A treatment of expansive soil using different additives

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There are many factors that govern the expansion behavior of soil. The primary factors are a change in water content and the amount and type of clay size particles in the soil. Other important factors affecting the expansion behavior include the type of soil (natural or fill), condition of the soil in terms of dry density and moisture content, magnitude of the surcharge pressure, and amount of no expansive material such as gravel or cobble size particles.

In this paper, a swelling soil from the site Hamamuk earth dam, which is located in Koya town north of Iraq, is treated by four types of additives; cement, steel fibers, gasoline fuel and injection by cement grout.

The treatment of the expansive soil with 5 % of cement or steel fibers or the injection with cement grout revealed a better improvement while 4 % of gasoline oil is sufficient to reveal the optimum treatment by this material. The angle of internal friction is not affected by the treatment while the cohesion between particles is slightly affected by these additives due to a change in the adhesion between the additive and soil particles.

Key words: *Expansive soil, swelling, consolidation, shear strength, treatment, additives.*

Introduction

There are many plastic types of clay that swell considerably when water is added to them and then shrink with the loss of water. Foundations constructed on these clays are subjected to large uplifting forces caused by the swelling. These forces will induce heaving, cracking, and breakup both of building foundations and slab-on-grade members. An increase of moisture content causes clay to swell [1].

Laboratory testing of swelling soils

The experimental investigations of the behaviour of swelling soils are numerous. Many were motivated by the expansion under shallow foundations and used one-dimensional testing apparatuses to predict vertical swell magnitudes as well as ‘swelling pressures’. ASTM D 4546 [2] provides three methods for evaluating the ‘swell pressure’ using the oedometer apparatus. One procedure includes measuring the increase in the height of specimens under either a nominal pressure or in situ stress, followed by the compaction down to the original height and further. The first phase measures the volume increase during wetting while the second phase measures the stress to counteract the swell potential. The stress required to bring the specimen to the original height is interpreted as the ‘swell pressure’. The second procedure involves first loading specimens to the in situ stress level and then inundating them with water while the load is added to keep the specimen at a constant volume. The final load applied is interpreted to be the ‘swelling pressure’. Many researchers have used these ASTM procedures to obtain measurements of swelling volume potential as well as the ‘swelling pressure’ [3, 4].

Notation

e_o	Initial void ratio.	Sw(free)	Free swell.
c	Cohesion.	w %	Water content.
C_c	Compression index.	ΔH	Height of swell due to the saturation.
C_r	Reloading index.	γ_d max	Maximum dry density of soil.
G_s	Specific gravity.	σ	Normal stress.
H	Original height of the specimen.	σ_I^t	Additional pressure added to prevent swelling after the addition of water.
LL	Liquid limit.		
$O.M.C$	Optimum moisture content.	σ_T^t	Total effective pressure to prevent swelling, or zero swell pressure.
PL	Plastic limit.		
S %	Degree of saturation.	ϕ	Angle of internal friction.

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Laboratory measurement of swelling

To study the magnitude of possible swelling in clay, simple laboratory odometer tests can be conducted on undisturbed specimens. Two common tests are the unrestrained swell test and the swelling pressure test.

In the unrestrained swell test, the specimen is placed in the odometer under a small surcharge of about 6.9 kN.m^{-2}.Water is then added to the specimen, and the expansion of the volume of the specimen (that is, height; the area of cross section is constant) is measured until an equilibrium is reached. The percent of free swell may be expressed as a ratio [1].

In this research, this method is used for measuring the swelling of the studied soil. The free swell is calculated as follows:

$$S_{w(free)}(\%)=\frac{\Delta H}{H}(100) \quad (1)$$

where: ΔH = height of swell due to the saturation,
H = original height of the specimen.

The swelling pressure test can be conducted by taking a specimen in a consolidation ring and applying a pressure equal to the effective overburden pressure (σ'_o) plus the approximate anticipated surcharge caused by foundation (σ'_o). Water is then added to the specimen. As the specimen starts to swell, the pressure is applied in small increments to prevent swelling. This is continued until the full swelling pressure is developed. At that time, the total effective pressure on the specimen is:

$$\sigma'_T = \sigma'_O + \sigma'_S + \sigma'_1 \quad (2)$$

where:

σ_T' = total effective pressure to prevent swelling, or zero swell pressure,

σ_1' = additional pressure added to prevent swelling after addition of water.

A value of $\sigma_T \approx$ 20 – 30 kN.m^{-2} is considered to be low, and a value of 1500 to 2000 kN.m^{-2} is considered to be very high [1].

Soil improvement

Soft saturated clay layers are often encountered at shallow depths below the foundation(s). Depending on the structural load and the depth of the clay layer(s), a large consolidation settlement or swelling occurs usually. Special soil improvement techniques are required to overcome such swelling problems.

In this work, the untreated soil and that treated by four types of additives; cement, steel fibers, gasoline fuel and injection by cement grout are subjected to a comprehensive laboratory tests for the sake of:

1. reducing the settlement of the structures,
2. increasing the factor of safety for a possible slope failure of embankments and earth dams,
3. reducing the shrinkage and swelling characteristics of soils.

The work is divided into two parts: The part 1 includes testing of untreated expansive soil, while the part 2 includes testing the soil treated by additives. Then, a comparison between the tested soils is done.

The cement, steel fibers and the cement grout materials are added to the soil at different percents: 5 %, 10 % and 15 % while the gasoline fuel is added at 2 %, 4 % and 6 %.

Cement stabilization

Cement is increasingly used as a stabilizing material for soils, particularly for the construction of highways and earth dams. It can be used to stabilize sandy and clayey soils. As in the case of lime, the cement has an effect to decrease the liquid limit and to increase the plasticity index and workability of clayey soils. For clayey soils, the cement stabilization is effective when fine fractions (passing No. 200 sieve) are less than about 40 %, the liquid limit is less than 45 to 50, and plasticity index is less than about 25 [5]. The optimum requirements of cement by volume for an effective stabilization of various types of soil are given in Table 1. Cement helps to increase the strength of soils and the strength increases with the curing time.

Tab. 1. Cement requirement by volume for an effective stabilization of various soils [1].

Soil type		**Percent cement by volume**
AASHTO Classification System	**Unified Soil Classification System**	
A-2 and A-3	GP, SP and SW	6-10
A-4 and A-5	CL, ML and MH	8-12
A-6 and A-7	CL, CH	10-14

An experience with the cement stabilization of swelling soils revealed the following:

- If the subgrade has an insufficient strength, then stabilization of the subgrade may be required.
- Adding cement is just one of the means of acquiring the additional strength.
- Above 10 % cement may be uneconomical and other methods should be considered.
- Table 2 presents a typical range but a material specific testing programmed should be carried out to conform the most economical cement content.
- For each 1 % cement added, an extra unconfined compressive strength of 500 kPa to 1000 kPa may be achieved.
- Shrinkage concerns for cement at >8 %.
- Tensile strength of ≈10 % unconfined compressive strength.

Tab. 2. Typical cement content for various soil types [6].

Soil type		**Cement requirement**
Fine crushed rock		0.5 % - 3 %
Well graded & poorly graded gravels	GW,GP	2 % - 4 %
Silty & clayey gravels	GM, GC,	
Well graded sand	SW	
Poorly graded sand, silty sands, clayey sands	SP, SM, SC	4 % - 6 %
Sandy clay, silty clays	ML, CL	6 % - 8 %
Low plasticity inorganic clays & silts		
Highly plastic inorganic clays & silts	MH, CH	8 % - 12 %
Organic clays	OL, OH	12 % - 15 % (per treatment with lime)
Highly organic	Pt	Not suitable

Soil Stabilization by Injection of Suitable Grouts

Grouting is a process whereby fluid like materials, either in a suspension or solution form, is injected into the subsurface soil or rock. The purpose of injecting a grout may be any one or more of the following:

1. to decrease the permeability,
2. to increase the shear strength,
3. to decrease the compressibility.

Suspension-type grouts include soil, cement, lime, asphalt emulsion, … etc., while the solution type grouts include a wide variety of chemicals. Grouting proves especially effective in the following cases:

1. When the foundation has to be constructed below the ground water table. The deeper the foundation, the longer the time needed for the construction, and therefore, the more benefit gained from grouting as compared with dewatering.
2. When there is a difficult access to the foundation level. This is very often the case in the city work, in tunnel shafts, sewers, and the subway construction.
3. When geometric dimensions of the foundation are complicated and involve many boundaries and contact zones.
4. When the adjacent structures require that the soil of the foundation strata should not be excavated (extension of existing foundations into deeper layers).

Grouting has been extensively used primarily to control the ground water flow under earth and masonry dams, where rock grouting is used. Since the process fills soil voids with some type of stabilizing material grouting, it is also used to increase the soil strength and to prevent the excessive settlement.

Many different materials have been injected into soils to produce changes in the engineering properties of the soil. In one method a casing is driven and an injection is made under a pressure to the soil at the bottom of the hole as the casing is withdrawn. In another method, a grouting hole is drilled and at each level in which the injection is desired, the drill is withdrawn and a collar is placed at the top of the area to be grouted and the grout is forced into the soil under the pressure. Another method is to perforate the casing in the area to be grouted and to leave the casing permanently in the soil. Penetration grouting may involve Portland cement or fine grained soils such as bentonite or other materials of a paniculate nature. These materials penetrate only a short distance through most soils and are primarily useful in very coarse sands or gravels. Viscous fluids, such as a solution of sodium silicate, may be used to penetrate fine grained soils. Some of these solutions form gels that restrict permeability and improve compressibility and strength properties [7].

Soil used in the present study

The soil used is Hamamuk soil which is located in Koya town, south east from the Erbil governorate, north of Iraq. The selected soil is subjected to comprehensive laboratory tests in order to make an evaluation and treatment of this expansive soil. The laboratory tests showed that the soil is expansive, so it is subjected to such a treatment.

The soil is selected from the site where its natural water content and the wet unit weight are measured. In this study, the swelling, consolidation and the direct shear tests are performed at the same water content and the wet unit weight of soil for remolded samples. Physical tests are performed on remolded soil samples. The physical properties of the tested soil are shown in Tab. 3.

As it is clear from Table 3, the liquid limit for the used soil is 48 % so that the soil can be considered to be expansive. It is classified as CH according to the unified soil classification system.

It is noticed that the soil contains about 93 % of fines and so it is used for the core material of the "Hamamuk earth dam". Since it is expansive, it may cause problems for the structure of the dam after the construction.

Tab. 3. Physical properties of the tested soil.

Specific gravity, Gs	2.72		
Liquid limit, LL %	48		
Plastic Limit, PL %	24		
Grain size (sieving) distribution	**Gravel** %	**Sand** %	**Silt + Clay** %
	0	7.0	93.0 %

Sample preprations for swelling and consolidation tests

The soil samples are prepared at the natural wet unit weight of 17.36 kN/m^3, the remolded samples are weighed and placed in the ring of the test oedometer at the same wet unit weight and compacted under the static compaction to get the same unit weight of the soil.

a) Sample Preparation for the Swelling Test

After placing the soil in the oedometer ring, the porous stones and load pad are placed on the sample, then the dial gauge is seated. Then a weight of 135 gm which is required to cause a pressure of 6.9 kN.m^{-2} is placed on the load arm. Water is added until the sample is covered completely. At that time the dial gauge is reading the swelling due to the soil expansion. The final swelling reading is recorded after (24) hours of adding water.

b) Sample Preparation for the Consolidation Test

The samples are prepared at the natural moisture content and the wet unit weight of the soil. For the treated samples, the amount of additive by weight is added to the dry weight of the soil to get the same unit weight while water (weighed by the total weight of dry soil) is then added [8]. For the sample treated by cement, the amount of cement by weight is mixed with the dry soil. Then, the water is added, the mixed soil with the additive is placed in the odeometer ring to carry out the test. When a layer of fine-grained (cohesive) soil, including ML, CL and CH, is subjected to an increase of the effective stress through an increase of the overburden stress, the soil undergoes a long-term reduction in the void ratio, e, which is accompanied by a settlement of the soil layer. The test is conducted according to ASTM D2435 [9].

c) *Sample Preparation for the Direct Shear Test*

The test is performed in accordance with ASTM D 3080 [10]. Following the same procedure described for the consolidation test, a sample of (60 × 60 × 30) mm dimensions is prepared to conduct the test.

Test Results

Table 4 presents the results of swelling test on the untreated soil.

Tab. 4. Results of swelling test on the untreated soil.

Sample No.	Untreated soil γ_{dry} [kN.m^{-3}]	Swelling [mm]
1	14.6	0.078
2	14.6	0.0558
3	14.6	0.0374

From the results obtained and according to the expansive soil classification system shown in Table 5 compiled from Holtz and Gibbs [11], the selected soil can be classified to be of medium potential. According to the classification, comprehensive tests are conducted to improve the selected soil using different materials mixed with the soil at its wet unit weight and natural water content to decrease the swelling ratio.

The results of the consolidation tests are also shown in Figs. 1 and 2. The results of consolidation test on both treated and untreated samples are also given in Table 6. It is obvious form Table 6 that the compressibility of the soil decreased since the compression index (C_c) decreased from (0.1174) to (0.0095) and the reloading index (C_r) decreased from (0.0615) to (0.0023). This is one of the advantages of cement treatment.

Tab. 5. Expansive soil classification based on the soil plasticity (Holtz and Gibbs, 1956).

Shrinkage limit	Liquid limit	Plastic limit	Potential for volume change
> 15	20 -35	< 18	Low
10 - 15	35 - 50	15 - 28	Medium
7 - 12	50 - 70	25 - 41	High
< 11	> 70	> 35	Very high

Tab. 6. Results of consolidation test on the untreated and treated soils.

Material	Untreated Soil	5% Cement Treated Soil	5% Steel fibers Treated Soil	Soil Injected with 5% Cement Mortar	4% Fuel Treated Soil
Compression Index (C_c)	0.1174	0.0095	0.1231	0.0080	0.1528
Swelling Index (C_r)	0.0615	0.0042	0.0688	0.0023	0.0901

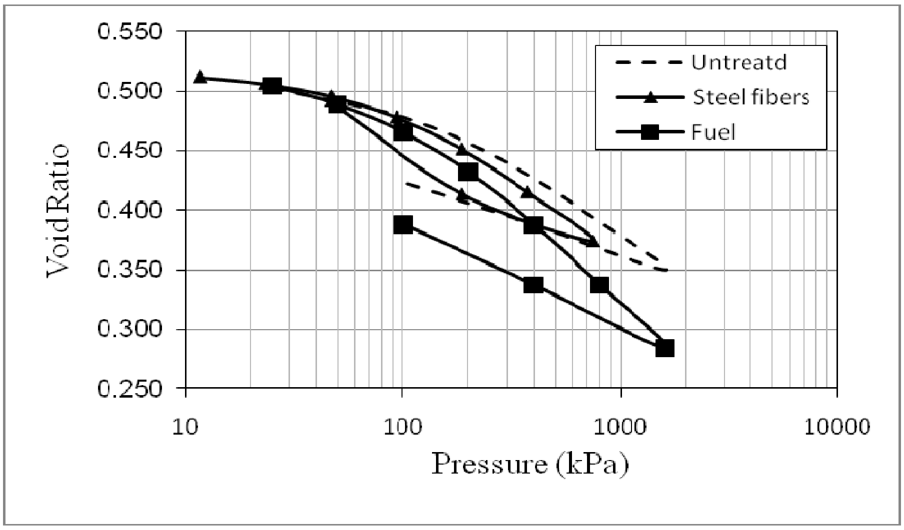


Fig. 1. Pressure-void ratio relationship curve for the untreated soil and the soil treated with 5 % steel fibers and 4 % fuel.

Tab. 7. Result of swelling test on treated soil.

Fuel [%]	**Swelling** [mm]	**Cement** [%]	**Swelling** [mm]
4	0.004	5%	0.0014
5	0.028	10%	0.0129
6	0.009	15%	0.0058
Steel fibers [%]	**Swelling** [mm]	**Cement grout** [%]	**Swelling** [mm])
5	0.0016	5%	0.001
10	0.0315	10%	0.018
15	0.0035	15%	0.003

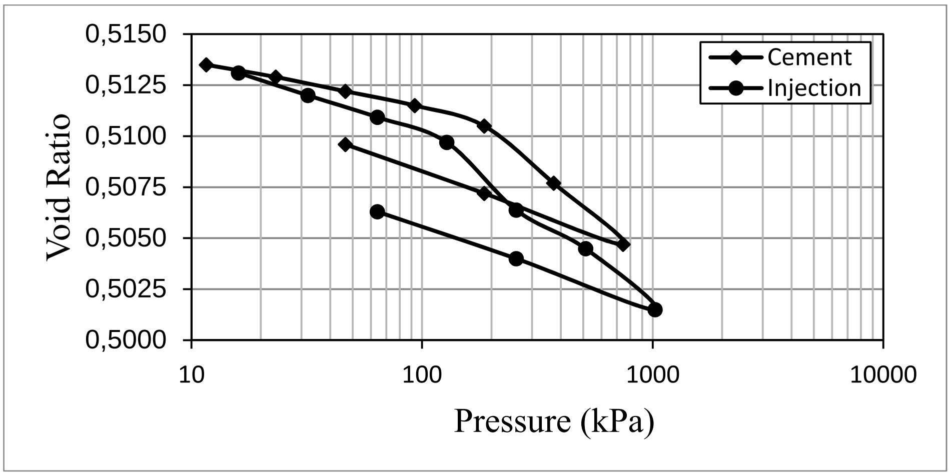


Fig. 2. Pressure-void ratio relationship curve for soil treated with 5 % cement.

The results of swelling tests on the soil treated using different materials are summarized in Tab. 7. Fig. 3 makes a comparison between different methods used in the treatment of the swelling soil.

It is evident from Tab. 7 and Fig. 3 that the treatment of the soil with 5 % of cement or steel fibers or the injection of cement grout revealed a better improvement while 4 % of gasoline oil is sufficient to obtain an optimum treatment by this material.

Results of the shear strength test

The results of direct shear test for the untreated and untreated soil are shown in Figs. 4 and 5. Fig. 4 shows a relationship between the vertical and horizontal displacement while Fig. 5 presents the relation between the normal stress and the shear stress for the soil treated by 5 % cement or steel fibers or cement grout or 4 % of fuel.

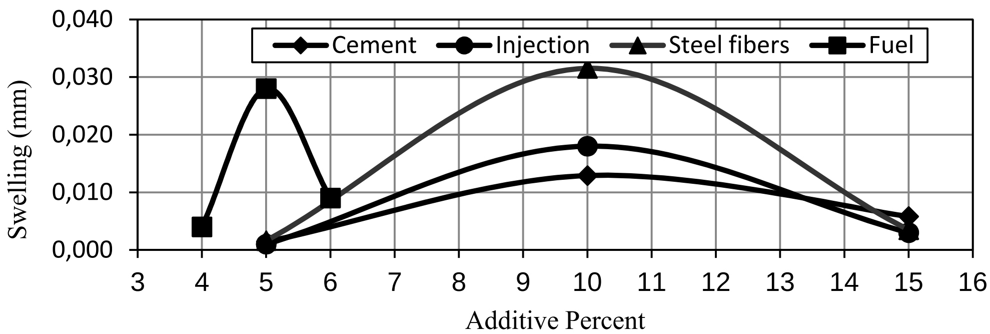
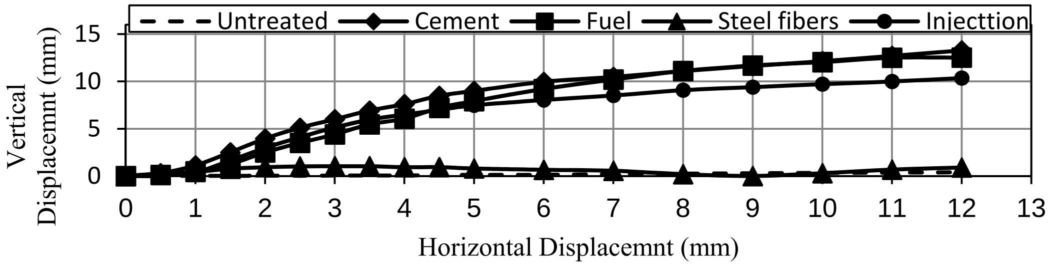
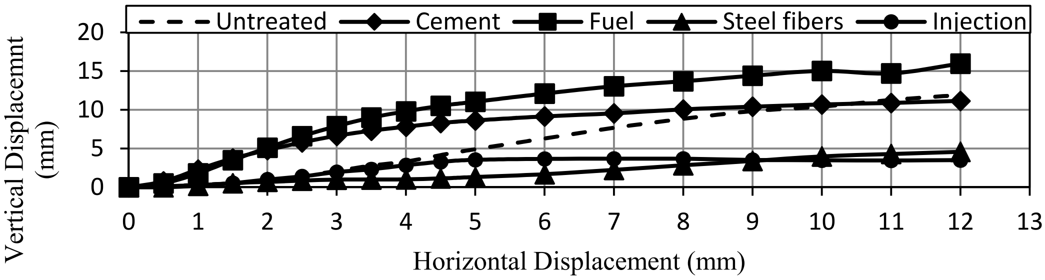


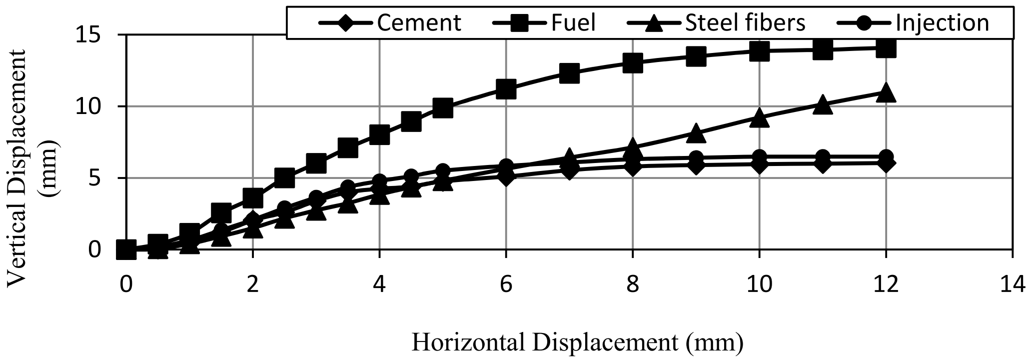
Fig. 3. Comparison between different methods used for the treatment of swelling soil.



a, σn = 50 kPa



b σ_n = 100 kPa



c, σ_n = 200 kPa

Fig. 4. Vertical versus horizontal displacement from the direct shear test of the untreated and treated samples.

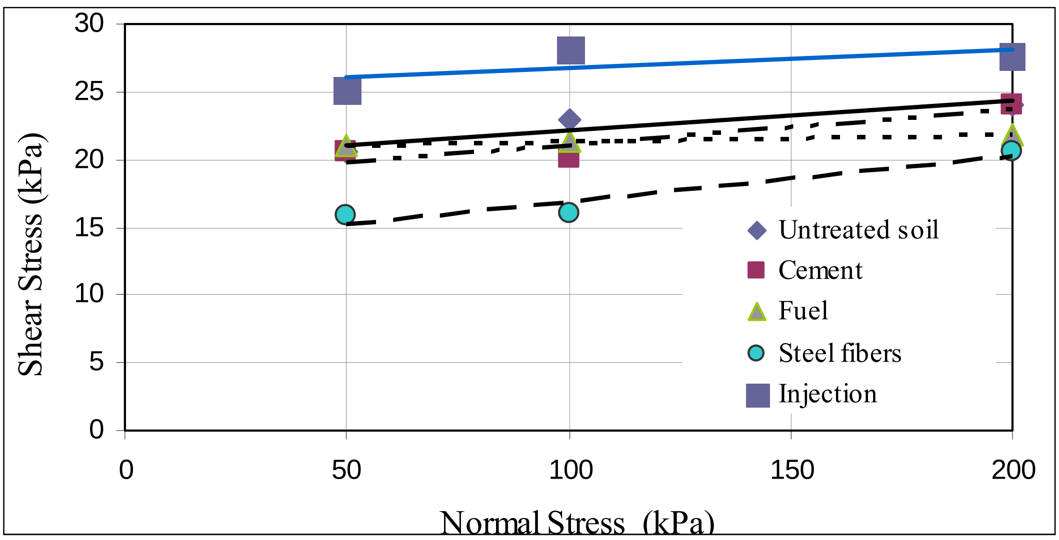


Fig. 5. Normal stress versus shear stress for the direct shear test of the untreated and treated samples.

The results of direct shear test on treated and untreated soil samples are summarized in Tab. 8 which indicates that the angle of internal friction is not affected by the treatment by any of the additives while the treatment by the cement injection caused an increase in the cohesion intercept. This may be due to a change in the adhesion between particles caused by the inclusion of additives. Cement particles are fine enough to make a film of cement material which increases cohesion. On the other hand, the treatment with steel fibers caused a reduction in the cohesion.

Tab. 8. Results of the direct shear test on the untreated and treated soils.

	Cohesion, c [kN.m^{-2}]	Angle of Internal friction, ϕ [degrees]
Untreated soil	19.8	2.8
Treated by 5 % cement	20.0	2.9
Treated by 5 % steel fibers	14.7	3.8
Treated by the injection with 5 % cement mortar	25.0	3.4
Treated by 4 % fuel	18.5	3.0

Conclusions

- The treatment of the expansive soil with 5 % of cement or steel fibers, or the injection with the cement grout results in the better improvement, while 4 % of gasoline oil is sufficient for the optimum treatment by this material.
- The compression index (Cc) and swelling (expansive) index (Cr) for the treated soil decreased compared with those for the untreated soil.
- The angle of internal friction is not affected by the treatment due to the fact that the cement has a larger surface area than the soil. This means that the friction between the particles decreases since the cement covers the particles of the soil. The cohesion between particles is slightly affected by the additives due to a change in the adhesion between the additive and soil particles.

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