Injection fixing of the less-like soil of Mongolia

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Abstract. The method of injection fixing of subsiding soils in the foundations of buildings and structures is widely used in many countries of the world, including Mongolia. This article presents the results of experimental studies on the injection strengthening of loess-like sandy loamy subsidence soil on the territory of the city of Darkhan Monolia. Experiments to determine the physical and mechanical parameters, the mineralogical composition of the fixed subsidence soil were carried out according to the standard method in laboratory and field conditions. For injection fixation of subsiding soils, 20%, 30% and 40% solutions of liquid glass with a density of 1.19 g/cm3 were used, as well as a cement mortar prepared at a ratio of 1:20, 1:30 and 1:40 from Portland cement grade 450 The modulus of deformation of the fixed soil is 7.92...14.1 MPa, the compressive strength of the soil fixed with a solution of liquid glass is 39.0 kPa, and with a cement solution of 1:40, it is 137.0 kPa. Based on the results of experimental and theoretical studies, an effective method for fixing subsiding soil, taking into account environmental considerations and the regional characteristics of the territory of Mongolia, is injection grouting using a cement slurry prepared with a composition of 1:40 and grade 450.
Keywords: silicification, cementation, field and laboratory studies, physical and mechanical properties, sedimentation of fixed soils.

INTRODUCTION

Injection chemical fixation of soils is an artificial, purposeful transformation of the building properties of soils by treating them in their natural occurrence with various chemical and cement mortars with appropriate various additives [1;2;3]. Injection fixing is used for soils with water permeability, including subsiding loess, loess-like sandy loam and loam [4;5;6]. With injection fixing, the natural structures and composition of soils are not disturbed. As a result of silicification and cementation by injection, in almost all cases, the irreversibility and durability of the physical and mechanical properties acquired by soils are ensured [7;8;9].

METHODS AND MATERIALS

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Laboratory and field studies to determine the parameters of deformation and strength of the fixed soil were carried out according to the standard methodology. In the test of injection fixation of subsiding soils, 20%, 30% and 40% solutions of liquid glass with a density of 1.19 g/cm3 were used, as well as a cement mortar prepared at a ratio of 1:20, 1:30 and 1:40 from Portland cement grade 450. The basic technological scheme of injection experiments is shown in Figure 1.

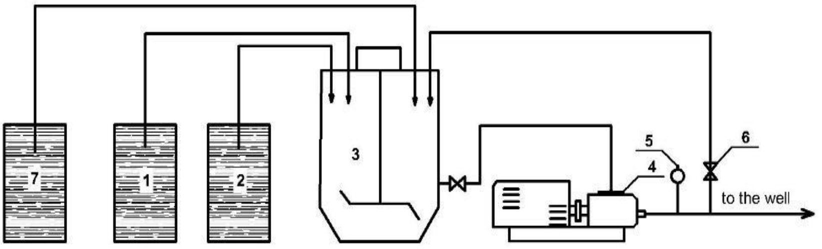

Fig.1. Schematic diagram of injection experiments. 1 - water tank, 2 - additive tank, 3 - mortar mixer, 4 - mortar injection pump, 5 - pressure gauge, 6 - screw, 7 - cement tank

RESULTS

Laboratory tests. Figure 1 shows the S=f(P) curve obtained by determining the settlement corresponding to a stepped load up to 1600 kPa using an odometer to determine the modulus of deformation of the fixed soil.

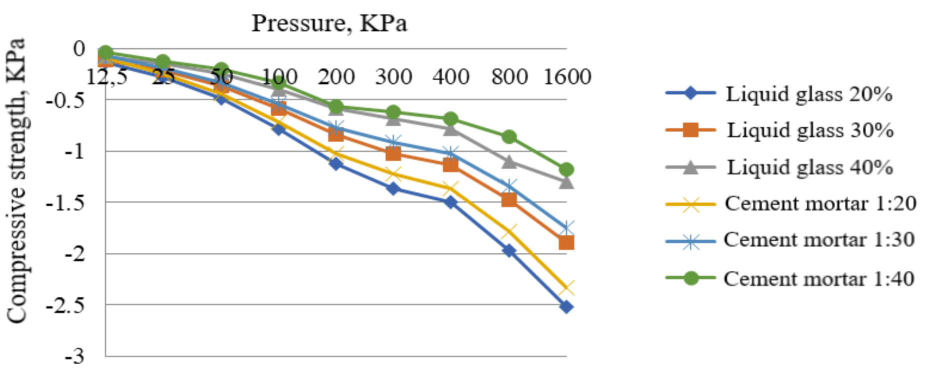

Fig.2. Dependence curves S=f(P) of soil fixed by chemical methods

The results determined by the average modulus of deformation of the reinforced soil by the chemical method are shown in Table 1.

Table 1. Deformation modulus for calculating enlarged and loose subsidence soils

Test №	Soils fixed with liquid glass, E_1, MPa	Soils fixed with cement mortar, E_2, MPa	Unclosed soils, E_3, MPa
1	8.62	13,76	5,48
2	7,34	13,98	5,96

3	7,81	14,52	5,60
Avg. meaning	7,92	14,1	5,68

It is proposed to determine the value of the k_{chem} coefficient, which reflects the growth pattern of the deformation modulus of chemically fixed subsidence sandy loam soil compared to the value of the deformation modulus of loose sandy loam soil, using the following ratio:

$$K_{chem} = \frac{E_{chem}}{E_{soil}}\ , \qquad (1)$$

where K_{chem} - is the deformation modulus of chemically fixed sandy loamy soil, MPa; E_{soil} - modulus of deformation of unfixed sandy loamy soil, MPa;

The value of the K_{chem} coefficient is determined by the ratio (1) depending on the type of mortar used, for example: according to the results of our tests, in the case of fixing with 40% liquid glass, $K_{l.glass}$ = 1.394, and when fixing 1:40 with cement mortar, K_{cem} = 2.480. When substituting the deformation modulus coefficient into the formula, the formula for determining the deformation modulus of chemically fixed soil takes the form:

$$E_o^{lab} = \frac{\Delta\sigma}{\Delta\varepsilon_1}\cdot\nu \Rightarrow E_{chem}^{lab} = \frac{\Delta\sigma}{\Delta\varepsilon_1}\nu\cdot K_{chem}\,, \qquad \nu = \frac{\Delta\sigma}{\Delta\varepsilon_2}\ , \qquad (2)$$

When loading soil samples with a pressure of 12.5 ... 1600 kPa on an odometric device, the settlement is 1.3 mm in soil reinforced with a 40% liquid glass solution, and 1.18 mm in soil reinforced with a 1:40 cement solution. The test results show that the precipitation of reinforced soils by the chemical method is reduced by 1.5 ... 2.5 times, depending on .
The results of testing the soil, reinforced with a solution of liquid glass, to determine the compressive strength σ=f(t) is shown in Figure 3.

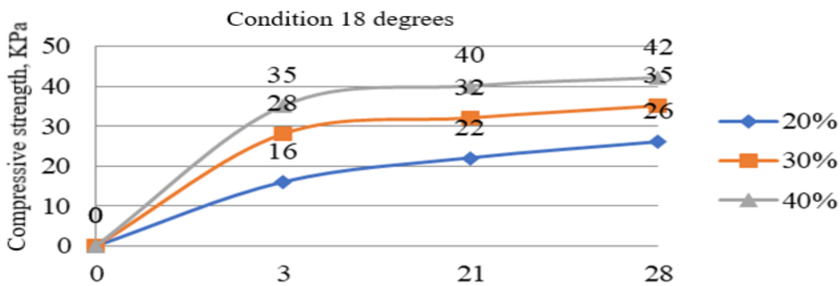

Fig. 3. Dependence curves of compressive strength on the number of days of exposure of samples σ=f(t) of soil fixed with liquid glass

The results of soil tests, the curves of dependence of cement fixed with mortar on compression σ=f(t) are shown in Figure 4.

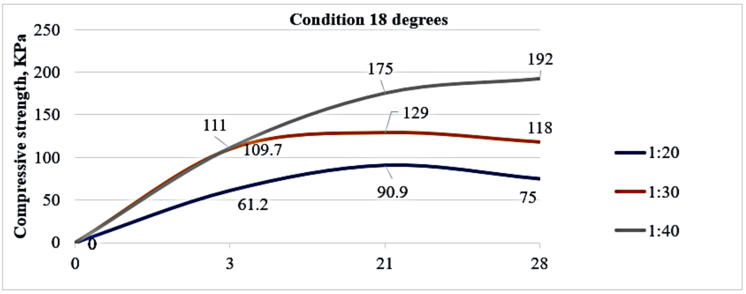

Fig. 4. Dependence curves of compressive strength on the number of days of exposure of soil samples σ=f(t) fixed with cement mortar

As can be seen from the above parameters, after 28 days, the average compressive strength of soil reinforced with a 40% liquid glass solution is 39.0 kPa, and the average compressive strength of soil reinforced with a 1:40 cement solution is 137.0 kPa , which is 3.3 times higher than that of solution-strengthened liquid glass. The filtration capacity was determined on the KF-00 device, the values of the filtration coefficient are given in Table 2.

Table 2. Comparison of average values of filtration coefficients of fixed soils

Soil type	Filtration coefficient, m/day
Soil with a natural structure	0,60
Soil fixed with liquid glass	0,43
Soil fixed with cement mortar 1:40	0,32

Field natural tests. The design scheme of the test and the location of sampling points for determining the mechanical parameters of the reinforced soil are shown in Figure 5.

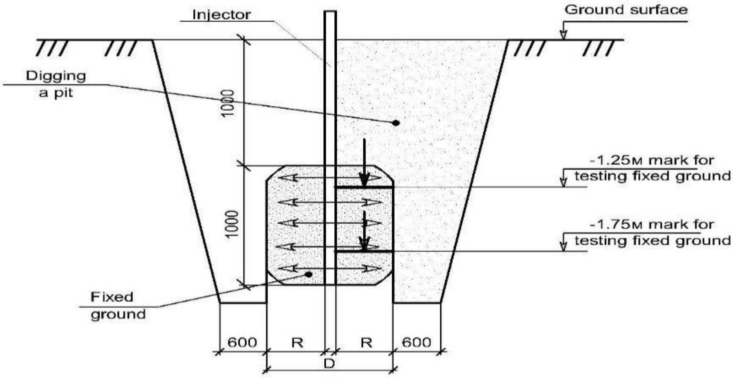

Fig. 5. Calculation scheme and points for the selection of reinforced soils

The design parameters of the strength of the reinforced soil were determined using a dynamic protative automatic density meter, including the frontal resistance of the dynamic probe q_s, the adhesion force c, the angle of internal friction φ, the density ρ, the humidity W and the degree of humidity S_r, which are compared in the diagrams and presented in the figures 6...11.

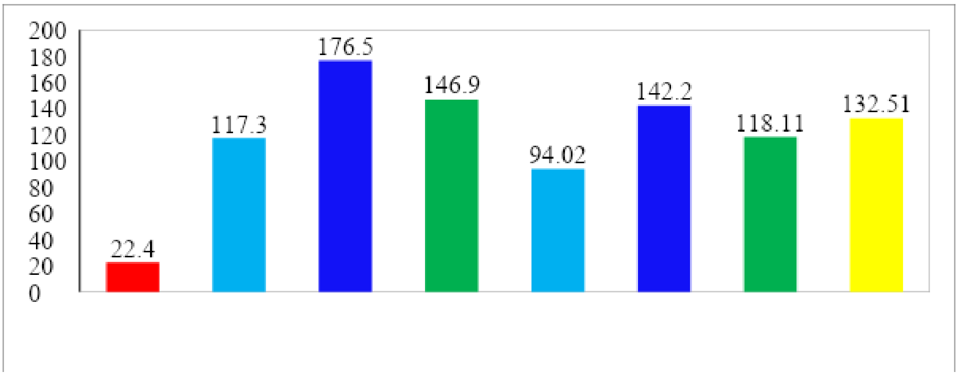

Fig. 6. Comparison of average values **C** of the soil reinforced with liquid glass

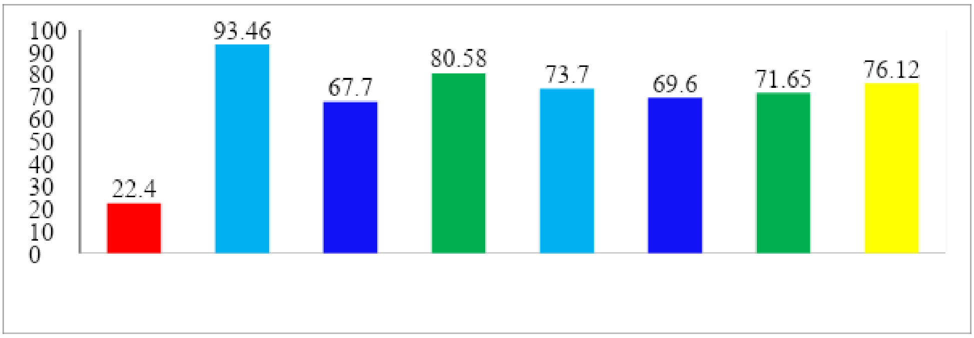

Fig. 7. Comparison of mean values **C** of cement-reinforced soil

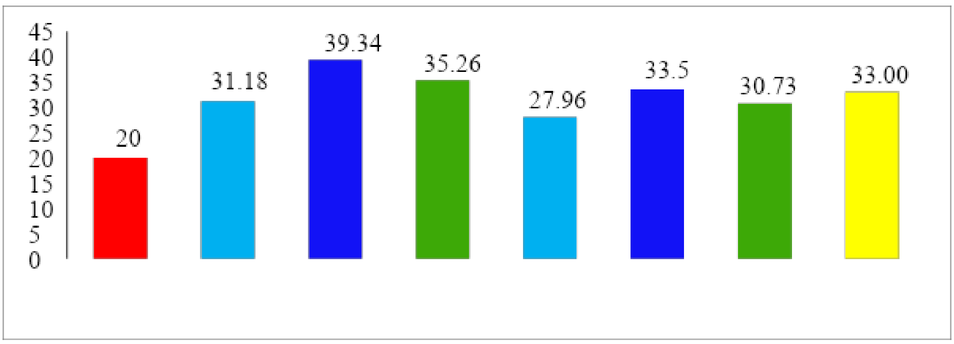

Fig. 8. Comparison of the average values of **φ** of soil reinforced with liquid glass

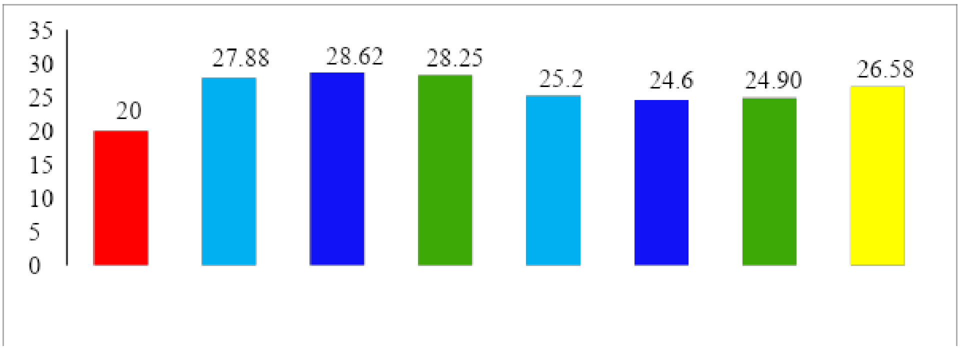

Fig. 9. Comparison of the average values of **φ** of soil reinforced with cement mortar

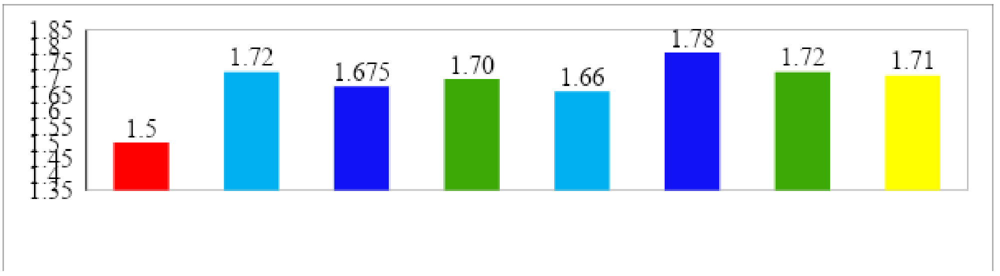

Fig. 10. Comparison of the average values of **ρ** of soil reinforced with cement mortar

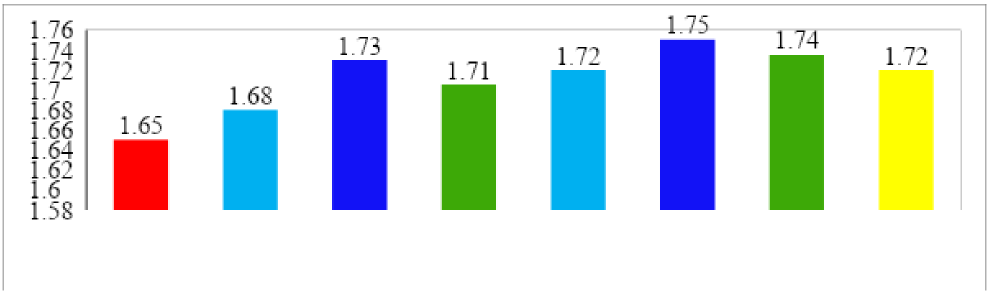

Fig. 11. Comparison of the average values of **ρ** of soil reinforced with liquid glass

According to the results of the analysis of the compared strength indicators, i.e. adhesion force C of chemically fixed sandy loamy soil, it was found that it increased by 5.9...3.4 times compared to unfixed soil, and φ of chemically fixed soil increased by 13°...15°, the density of fixed soil was also increased by 1.21 g /cm3.

Determination of settlement of fixed soil. Field testing of 6 soil samples with undisturbed structure (3 pieces x 2) were tested under a pressure of 12.5 ... 1500 kPa and precipitation was determined. Based on the results of the experiments, a graph of the dependence S=f(P) was plotted, shown in Figure 12.

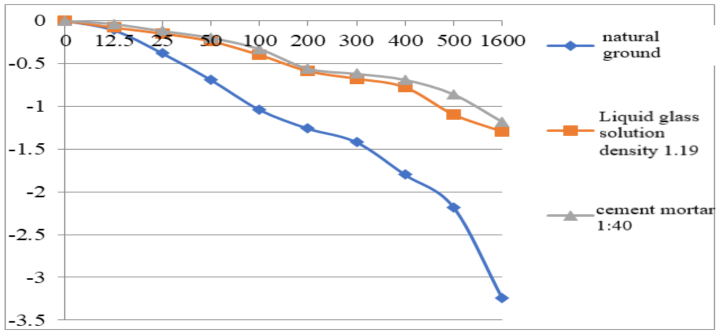

Fig. 12. Dependence curve S=f(P) according to the results of tests of fixed subsidence soil

The analysis of the S=f(P) dependence graph, carried out on the basis of the results of odometric tests of unreinforced and chemically reinforced sandy loamy soil, revealed the following dependencies: In the compression test of reinforced soil with a solution of liquid glass, the values of settlement corresponding to a pressure of 50 kPa were determined by 1.8 times, and the magnitude of the settlement corresponding to the same pressure of the settlement of the soil, reinforced with a solution of cement, is 2.1 times less.

Deformation modulus of fixed soil. After 28 days for the reinforced soil in the field, digging with measurements at a depth of 1.25 m, with a diameter of 0.95 m, and at a depth of 1.75 m with a diameter of 1.20 m, enlarged soil monoliths were obtained with a length (height) 1.1-1.2 m (Figure 13).

Fig. 13. Photo of measuring the geometric dimensions of the fortified subsidence soil.

When comparing the results of field and laboratory tests and analytical calculations, it was found that the average modulus of deformation of soil reinforced with a solution of liquid glass with a density of 1.19 g/cm3 is E = 7.80 MPa, and soil reinforced with cement solution E = 11.52 MPa , the difference is 33.0%.

Mineralogical composition of the fixed soil. Figures 14...16 show the results of X-ray dipractographic tests of 7 polished samples from natural and reinforced soils under field test conditions and determination of mineral formation indicators in the nanotechnology laboratory MUST.

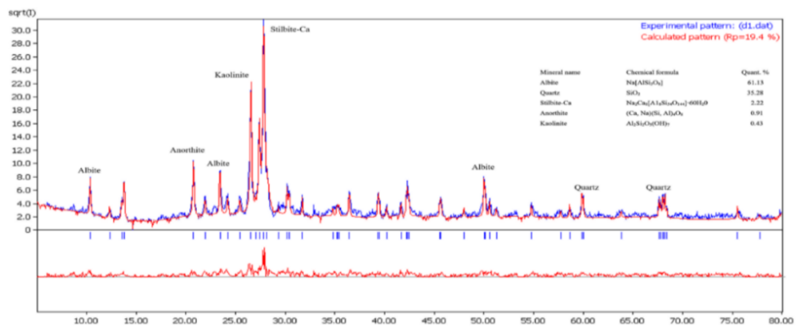

Fig. 14. The result of X-ray dipractographic tests of natural soil

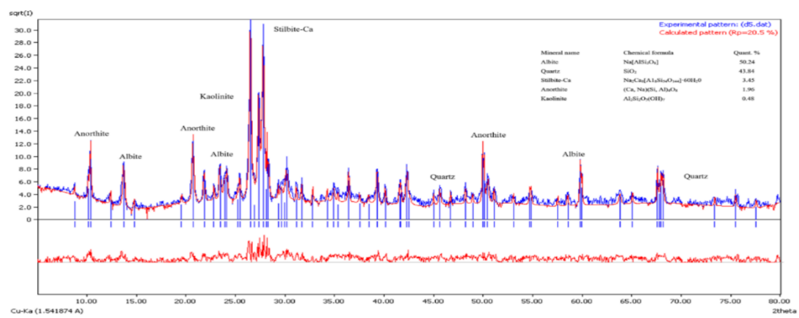

Fig. 15. The result of X-ray dipractographic testing of cemented soil

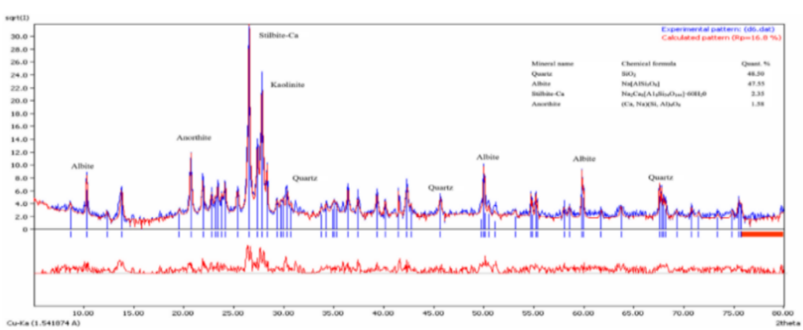

Fig. 16. The result of X-ray dipractographic testing of silicified soil

According to the results of a comparative analysis of the above X-ray images, it was found that the sandy loamy soil contains mainly quartz, albite, stilbite-Ca, kaolinite and anorthite, with albite making up 46-61% and quartz 31-48%, and the total amount is 92- 96%.

The results of fixing the under-compacted soil of the backfill of the foundation and floor. Production complex according to class II liability classification with modern automatic technological equipment and machines. 4-5 years after commissioning, under-compacted soils for backfilling the equipment foundation with depths of 7.0; 4.0; 2.75 and 2.0 m, as well as bulk soils, led to the fact that the underground floors of the workshops sank by 30 ... 50 cm due to vibration from the operation of equipment and moisture. In connection with the possibility of further subsidence of the soil, we developed a design solution for cementing backfill soils. To fulfill the requirements for backfilling and soil dumping, it is necessary to have a deformation modulus E ≥ 10.0 MPa. and the results are shown in Table 3.

Fig.17. Photo of the process of carrying out work on cementing the soil backfilling the foundation of an industrial building

Table 3. Comparison of backfill soil performance before and after grouting

№	Indicators	Indicators of soil before grouting	Calculated indicators	Indicators determined by testing	Dynamics of change
1	Porosity coefficient	0,77	0,60	0,51	15% reduction
2	Solution volume per 1 well, м^3	-	0,62	0,62	-
3	Deformation modulus, MPa	5,50	15,0	16,2	3.34 times increase

CONCLUSIONS

The sediment of the soil fixed with a solution of liquid glass, corresponding to a pressure of 100 kPa, is 1.76 times less, the sediment of the soil fixed with a solution of cement is 2.0 times less. The sediment of the soil fixed with a solution of liquid glass, corresponding to a pressure of 500 kPa, is 2.15 times less, the sediment of the soil fixed with a solution of cement is 2.45 times

less. The sediment, corresponding to a pressure of 1600 kPa, in soil fixed with a solution of liquid glass is 2.5 times lower, and fixed with a cement solution, 2.75 times lower.
As a result of fixing with silicate and cement mortar, the filtration capacity of the soil decreases by 17...28%, and it can be seen that the injected solutions filled the pores between the solid particles of the loess-like soil.

According to the results of the repair work on grouting the backfill of the foundations of buildings and equipment, the value of the porosity coefficient decreased by 15%, and the deformation modulus increased by 3.34 times, demonstrating the high efficiency of the grouting method.

Based on the results of experimental and theoretical studies, an effective method for fixing subsiding soil, taking into account the regional characteristics of Mongolia, is cementation using a cement slurry prepared with a composition of 1:40 and grade 450.

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