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EFFECT OF HARDENED CEMENT WASTE AND FRESH CEMENT IN THE TREATMENT OF EXPANSIVE SOIL

Purpose. To study the effect of hardened cement waste and compare it to the effect of fresh cement in the treatment of expansive soil.

Methodology. To show the performance of hardened cement waste compared to that of fresh cement, an experimental study is conducted concerning a swelling clay soil in the Mila region of eastern Algeria. The study involves a series of soil treatment tests with fresh cement and hardened cement waste (with reasonable proportion) for each type of cement. Finally, a comparison of the influence of the addition of hardened cement waste and the addition of fresh cement on the physical and mechanical behavior of the soil.

Findings. Treatment with fresh cement provides a good improvement in certain properties, and in this work we show that the use of hardened cement waste could also improve the physical and mechanical characteristics of the treated soil.

Originality. The originality of this work is to replace fresh cement with the waste of hardened cement in the treatment of clay soils in general and swelling soils in exceptional cases to minimize the cost of treatment with fresh cement and protect the environment from waste of the cement.

Practical value. This study shows that the results obtained by adding 6 % of fresh cement and 6 % of hardened cement waste changed the physical and mechanical properties of the soil (plasticity, bearing capacity, swelling and settlement). Comparison of the results obtained shows that the performance of hardened cement waste represents 90 to 98 % of the performance of fresh cement. The convergence of the treatment results indicates the possibility of replacing fresh cement with hardened waste cement in soil stabilization.

Keywords: *treatment, expansive soil, plasticity, hardened cement waste, fresh cement*

Introduction. Soil improvement is a solution to avoid the consequences of the behavior of poor sandy or clayey soils. Fine sandy soils are loose sands with the presence of other factors such as water flow and seismic action cause the phenomenon of liquefaction of soils, this phenomenon of liquefaction causes instability of the soil followed by movement in the ground which leads to significant damage to structures built on this type of soil. Clayey soils are the soils most encountered in construction in general and in geotechnical works in particular. Swelling clay soils are some of the unstable soils, these clays are known by the phenomenon of shrinkage-swelling, this phenomenon is caused by the mineralogical structure of the soil with the presence or absence of water. In the design of construction materials resulting from the stabilization of disturbed soils, the choice of stabilizer and the stabilization process are decisive. Improvement methods have been developed in recent years: mechanical, thermal, and chemical [1, 2]. Binders used in soil treatment have proven their effectiveness in improving mechanical, physical, and chemical [3, 4] properties such as: cement, lime, cement, and lime [5], lime and pozzolans [6] and salts [7, 8].

The first attempt at stabilization with cement was made in the United States in 1915 in the road sector, the setting and hardening of the cement introduced into a concrete floor provides it with the cohesion necessary to ensure stability. The addition of cement also reduces the swelling of the finest particles. Soils treated in this way are called “Cement Soil”.

Portland cement is most commonly used in stabilization. Recently, studies have shown that all standardized cements are suitable in principle for soil stabilization, some authors have given preference to low class cements because it is not necessary to have great resistance. On the other hand, others proposed using CLK or CPA cements with a class greater than 30 and others recommended the use of cement rich in C3S and C2S with a class greater than 30. Almost all floors can be stabilized with cement. Certain orientation criteria make it possible to see which soils are likely to be economically stabilized with cement. They are mainly based on particle size characteristics and Atterberg limits. Stabilization with chemical binders is ensured by several mechanisms such as cation exchange, flocculation, grain agglomeration, hydration, pozolanic reaction and carbonation. Each mechanism has a role in improving soil properties.

In recent years [9], researchers are oriented towards the exploitation of waste in soil treatment such as fly ash, plastic waste, tire rubber, glass waste, marble waste, tiles, brick waste [10]. Recently, studies have focused on the cost of carrying out the treatment and environmental protection. Certain wastes have demonstrated their performance in soil stabilization.

This study is part of the stabilization of the expansive from the region of Mila city located in the northeast of Algeria. This region has suffered great damage to the construction of houses, roads, and bridges due to the saturation of the swelling clay type soil plus severe seismic action. The addition of the treatment used is hardened cement waste, the exploitation of waste from factories and construction sites has become a topical subject, they are used in several areas, particularly in geotechnics, such as the stabilization of soils with bad behavior.

The objective of this work is to study the effectiveness of the hardened cement waste in the treatment of the soil and to evaluate the rate of influence of the hardened cement compared to the influence of the fresh cement which is known by its effectiveness in soil stabilization.

The work focuses on carrying out a series of experimental tests (plasticity tests, compaction tests, puncture test, shear test and oedometric test) to assess the influence of a variation in the percentage of fresh cement and the hardened cement waste (2, 4, 6 %) on the physical and mechanical properties of the soil.

Methods and materials. Preliminary tests are carried out for the identification of the soil object of the study (physical, chemical, and mechanical) and the main tests carried out on the treated soil (physical: plasticity, Proctor compaction and mechanical such as compressibility and swelling oedometric, CBR and shear strength).

The materials used in this work are:

Soil used for stabilization. The soil used in this work is clay soil from the town of Milla located in the north-eastern region of Algeria, taken from a depth of 4–7 m. It is a soil considered to be swelling clay following the damage seen on the soil and buildings in this city.

Stabilization cement. The addition of treatment is the fresh cement and the hardened cement waste, is used with the following percentages: 2, 4, 6 %.

The stabilization cement is CPJ-CEM II 42.5, it is a composite portland cement obtained by the finely ground mixture of clinker and additions of calcium sulfate is added in the form of gypsum, as a setting regulator. CPJ-CEM II 42.5 composite portland cement consists of:

- 80 to 94 % Portland clinker;
- 6 to 20 % maximum addition (pure limestone);
- secondary constituents (0 to 5 % calcium sulfate as setting regulator).

Results and discussions. ***Results of natural soil.*** The soil is classified as class A fine soil (clay and marly clay, very plastic silt A3) according to the GTR.

The results of the preliminary tests of the untreated natural soil are presented in Table 1.

According to the results obtained, the soil is considered as plastic clay soil with a high swelling rate and considerable compaction. The soil has a low bearing capacity.

Results of treated soil. The main tests carried out on the soil treated according to the percentage of 2, 4 and 6 % of fresh cement and 2, 4 and 6 % of hardened cement are:

- Plasticity limits;
- Standard Proctor;
- CBR;
- Shear;
- Oedometer.

Effect of cement on soil plasticity. From the results obtained, we note that the influence of cement is considerable for both types of fresh and hardened cement waste. In most cases we see that the reduction in the liquidity limit is proportional to the percentage of cement added, from 63 % for untreated clay, to 54 % for an addition of 6 % fresh cement and 48 % for 6 % of hardened cement.

Table 1

Characteristics of untreated clay soil

Soil characteristics	Values
Water content w (%)	16.28
Liquidity limit Wl (%)	63
Plastic limit WP (%)	32
Plasticity index IP (%)	31
Maximum compaction dry density Gs	1.61
Optimal water content of compaction wop (%)	17.52
Percentage of clay (%)	74
VBS	6
Punching force (kN)	0.89
CBR lift index (%)	5.0
Shear resistance τ (kN/m^2) for $\sigma = 150$ (kN/m^2)	71
Cohesion C (kN/m^2)	32
Angle of internal friction (°)	15
Consolidation pressure Pc (kN/m^2)	120
Compressibility index CC (%)	30.98
Swelling index Cg (%)	11.4

The reduction in this limit is in agreement with the published results of El Sharif, et al. (2013) [1] and Djouimaa, et al. (2018) [5]. It can be explained by the flocculation reaction of the clay grains which have an important influence on the reduction in the thickness of the double layer or by the reduction in the specific surface area [11].

On the other hand, the plasticity limit undergoes a slight reduction from 32 % for untreated clay, to 27 % for an addition of 6 % fresh cement and 23 % for hardened cement Table 2.

Reducing both limits produces an appreciable decrease in the plasticity index. The effect of cement and hardened cement waste are presented in Fig. 1.

The treatment with cement in general reduces the plasticity of clay soil, but hardened cement has the same performance for improving the rate of plasticity where we notice that the soil treated with 6 % hardened cement waste changes from a very plastic soil to a low plastic soil. This proves that hardened cement waste is more efficient than fresh cement.

Effect of cements on Proctor results. The addition of cement tends to increase the optimal water content and reduce the maximum dry density with the proportional increase in the percentage of the addition.

Optimum water content. For the same compaction energy, the optimal water content of the untreated soil is passed from 17.52 to 18.10 % for the addition of 6 % fresh cement and 17.82 for 6 % hardened cement.

The increase in optimum water content is that fresh cement and hardened cement require more water for the initial immediate reaction of the drying process by absorption and evaporation as well as the ion exchange process generated by the reactions between the cement and the minerals of the clay soil causing the flocculation and agglomeration of the minerals of the particles fine soil.

The comparison of the results of both treatment with fresh and hardened cement is presented in Fig. 2.

Optimal dry density. According to the compaction curves presented in Figs. 3, 4, the maximum dry density decreased from 1.61 to 1.58 g/cm^3 for the addition of 6 % fresh cement and 1.56 g/cm^3 for the addition of 6 % hardened cement. This change is considered an indication of improving the compaction characteristics of cement-stabilized soil. The reduction in max dry density occurred because agglomerated and flocculated soil particles occupy larger spaces.

According to the results obtained from the Proctor compaction curves, the two additions performed almost the same, the comparison is presented in Fig. 5.

As a conclusion of these results, the treatment with fresh cement modifies the optimum characteristics of compaction or it increases the optimum water content and the agglomeration of the cement around the fine soil grains increases the grains size and this leads to a decrease in the maximum dry density. The same phenomenon happens with hardened cement.

Effect of cement on lift (after immersion). Cement is recommended in the treatment of clay soils and specifically swelling soils to improve their bearing capacity to support a roadway or another load. The punching load increases gradually with the increase in the percentage of cement. The punching curves are shown in Figs. 6, 7.

Table 2

Plasticity limits with addition of fresh cement and hardened cement waste

Atterberg limits (%)	Percentage of fresh cement (%)				Percentages of hardened cement waste (%)			
	0	2	4	6	0	2	4	6
Liquidity limit (wl)	61	60	56	54	61	60	53	48
Plasticity Limit (wp)	31	31	28	27	31	28	27	23
Plasticity Index (lp)	30	29	28	27	30	28	26	25

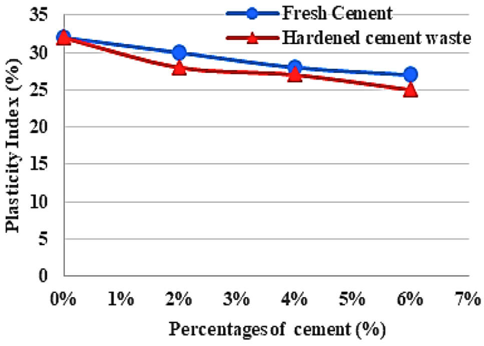

Fig. 1. The plasticity index (Ip) according to the percentage of cements

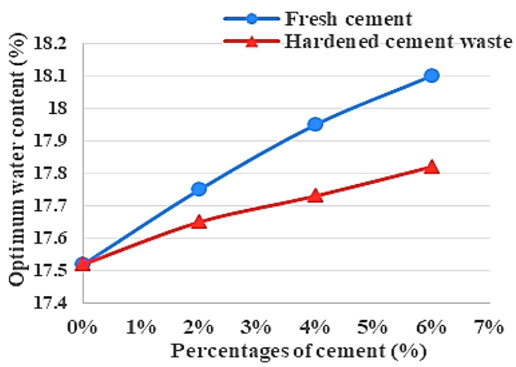

Fig. 2. The optimal water content index as a function of the percentage of cement

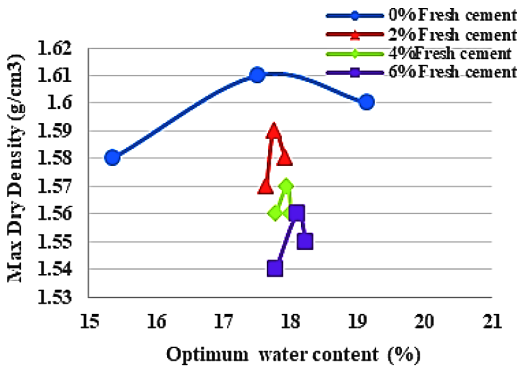

Fig. 3. Proctor curves with percentages of fresh cement

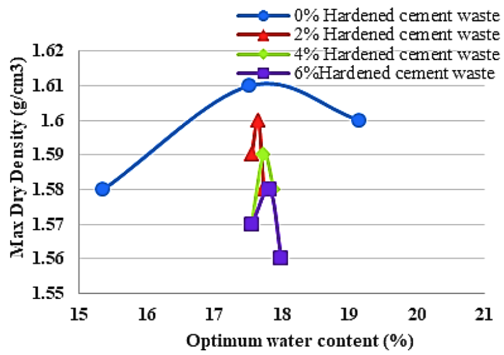

Fig. 4. Proctor curves with percentages of hardened cement waste

The punching load for the untreated soil is 0.89 kN with 6 % fresh cement it reaches 1.56 kN.

The value max of the punching load for soil treated with 2 % of hardened cement waste is 2.4 kN.

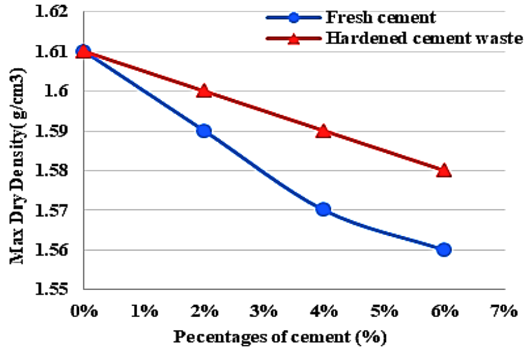

Fig. 5. Evolution of the optimal dry density as a function of the percentage of cement

The geotechnical characteristics of soil bearing capacity are represented by the bearing index.

The addition of cement has a significant influence on the increase in the load-bearing capacity of the soil where the value of the load-bearing index increases from 5.02 % for the untreated soil to 12.04 % for the soil treated with 6 % of fresh cement and at 10.03 % for the addition of 6 % hardened cement.

This change is perhaps due to the cementation of the soil, which acts as a glue between the grains and produces significant resistance to the effort exerted. The results are detailed in Fig. 8.

The use of cement for the treatment of the soil promotes the bearing capacity of the soil in a remarkable way almost double, either for fresh cement or hardened cement (Fig. 8).

Effect of Cement on Strength Parameters. The shear resistance parameters are influenced by the treatment with the two types of cement addition which influences the shear resistance of the soil.

Angle of friction. The friction angle value is increased with increasing percentage of addition. The value presented in Fig. 9, it goes from 15° for the untreated soil to 20° for the soil treated by the addition of 6 % fresh cement and to 16° for the soil treated by the addition of 4 % hardened cement waste.

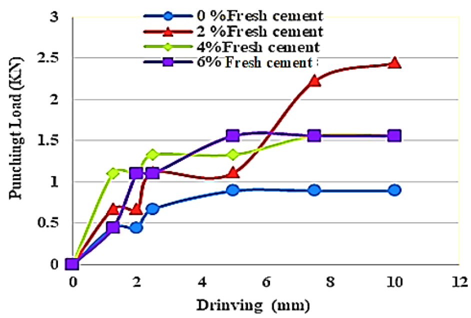

Fig. 6. Punching curves depending on the percentages of fresh cement

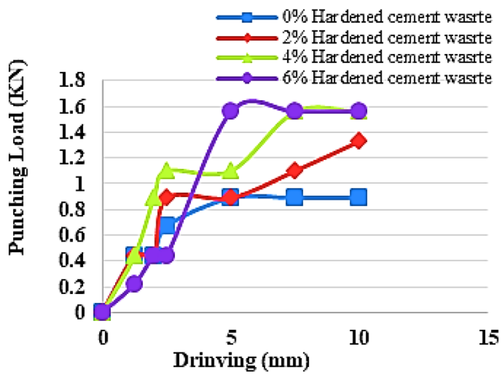

Fig. 7. Punching curves as a function of percentages of hardened cement waste

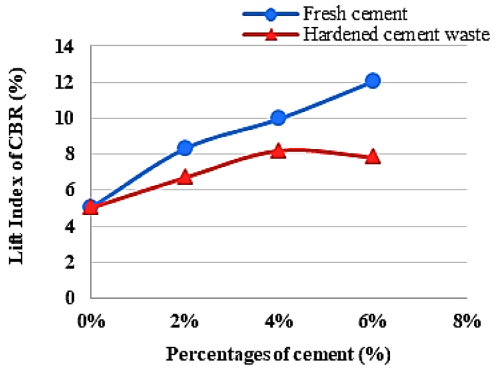

Fig. 8. Evolution of the lift index as a function of the percentage of cement

Cohesion. The addition of cement tends to reduce the cohesion between the grains because of the change in the shapes of the soil particles. The reduction is considerable, it varies between 32 kN/m^2 for the untreated soil and 22 kN/m^2 for the soil treated by the addition of 6 % fresh cement and 21 kN/m^2 for the soil treated with 6 % hardened cement. The variation of the cohesion according to the percentage of cement is presented in Fig. 10.

A variation of the resistance parameters is caused by the addition of cement with a decrease in the cohesion between the fine grains of soil.

Effect of cement on oedometric results. The stabilization of swelling by adding cement has been the subject of several studies (A. Soltani, A. Taheri, M. Khatibi, A. Restabish, 2017) [12], (C. Consoli, M. T. de Araújo, S. Tonatto Ferrazzo, V. de L. Rodrigues, C. Gravina da Rocha, 2020) [13] and all these studies confirm the positive role that this addition has in reducing the swelling of swelling soils.

Pre-consolidation stress (Pc). According to the results obtained, we notice a significant reduction in the consolidation stress from 120 kN/m^2 for the untreated soil to 71 kN/m^2 for the soil treated by the addition of 6 % fresh cement and to 98 kN/m^2 for the ground treated by adding 6 % hardened cement. The results of the pre-consolidation stress as a function of the percentage of cements are shown in Fig. 11.

The compressibility index (Cc). Treatment with cement promotes a reduction in the compressibility rate of the general floor. The compressibility index gradually decreases with increasing percentage. The reduction in the compressibility rate is due to the filling of the voids with the added cement.

The compressibility index goes from 30.98 % for the untreated soil to 25.98 % for the soil treated by the addition of 6 % of fresh cement and to 23.98 % for the soil treated by the addition of 6 % of hardened cement. These results are presented in Fig. 12.

The swelling index (Cg). Treatment with fresh cement or hardened cement results in a good improvement in the swelling rate, more than doubling. The reaction of cement with clay minerals minimizes the rate of swelling. The value of the swelling index varies from 11.4 % for untreated soil to 5.21 % for soil treated with 6 % fresh cement and 5.14 for 6 % hardened cement. The variation in the swelling index is very significant; the soil goes from a swelling soil to a low swelling soil. The variation is shown in Fig. 13.

The cement treatment minimizes soils swelling and decreases settlement during consolidation of soil. The hardened cement waste has same effect on soil behavior as the fresh cement.

Conclusion. This study is part of the stabilization of swelling clay from Mila region in northeastern Algeria and the objective is to show the performance of hardened cement waste compared with that of fresh cement.

According to the results obtained within the framework of the study of the mechanical behavior of a treated clay soil. Adding fresh cement and hardened cement to clay soil allows the following:

1. To reduce the sensitivity of soils to water by increasing the value of the optimum water content.

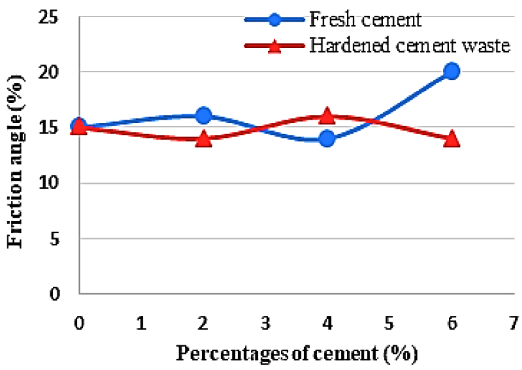

Fig. 9. Evolution of the angle of friction according to the percentage of cement

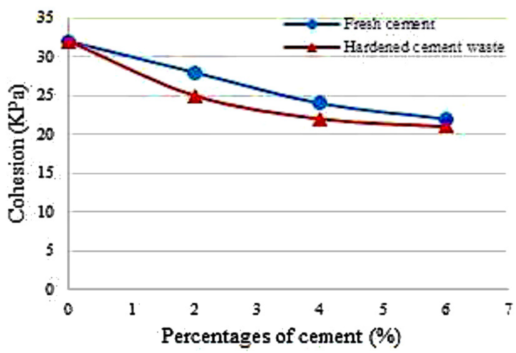

Fig. 10. Evolution of the cohesion according to the percentage of cement

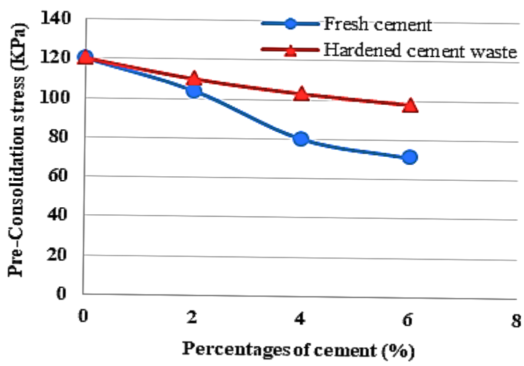

Fig. 11. Evolution of the pre-consolidation stress (Pc) as a function of the percentage of cement

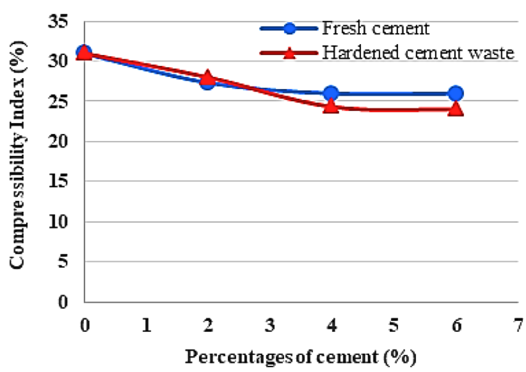

Fig. 12. Evolution of the compressibility index (Cc) as a function of the percentage of cement

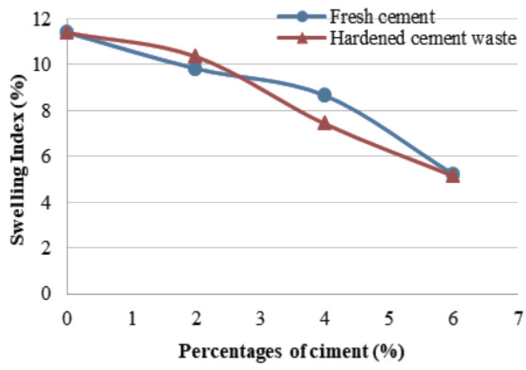

Fig. 13. Evolution of the swelling index (Cg) as a function of the percentage of cement

2. Reduction of the plasticity index.
3. Cement causes an increase in the lift index.
4. Increased shear strength.
5. Reduced compaction and swelling.

The results obtained show the effectiveness of the treatment with the fresh cement and the hardened cement carried out individually in the improvement of the clay.

The comparative study between the effect of fresh cement and hardened cement proves the performance of hardened cement waste in the treatment which had a rate of 96 % of that of fresh cement. So, we can use the hardened cement waste in the treatment of soils instead of fresh cement.

Finally, treatment with hardened cement leads to the improvement of several soil properties and protects the environment through the exploitation of waste from construction sites and factories.

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Вплив затверділих відходів цементу та свіжого цементу на обробку набухаючого ґрунту

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Мета. Вивчення впливу затверділих відходів цементу та порівняння його із впливом свіжого цементу при обробці набухаючого ґрунту.

Методика. Для демонстрації ефективності використання затверділих відходів цементу порівняно зі свіжим цементом проводиться експериментальне дослідження щодо збільшення об'єму глинистих ґрунтів у регіоні Міла на сході Алжиру. Дослідження включає проведення серії тестів з обробки ґрунту з використанням свіжого цементу й затверділих відходів цементу (з відповідними пропорціями) для кожного типу цементу. Нарешті проводиться порівняння впливу додавання затверділих відходів цементу та додавання свіжого цементу на фізичну й механічну поведінку ґрунту.

Результати. Обробка свіжим цементом сприяє значному покращенню певних властивостей, і в цій роботі ми показуємо, що використання затверділих відходів цементу також може покращити фізичні й механічні характеристики обробленого ґрунту.

Наукова новизна. Оригінальність цієї роботи полягає в тому, що замість свіжого цементу використовують відходи затверділого цементу для обробки глинистих ґрунтів загалом і набухаючих ґрунтів у виняткових випадках з метою мінімізації витрат на обробку свіжим цементом і захисту навколишнього середовища від відходів цементу.

Практична значимість. Це дослідження показує, що результати, отримані із додаванням 6 % свіжого цементу та 6 % затверділих відходів цементу змінили фізичні й механічні властивості ґрунту (пластичність, несучу здатність, набухання ґрунтів і осідання). Порівняння отриманих результатів показує, що ефективність використання затверділих відходів цементу становить від 90 до 98 % ефективності свіжого цементу. Збіг результатів обробки свідчить про можливість заміни свіжого цементу відходами цементу у процесі стабілізації ґрунту.

Ключові слова: *обробка, набухаючий ґрунт, пластичність, відходи затверділого цементу, свіжий цемент*

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