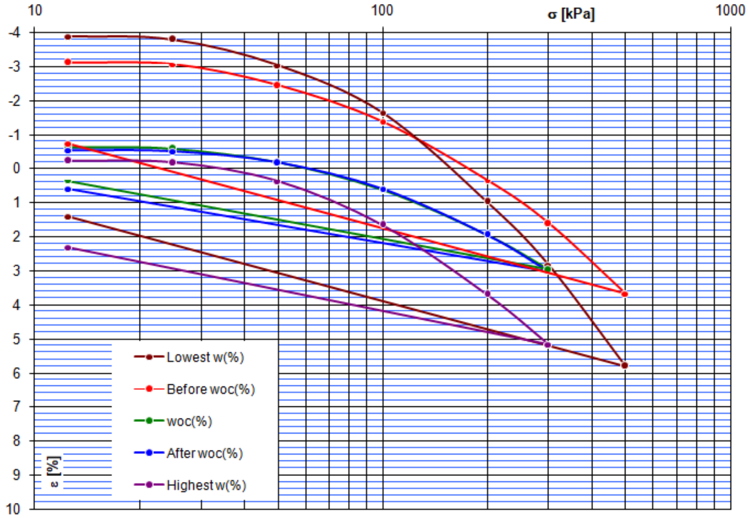


Figure 2. Oedometric curves on si.Cl samples

The tests for the determination of the mechanical characteristics were performed on compacted samples around optimum compaction, taken from the Proctor test, without following a compacted sample at the optimal parameters, because it was observed that the dry density varies on the height of the compacted sample in 3 layers.

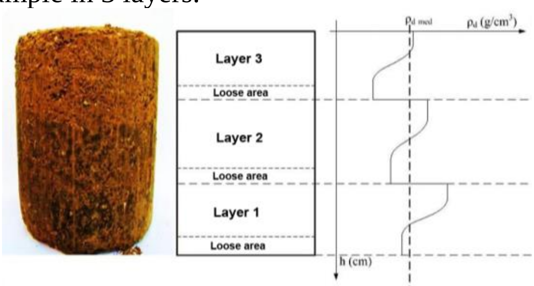


Figure 3. Dry density teoretical variation depending on the height of the compacted sample (Burlacu et al., 2013)

3.2 *The necessity of soil-mixing*

The objectives of improving the available material were generated by the following technical requirements

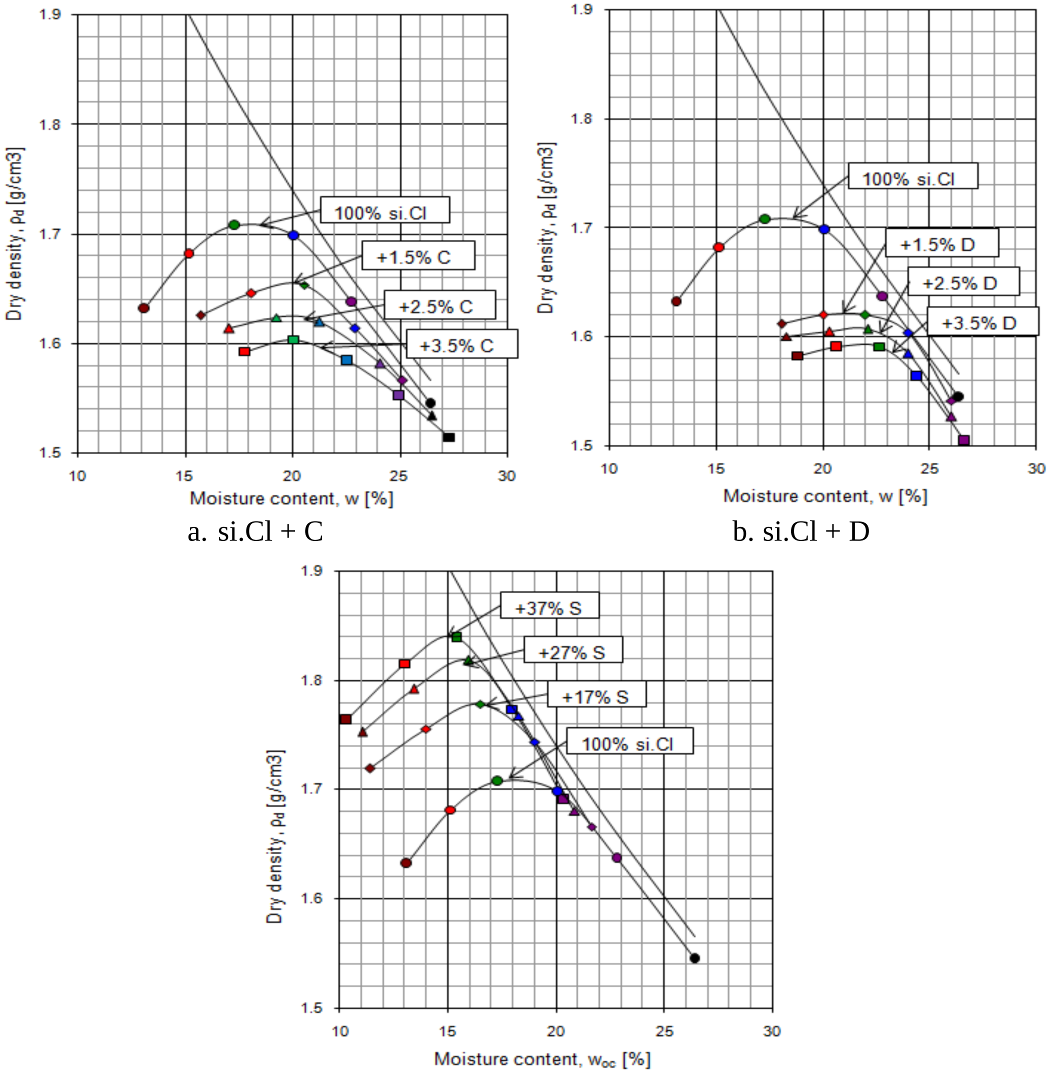
- Desensitization in relation to water, taking into account the swelling pressures that develop on compacted samples
- Enhanced compressibility modulus in connection with the compressibility of the foundation soil to ensure the deformation compatibility;
- Reduced permeability in order to prevent water seepage in the foundation clayey soil, soil wich is active in relation to water.

Based on laboratory tests on natural compacted samples (**si.Cl**), were proposed three mixtures: one with natural granular materials (**sand**) and two with hydraulic binders (based on **cement and lime**). In order to study the mechanical behavior of soil-mixtures, the following percentages of added material were proposed:

- **medium sand (S)**: 83.3%si.Cl + 16.7%S, 73.3%si.Cl + 26.7%S, 64.3%si.Cl + 36.7 %S;
- **hydraulic binder 1 (C):** 98.5%si.Cl + 1.5%C, 97.5%si.Cl + 2.5%C, 96.5%si.Cl + 3.5%C;
- **hydraulic binder 2 (D):** 98.5%si.Cl + 1.5%D, 97.5%si.Cl + 2.5%D, 96.5%si.Cl + 3.5%D.

3.3 *Characteristics of soil-mixtures*

The optimal compaction parameters were determined by the normal Proctor test (Figure 4).



a. si.Cl + C

b. si.Cl + D

c. si.Cl + S

Figure 4. Compaction curves of normal Proctor test

In Figure 4, it can be observed that for the si.Cl + S mixtures the optimum moisture content decreases and maximum dry density increases as the percentage of granular material increases. In the case of chemical stabilization, the optimum moisture content increase and the maximum dry density decrease as the percentage of hydraulic binder increase.

The swelling pressure was determined by oedometric tests, performed on initially saturated samples. The Figure 5 shows that for all compacted samples, regardless of the percentage of added material, the swelling pressure increases as the decrease of the moisture content of the compacted samples.

In the case of mixtures of si.Cl + S, swelling pressures decrease as the percentage of sand added increase. For the mixture with 37% sand the resulting material has no longer the behavior of a swelling – shrinkage material.

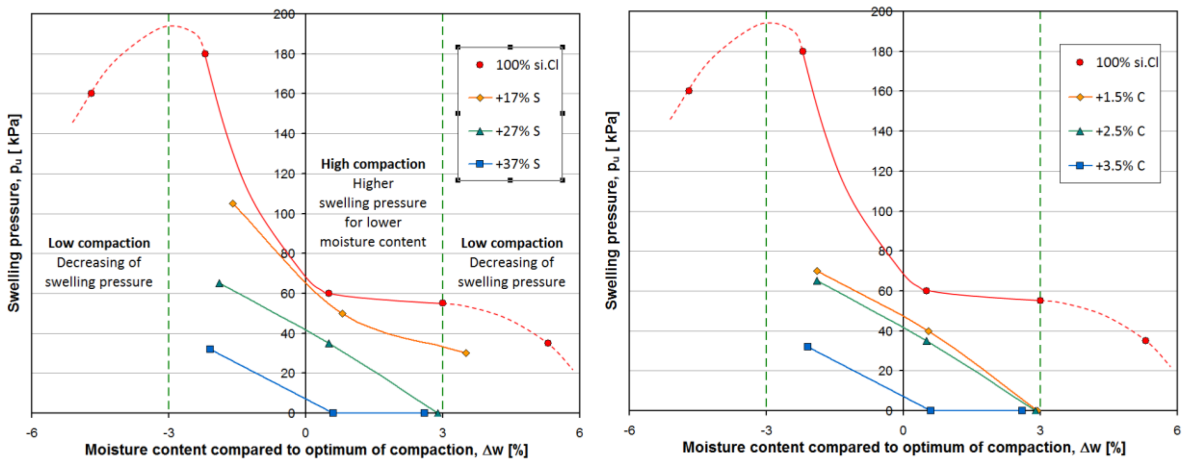
The variation of the swelling pressure according to the compaction range $w_{oc} \pm 3\%$ are summarized in Table 2.

Table 2. The variation of the swelling pressure

	w_{oc} + 3%	w_{oc}	w_{oc} - 3%
100%siCl	52	85	180
83.3%siCl + 16.7%S	30	65	148
73.3%siCl + 26.7%S	0	39	84
63.3%siCl + 36.7%S	0	7	43
98.5%siCl + 1.5%C	0	47	80
97.5%siCl + 2.5%C	0	42	75
96.5%siCl + 3.5 %C	0	7	40

In the case of si.Cl + D mixtures, regardless of the percentage of added D, it has been noticed that the swelling pressure is zero resulting that the materials obtained do not have the behavior of a swelling – shrinkage material.

The results of the chemical reaction from the mixtures between si.Cl + C and si.Cl + D were followed by subjecting the compacted samples to compressibility tests in the oedometer at 7 days after compaction. These results can be seen in Table 3.



a. si.Cl + S *b. si.Cl + C*

Figure 5. Determination of the swelling pressure on compacted samples

Table 3. Geotechnical characteristics of soil mixtures

	w_{oc} [%]	ρ_d^{max} [g/cm^3]	$E_{oed}^{200\text{-}300}$ [kPa] 1 day / 7 days after compaction	ϕ [°]	c [kPa] 1 day after compaction
100%siCl	18.0	1.71	9709	17.5	74.5
83.3%siCl + 16.7%S	16.5	1.78	13333	21.6	57.1
73.3%siCl + 26.7%S	16.0	1.82	12821	30.8	30.3
63.3%siCl + 36.7%S	15.4	1.84	12579	34.1	4.2
98.5%siCl + 1.5%C	20.0	1.66	16129 / 14706	20.7	79.9
97.5%siCl + 2.5%C	**20.0**	**1.624**	**26300 / 30300**	**19.0**	**92.8**
96.5%siCl + 3.5 %C	19.8	1.60	25641 / 32258	37.3	25.1
98.5%siCl + 1.5%D	21.3	1.62	18868 / 17857	23.3	62.7
97.5%siCl + 2.5%D	**21.7**	**1.61**	**20408 / 18868**	**23.3**	**79.4**
97.5%siCl + 3.5%D	1.59	1.59	17857 / 23810	21.4	37.9

4 IN SITU TESTS

For the applicability to real scale an in-situ test pad was organized with the following mixtures:

- 70%si.Cl + 30%S;
- 97.5%si.Cl + 2.5%C;
- 97.5%si.Cl + 2.5%D.

The main stages of execution of the in situ test pad were:

- Contruction of the support layer;
- Building the compacted cushion, realized in 3 layers of improved material (Figure 6, Figure 7)

Construction of the support layer consisted of:

- Drawing the experimental polygon on an area of 50mx30m;
- Cutting the vegetation soil layer to a depth of 30 cm;
- Preparing the working platform by improvement on a depth of approx. 50 cm with specific added materials.

The entire test pad was monitored by field tests (static plate and dynamic plate tests) and laboratory tests to determine: moisture content, density in natural and dry state, the degree of compaction achieved, the mechanical characteristics of the compacted mixture.

Table 4 shows the synthesis of all results.

Table 4. Physico-mechanical properties of experimental polygons

Soil-mix	70%siCl + 30%S	97.5%siCl + 2.5%C	97.5%siCl + 2.5%D
Step I Compaction			
Degree of compaction [%]			
0 – 6 cm depth	88.1 / 91.5 / 91.4	89.5 / 94.2 / 98.9	93.9 / 91.4 / 93.3
10 – 16 cm depth	91.4 / 92.1 / 95.2	93.8 / 93.4 / 95.2	98.1 / 94.1 / 93.3
20 – 26 cm depth	92.5 / 92.8 / 92.6	88.7 / 88.3 / 94.0	91.0 / 89.8 / 90.2
Step II: Compaction			
Degree of compaction [%]			
0 – 6 cm depth	96.3	98.5	93.3
10 – 16 cm depth	97.2	98.5	91.6
20 – 26 cm depth	95.9	101.2	94.5
Compresibillity from dinamic plate, Ev1; Ev2 [MPa]	12 ; 27.9	139 ; 270	68.6 ; 180

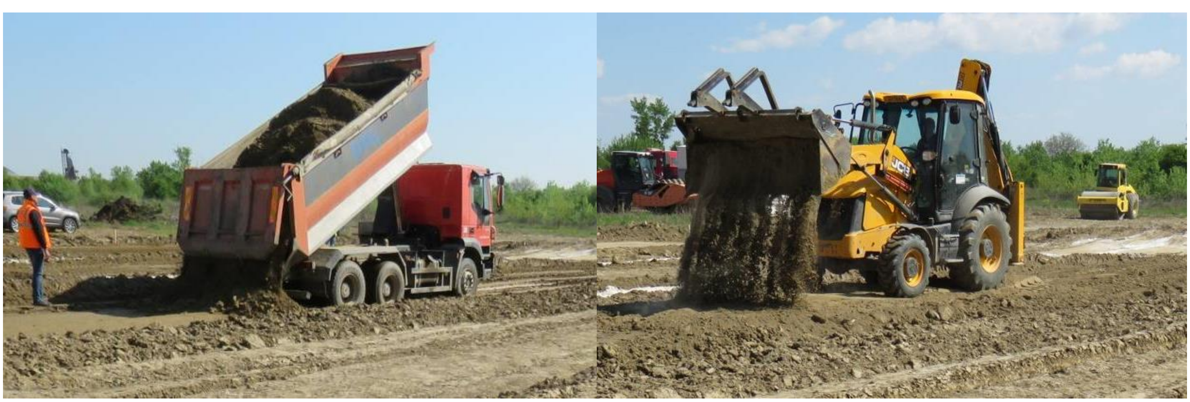


Figure 6. Spreading of the clayey soil and sand in addition

Figure 7. Spreading of 2.5% hydraulic binder, mixing of the si.Cl with the hydraulic binder and the compaction with the cam roller

5 CONCLUSIONS

The analysis of the laboratory test results carried out on compacted samples revealed the following:

- The compressibility characteristics are not significantly influenced by the time of testing, respectively, immediately or after 7 or 28 days after the execution of the in situ test pad;
- In terms of deformability compatibility, the mixture of si.Cl + S is the proper material, but the amount of necessary volume could not be ensured through a local source, requiring very high transport costs;
- In the case of mixtures with hydraulic binders, the deformability modulus increases significantly and reaches very high values; the material that has a behavior compatible with the foundation soil is the mixture of si.Cl+D;
- Based on the compaction degree obtained from the 'in situ' tests, the number of passes and the weight of the compaction equipment for the final solution will have to be recalibrated.

The material considered optimal for the filler material used to build the platform of approx. 2 m is the mixture of 97.5% si.Cl + 2.5% D, which satisfies all the proposed objectives, ensuring a deformability compatible with that of the foundation soil.

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