International Journal of the Physical Sciences Vol. 6(35), pp. 7985 - 7990, 23 December, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.099
ISSN 1992 - 1950 © 2011 Academic Journals

Full Length Research Paper

An experimental study on the effects of different injection materials on consolidation settlement

Salih Bektas[1]* and Ercan Ozgan[2]

[1]Civil Engineering Department, Engineering Faculty, Aksaray University, Campus, Aksaray, Turkey.
[2]Structural Department, Technical Education Faculty, Duzce University, Konuralp Campus, Duzce, Turkey.

Accepted 30 September, 2011

Injection applications with injection material types such as bentonite, rheocem, rheobuild 1000, bentonite+rheocem was made and the effect of the injection on soil consolidation settlement was experimentally studied. A sample of natural soil, whose geotechnical characteristics are known to be weak, was analyzed to determine its basic physical properties and the sample was injected with mixtures prepared with natural bentonite, rheocem650 and rheobuild1000. Settlement values of these samples under different loads were experimentally determined and settlement values of the natural sample were taken as reference values. Settlement values for different loads obtained from the experiments were compared with each other. When reference values for all loads on natural samples are taken as (100%), it was seen that the average settlement value of bentonite injected samples was 47.19% higher compared to the settlement values of the natural sample, the average settlement value of rheocem injected samples was 18.51% less compared to the settlement values of the natural sample and the average settlement value of bentonite+rheocem injected samples was 36.12% less compared to the settlement values of the natural sample.

Key words: Soil improvement, cohesive soils, consolidation settlement.

INTRODUCTION

One of the important problem soil properties encountered is lack of desired level for engineering applications. Soil improvement is classified as cohesive and cohesionless according to soil type, and as surface improvement or deep improvement based on the distance of application area to the soil surface (Mitchell, 1981). Injection of various mixtures into gaps, cracks and inter particle pore spaces of soils can improve their stabilization properties. The main injection applications are utilized to create impermeable zones below the dams, to increase the strength of foundation ground, to create diaphragm walls, to fill around the anchor bars, to create domestic and industrial waste repositories (Cinicioğlu, 1997). Mixtures in where injection is used are usually divided into two as suspension and solution mixtures. Although bonds in clay suspensions are weaker than those cement suspensions (Shroff and Shah, 1193), these mixtures improves geo-technical properties of the soil by creating fillings in gaps. Laboratory studies related to cement injection are concentrated on the effects of mixture and pressure on strength. Some studies were made on injectionability. These studies concluded that the soil whose grain size is less than 0.6 mm cannot be injected (Akbulut and Saglamer, 2002). Some studies were made on the preparation of the mixture. The mixing duration of the mixtures were seen to be effectless on socket times and resistance. Settling duration was determined to be inversely proportional to mixing duration (Schwarz and Krizek, 1992). In studies related to the resistance of the injection samples, resistance and dilution amount of mixtures into which cement and silica fume weighting to

*Corresponding author. E-mail: salihbktsg@hotmail.com. Tel: +903822882340. Fax: +903822801365.

Abbreviations: PVC, Polyvinyl chloride; **TS,** Turkish standards.

5, 10, 15 and 20% of cement were added, and were investigated (Aitcin et al., 1984). After the experiments, the greatest pressure resistance is obtained from the mixture into which 20% silica fume was added and the resistance was found to be 10% higher than the reference value of the cement.

The dilution amount of this mixture was seen to be decreased. Sandra and Jeffery (1992) calculated the resistance of mixtures bu using cement, evaporating ash, bentonite and air-entraining additives. After the tests, the maximum resistance was obtained from samples; which were mixed with 50% sand and 50% evaporating ash and whose water/cement ratio was 1/1. Low pressure resistance was obtained from mixtures of evaporating ash and sand/evaporating ash where air-entraining additives were used. They looked into the shrinkage and swelling of the mixtures due to the bentomite amount. Accordingly, swelling occurred, due to bentonite ratio, in mixtures with 50% sand and evaporating ash. They stated that shrinkage was prevented as bentonite decreased the dilution. Incecik and Ceren (1995) prepared mixtures of different water/cement ratios with cement, bentonite, plasticizers and air entraining additives. They used bentonite, weighting up to 4% of the cement, plasticizer weighting to 1% of the cement and air entraining additives. They utilized cylinder molds, of 15 cm in diameter and 30 cm long, in the experiments of pebble with a relative density of 50%. They injected the mixtures with 100 kPa vertical pressure. They reached a maximum resistance in samples injected with mixtures of water/cement, with 0.30 ratio and plasticizer. They acquired the lowest values in samples with 4% bentonit additives. The geotechnical properties of sand injected with cement based mixtures were studied by Vipulanandan and Shenoy (1992). They examined viscosity, setting time, dilution and pressure resistance of cement, cement-sodium silicate, cement-bentonite, cement-calcium silicate, cement-evaporating ash and cement-silica smoke mixtures. While the highest pressure resistance was provided by cement mixtures, it was determined that the pressure resistance of silica smoke mixture was higher than that of the betonite mixture.

More resistance against pressure and shrinkage was found to be in samples injected with bentonite than those samples injected with cement and silica smoke. Krizek and Helal (1992) investigated the seven and twenty eight day permeability, pressure and shrinkage resistance of sand with 65 ± 5% relative density, by injecting it, under 70 kPa pressure, with fine-grained cement mixture. They cured their samples, 15 cm in height and 5 cm in diameter, half of them vertically half of them horizontally after injecting them vertically with mixtures of water/ cement with rates varying from 1 to 3. They stated that the vertically cured samples had a lower permeability than those cured horizontally and that the permeability increased at the same rate as water/cement ratio increased. Even though there was no difference in pressure resistance between vertically and horizontally cured samples with 1/1 water/cement ratio, they concluded that the pressure resistance of horizontally cure samples with 1.5/1 and higher water/cement ratio was higher. Perret et al. (1997) prepared mixtures of different water/cement ratio using standard portland cement and fine-grained cement. They utilized different amounts of silica smoke, super plasticizers and water trapper additives. They analyzed the mixtures for their rheological properties and injectability. They used super plasticizers in all the mixtures.

They injected sand located in cylinder molds of 22 mm diameter and 370 mm height with the mixtures under a pressure of 75 kPa. Injection time and the span of the injection were calculated. From this respect, both the portland cement and fine-grained cement of 1, 2 and 2 water/cement ratio were 100% injected yet mixtures of 0.5 and 0.6 water/cement ratio were only injected to 14 and 54%. Akbulut (1999) injected samples of 0.30 and 0.80 relative densities with cement, cement-silica smoke, cement-evaporating smoke and cement-clay mixtures. They did experiments on injection pressure, ground grain size, gap rate, mixture water rate, taking type of the additive materials and time as parameters. They figured that pressure resistance of samples injected with silica smoke increased up to 30 and 70% in mixtures with 1/1 water/cement ratio. The resistance was found to decrease by 5 to 20% in evaporating ash mixtures and 15% in injections added with clay. In experiments done on permeability, the parameter was down from 1.26 cm/s to between 10-5 and 10-7. Injecting standard cement into soil formations which has particles smaller than sand lately suggest the use of micro-sized cement to stabilize fine and middle sized sand in order to overcome problems such as the lack of penetration and poisoning and incompetency due to chemical injections (Ozgan et al., 2007). Therefore, the results of laboratory studies on injections of micro-sized cement shows that this kind of injection possesses a better sedimentation capacity, penetration capability and a lesser socket duration than standard Portland cement.

It was also reported to easily penetrate, along with Microcem H900 mixture with ½ water/cement ratio, into sand of 70% relative density under 20 kPa pressures (Tekin and Mollamahmutoğlu, 2010). They showed that they are highly successful in overcoming the problems of toxicity and permeating into materials when very-fine grained cement is injected into fine and middle sized sand. Observed from the result of these studies, comercially acquired fine-grained cement provides more suitable flow and perspiration conditions than standard Portland cement. In the studies by these researchers, it was seen that fine-grained cement injections could penetrate up to a few feet into low water/cement ratio, sandy soil compressed into D15 size of 0.15 mm. Granulometrical dispersion of sandy soil was observed to be more influential on injectablity rate (Zebovitz et al., 1989). Injection mixtures were prepared by using different rates of waste materials such as bentonite, evaporating ash, silica smoke. A grained ground sample with certain grain size dispersion was placed in cylindrical molds with a relative density of 0.70 and the prepared injection mixtures were added. The effects of bentonite, evaporating ash and silica smoke on 7, 14 and 28 days single axis pressure resistance were investigated by Tagunchi method (Zaimoglu, 2003). After the investigation, the most effective parameter in 7, 14 and 28 day single axis pressure resistance of the injected samples was the silica smoke. General injection types can be noted as permeation injection, compaction injection, fraturing injection, mixing/jet injection, filling (contact) injection and fine-grained cement injection.

EXPERIMENTAL STUDIES

Natural soil sample

The properties of cohesive soils such as shearing resistance, permeability and compressibility are highly in relation to their stiffness. The compressibility of cohesive soil is related to its water content and plastic limit values. The compressibility of cohesive soils is given for three classified groups in Table 1. Test samples to be injected were taken from a depth between 2.5 to 3.0 m. As the result of the laboratory experiments, natural unit weight of soil samples was 20.9 kN/m^3, water content was 28%, shrinkage and shrinkage rate was 1.35% and value of shrinkage limit was 25.63%. In addition, sieve analysis experiment was done for this test sample. As a result of the hydrometer test, the part of the sample which passed through the sieve no 200 was proportional to 42% of the sample. Safety stress for the injected ground sample was 90 kN/m^3 and the value of bearing capacity of the soil was 270 kPa.

Injection materials

In the study, bentonite, rheocem, rheobuild 1000 and the mixture of bentonite and rheocem materials were used. The general properties of the materials are explained below.

Natural bentonite

In addition to having high swelling capacity and high natural sodium content (pure), natural bentonite contains at least 90% montmorillonite and API 13 A (Nontreated bentonite), and it is a clay mineral in compliance to TS 977 type-2 standards. It is easily dispersed when added to water and it does not become lumpy. When added to cement sorbet or grout, it enables the stability of the grout by holding the cement particles and sand during the process of mixture and injection. It minimizes the decomposition of water in cement/water mixture. When mixed with cement sorbet, it raises the degree of penetration into fine-grained alluvial. Thus, the cement loss is prevented. Bentonite mixtures act as a fluid, but when mixing is stopped, a homogeneous hardening occurs and they gain high resistance. General properties of 25 g natural bentonite prepared by adding 350 mL distilled water for the solution.

Rheocem (micro cements)

Rheocem microcement is classified as super fine-grained cement. It is developed for earth and rocky ground and it can easily penetrate capillary cracks. Rheocem microment is produced in four different particle sizes for their application purposes. During the process of preparation and implementation of microcements, water was poured into a clean mixing equipment, rheocem microcements were slowly added on, and the mixture was mixed in 1500 rev/min colloidal type mixer or 400 rev/min winged type mixer until a lump-free homogeneous mixture was obtained (approximately 3 min). Rheobuild1000 weighting from 1.5 to 3% of binder was added. The new mixture was blended for approximately 1 more min. Rheocem microcements were used in conjunction with super-plasticizers like Rheobuild1000 or such. The prepared injection grout was transferred from mixer equipment to churning unit. In the churning unit, sedimentation was prevented due to continuous mixing. A high-pressure piston pump was used during molding and the injection grout was used up in 20 to 30 min.

Table 1. The compressibility of soil (Sowers, 1979).

Definition	Water content	Plastic limit
Low compressibility	0 to 0.19	0 to 20
Medium compressibility	0.20 to 0.39	21 to 50
High compressibility	>0.40	>50

Rheobuild 1000

Rheobuild 1000 is a fluid-concrete additive material which is formulated to give a reoplastic feature to concrete. It is water-soluble synthetic polymer sulphone based, chlorine-free, highly water reducing, super plasticizer and it accelerates and increases resistance of concrete at early times. Additives generally react only with cement. When added to concrete additives, it is absorbed by cement particles. Cement particles push each other with electrostatic force. By enchancing the movement of cement grains, the flow property of concrete is ensured with a lower amount of water. Early and final resistance gain is provided in proportion to the reduction of mixing water. The early and final resistance improves the engineering properties of concrete, such as modulus of elasticity, adhesion to steel, shrinkage, yield and resistance to aggressive chemicals. It enables the same processability with lower water/cement ratio, or higher processability with the same water/ cement ratio. It gives a reoplastic property to water by reducing weathering and sweating. Rheobuild 1000 is a liquid additive which is added to concrete along with mixing water and it improves the properties of hardened concrete. Rheobuild 1000, when added after 60 or 70% the mixing water is added, and it has a higher plasticizer effect. Mixing time should be sufficient to obtain a homogeneous mixture. Rheobuild 1000 should not be added directly on dry aggregate.

Injection applications

The preparation of suspension for bentonite injection

Mixer revolution time and mixing time is extremely important for the suspension to be used for bentonite injection. The mixing procedure was executed carefully as a long-held mixing duration would result in temperature rise which would lead to hydration and particle flocculation. While the values for mixing duration and number of revolution are met as advised in product guide, it was decided to use the colloidal mixer which is recommended by the manufacturer. The bentonite for the injection was previously kept in water for 12 h to enable its swelling. The suspension for the injection was

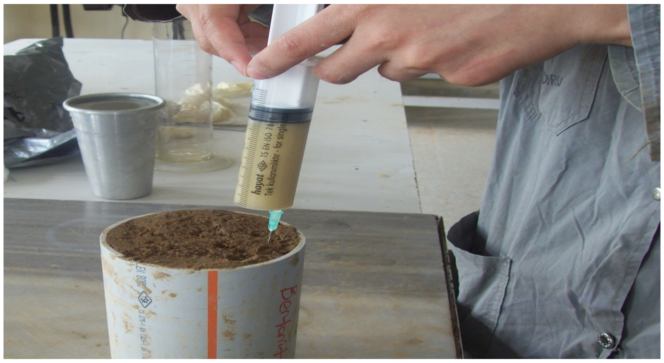

Figure 1. Bentonite injection into soil sample.

Figure 2. Rheocem injections into soil sample.

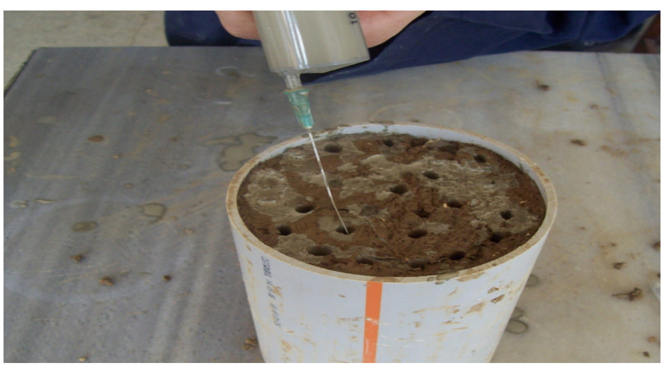

Figure 3. Injection of bentonite + rheocem into soil sample.

prepared by using 100 g bentonite, 1400 ml water, and 3 g rheobuild100. The sample was acquired with a PVC pipe (polyvinyl chloride) of 214 g empty weight. The net weight of the sample was 2650,7 g. Into this soil sample, 159 g of suspension prepared with bentonite, weighting to 6% of the sample, was injected as shown in Figure 1.

The preparation of suspension for rheocem injection

For rheocem injection, a suspension consisting of 100 g rheocem, 80 ml water and 3 g rheobuild100 was prepared. The PVC pipe used for sampling was 214 g, the acquired sample was 2792.8 g, therefore the new weight of the soil sample was 2578.8 g. The suspension was weighted to 6% of the sample (154.7 g). It was injected to the sample as shown in Figure 2.

The preparation of suspension for bentonite+rheocem injection

The suspension prepared for bentonite+theocem injection consists of 100 g. rheocem, 80 ml water and 3 g rheobuild1000. The mixture was kept in water for 12 h to enable its swelling and 5 g of bentonite was added. The sample taken by PVC pipe was recorded as 2663.8 g and after deducting the weight of PVC pipe, which was 214 g, the net weight of the soil sample to be injected was found to be 2449.8 g. The plasticizer amount was specified as 4% of the bentonite+rheocem weight. In order to prevent the flocculation caused by the plasticizer, it was specially avoided to directly mix it with bentonite+rheocem. The plasticizer was added to the suspension to acquire a more homogeneous mixture. Into the soil sample, the bentonite+rheocem suspension weighting to 6% of the sample (147 g) was injected as shown in Figure 3.

Consolidation tests

Consolidation experiments were conducted in accordance to TS 1900 (Turkish Standarts, 1900). Undisturbed soil samples used in the experiments were taken from a depth of 2.5 to 3.0 m in cylindrical molds with 15 cm diameter and 10 cm height. Two of eight cylindrical samples brought to the laboratory were subjected to consolidation test without any injection. Two of eight samples were injected with bentonite and then tested. Another two samples were injected with rheocem and then tested. The remaining two samples were injected with bentonite+rheocem and tested followingly. During the tests, the serie of 0.5, 1 and 2 kgf/cm^2, in this order, was followed on consolidation cell and on each load, settlement values at 8.5 s, 1 min, 6.25 min, 15 min, 30 min and 64 min were measured and recorded. Following the experiments, consolidation cell with the wet samples in them were removed from the consolidation device and scaled. Then, they were placed in oven to determine their water content and were recorded.

EXPERIMENTAL RESULTS

In order to determine the consolidation parameters in injected soil sample, consolidation experiments were carried out on the natural sample, bentonite injected sample, rheocem injected sample and bentonite + rheocem injected sample. In the consolidation tests, vertical loads of 50, 100 and 200 kPa, which were specified according to soil bearing capacity and allowable stress values, were applied. As a result of experiments, the average dry and wet weights of the samples are given in Table 2. The consolidation experiments were carried out in the samples 7 days after injection. The settlement values for each load value obtained from the consolidation tests are given in Figure 4.

CONCLUSION AND RECOMMENDATIONS

According to results of consolidation tests performed on

Table 2. Wet and dry weights of soil samples in the consolidation test.

Weights (g)	Natural sample	Bentonite	Rheocem	Bentonite+Rheocem
Mold	111.51	111.14	111.14	109.8
Mold+wet sample	179.8	181.5	182.4	185.7
Mold+dry sample	163.1	164.3	167.2	168.1

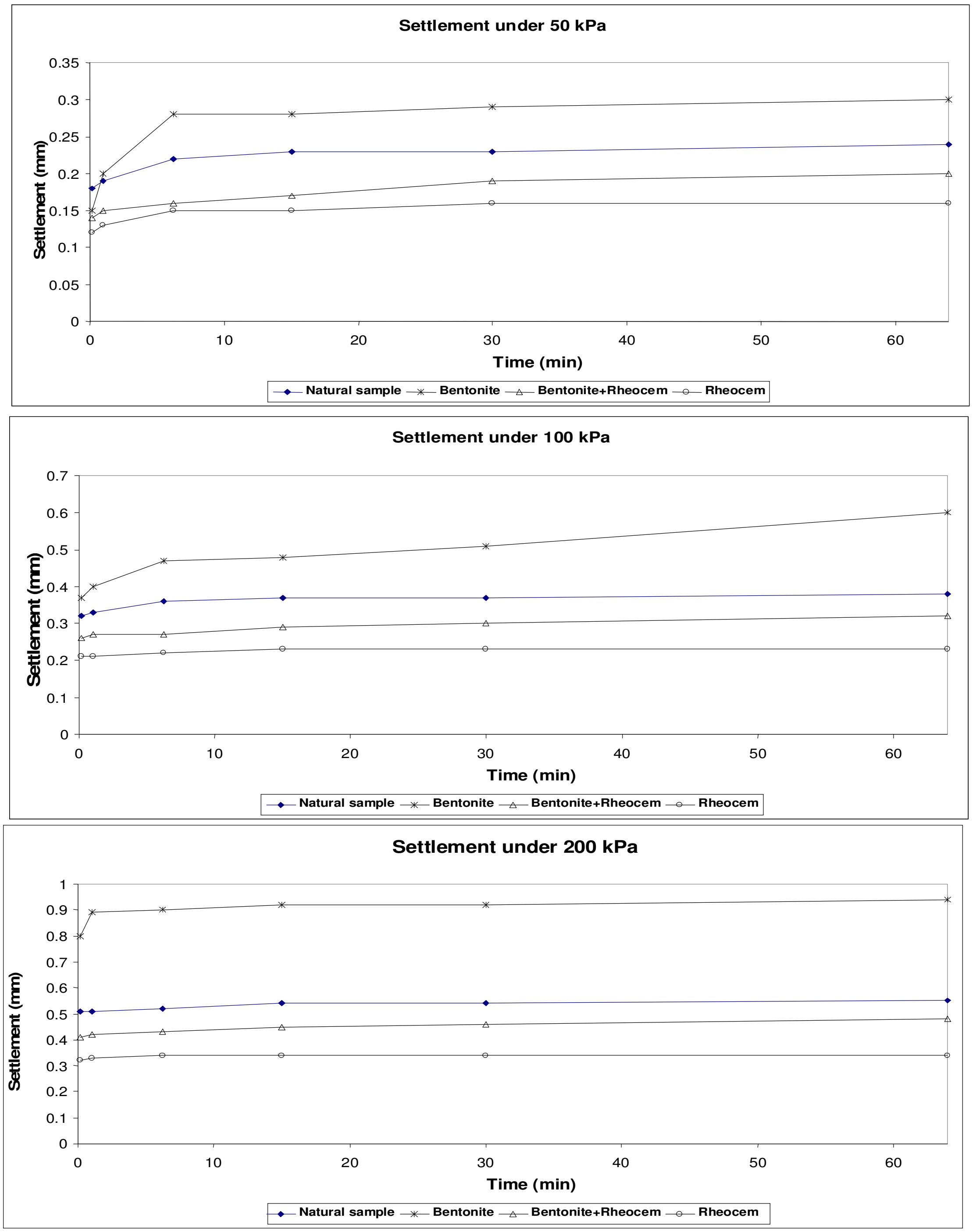

Figure 4. Settlement values under 50, 100 and 200 kPa.

the second lowest value was obtained from rheocem injected samples, soil samples, the lowest settlement value by elapsed time was recorded for bentonite+ rheocem injected samples. The third lowest value was from the natural samples which were not injected at all. The highest settlement was seen on the samples injected with bentonite. Avarage settlement values obtained from the natural sample when applied to 50 kPa vertical load were taken as reference (100%) values. In this case, the average settlement value of the bentonite injected samples was 16.28% more compared to the natural sample, whereas the average settlement value of the samples injected with rheocem was 21.71% less than the natural sample and the value for bentonite+rheocem injected samples was 32.56% less compared to the values of the natural. In other words, it was determined that the settlement was the least in bentonite+rheocem injected samples, rheocem injected samples were in the second place and bentonite injected samples had a higher (16.28%) settlement value than the natural sample. Average settlement values obtained from the natural sample when applied to 100 kPa vertical load were taken as reference (100%) values. Accordingly, it was seen that the settlement value in bentonite injected samples were 32.86% higher compared to natural samples, whereas samples injectioned with rheocem had a 19.72% lower value and the values from bentonite+rheocem injected samples were 22.22% less.

In other words, it was concluded that the bentonite+ rheocem injected samples had the least settlement, rheocem injected samples were in the second place and the injection of bentonite into samples resulted in a higher (32.86%) settlement value than the natural sample. Avarage settlement values obtained from the natural sample when applied to 200 kPa vertical load were taken as reference (100%) values. Thus, the average settlement value of the bentonite injection was 69.40% higher than the average settlement value of the natural sample, whereas, the average settlement value was 16.40% less in rheocem injected samples and the average settlement value in bentonite+rheocem injected samples was 36.59% less. In other words, the bentonite+rheocem injection had the lowest settlement, the rheocem injection was the second and the bentonite injection had a higher (69.40) settlement value than the natural sample. When values from natural samples under full load are taken as reference values, the average settlement value of the bentonite injected samples were 47.19% higher than the values of the natural sample, the average settlement value of the rheocem injected samples were 18.51% lower than the values of the natural sample and the bentonite+rheocem injected samples had 36.12% lower average settlement values than those of the natural sample. In this study which makes a comparative analysis of consolidation settlement in injected soil, it was concluded that the lowest the settlement value under different vertical loads and after the specified duration was acquired from the bentonite+rheocem injected samples; on the other hand, the bentonite injected samples had the highest value. In this case, it is concluded that, for injections to be made into the soil, the injection should be prepared with bentonite+rheocem in order to ensure the minimum settlement in soil. On the other hand, bentonite should not be individually utilized and it was also seen that the the settlement value from rheocem injected samples was 95% higher than bentonite+rheocem injected samples. Under these circumstances, it can be said that bentonite and rheocem mixture should be applied as much as possible in injection applications.

REFERENCES

Aitcin PC, Ballivy G, Parizcau R (1984). The use of condensed silica fume in grouts, Innovative Cement Grouting, ACI Publication SP-83, Detroit.

Akbulut S, Saglamer A (2002). Estimating the groutability of granular soils: a new approach, Tunnelling and Underground Space Technology. 4(17): 333-437

Akbulut S (1999). Geotechnical properties of Injection with the improvement of granular soils, Ph.D. Thesis, Istanbul Technical University, Istanbul.

Cinicioglu SF (1997). Soil mechanics ınjection mortar. Istanbul University Press, University Publication No. 4021, Faculty of Engineering Publication No. 100, ISBN: 975-404-458 – Istanbul, pp. 63-172.

Incecik M, Ceren I (1995). Cement grouting model tests, Bulletin of the Technical University of Istanbul, 2(48).

Krizek RJ, Helal M (1992). Anisotropic behavior of cement-grouted sand, Grouting, Soil Improvement and Geosynthetics, Geotechnical Engineering Division of ASCE, Lousiana. 30(2).

Mitchell JK (1981). Soil improvement: state of art, Proceedings, 10th International Conference on Soil Mechanics and Foundation Engineering, Cilt 4: 09-565

Ozgan E, Gokdemir A, Subası S, Yıldız K (2007). Low porosity grounds microcem 900 H cement injection application, Internatinal Earthquake Symposium, Kocaeli.

Perret S, Ballivy G, Khayat K, Mnif T (1997). Injectability of fine sand with cement-based grout, Grouting, Geotechnical Special Publication of ASCE, No: 66, Utah

Sandra T, Jeffrey CE (1992). The effects of fillers and admixtures on grout performance, Grouting Soil Improvement and Geosynthetics, Geotechnical Engineering Division of ASCE, Lousiana. 30(2).

Schwarz LG, Krizek RJ (1992). Effects of mixing on rheological properties of microfine cement grout, Grouting Soil Improvements and Geosynthetics, Geotechnical Enginnering Division of ASCE, Lousiana. 30(2).

Shroff AV, Shah DL (1993). Grouting technology in tunnelling and dam construction, Balkema Publishers, Brookfield. pp. 235-298.

Sowers G (1979). Introductory Soil Mechanics and Foundations: Geotechnical Engineering, Fourth Edition. Macmillan and Company, New York. p. 621.

Tekin E, Mollamahmutoglu M (2010). The Groutability of Microfine Cement (Rheocem 900) Grouts Into Various Graded Sands. (In Turkish) J. Fac. Eng. Arch. Gazi Univ. 25(3): 533-539.

Vipulanandan C, Shenoy S (1992). Properties of cement grouts and grouted sands with additives, Grouting Soil Improvements and Geosynthetics, Geotechnical Enginnering Division of ASCE, Lousiana, 30(2) .

Zaimoglu AŞ (2003). Bentonite injection of fly ash and silica fume-blended cement mixtures with Taguchi method examination of the physical and mechanical properties, Ph.D. Thesis, Atatürk University, Science and Technology Institute, Erzurum.

Zebovitz S, Krizek RJ, Atmatzidis DK (1989). Injection of fine sands with very fine cement grout, J. Geotech. Eng., 12(115): 1717-1733.