doi: 10.18720/MCE.83.20

Improvement of the soil deformation modulus using an expandable polyurethane resin

Улучшение модуля деформации грунта с использованием расширяющейся полиуретановой смолы

M.M. Sabri*,
Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia
K.G. Shashkin,
OOO "PI Georekonstruktsiya", Saint Petersburg, Russia

M.Sc., аспирант М.М. Сабри*,
Санкт-Петербургский политехнический университет Петра Великого, г. Санкт-Петербург, Россия
канд. техн. наук, зам. директора, член технического комитета № 207 ISSMGE К.Г. Шашкин,
ООО "ПИ Геореконструкция", г. Санкт-Петербург, Россия

Key words: soil injection technology; soil modulus of deformation; soil stiffness; foundation lifting; soil consolidation; soil improvement; foundations settlement; soil bearing capacity; polyurethane resin

Ключевые слова: осадка фундаментов; усиление грунтов; технология инъектирования грунтов; модуль деформации грунта; жесткость грунта; подъем фундаментов; консолидация грунта; несущая способность грунтов

Abstract. Different methods are used in the field for foundations remediation and improvement of the soil properties, but every method has its advantages and limitations. Moreover, not all the existing methods are able to stabilize the soil and elevate the foundations effectively, regulating the process depending on the desired results. The settlements of the foundations of the buildings and structures lead to negative consequences and controlling the settlements is complex itself essentially in the type of soils which contains organic materials or acids where the treated materials used might react with the soil components. The soil injection technology using an expandable polyurethane resin is an innovative technique that leads to the stabilization of the soil beside lifting and remediating of the foundations. Therefore, a full-scale experiment has been implemented in-situ to investigate the effect of injecting an expandable polyurethane resin on different soil properties besides lifting a concrete foundation. The paper demonstrates the results of an experiment which has been conducted to improve the soil's modulus of deformation, lifting of a concrete foundation, settlement compensation and increase the bearing capacity of the investigated soil after the injection of an expandable polyurethane resin consists of two components. The deformation modulus (E) of the investigated soil before and after the injection of the resin at different depths are achieved and incorporated. Also, comparisons of the load-settlement graphs at different soil depths before and after the injection of the resin are presented and analyzed. The in-situ injection process and the propagation of the resin in the soil massive are obtained and described in this paper.

Аннотация. Существует множество методов, которые используются для стабилизации грунтов и подъема фундаментов, но каждый из этих методов имеет свои область применения, преимущества и недостатки. Более того, не все методы, используемые на мировом рынке, способны стабилизировать грунт и компенсировать осадку фундаментов комплексно, регулируя сам процесс в зависимости от ожидаемого результата. Осадка фундаментов зданий и сооружений приводит к негативным последствиям. Контроль осадок требует комплексного подхода, так как некоторые грунты, которые включают в себя органические материалы или кислоты, могут реагировать с обработанном материалом, использованным в том или ином методе. Технология инъектирования грунтов расширяемой полиуретановой смолой является новаторским способом, ведущим к контролируемому процессу стабилизации грунтов и подъему фундаментов. На основе проведенного анализа был выполнен натурный эксперимент для наблюдения контроля подъема фундамента и определения влияния расширяемой смолы на различные свойства грунтов. В статье показаны результаты проведенного эксперимента, а именно: улучшение модуля деформации грунта, контрольный подъем и восстановление бетонного фундамента, компенсации осадок и увеличение несущей способности исследуемого грунта после инъекции полиуретановой смолы. Модуль деформации грунта (E) и сопоставление расчетных графиков зависимости осадки от

Сабри М.М., Шашкин К.Г. Улучшение модуля деформации грунта с использованием расширяющейся полиуретановой смолы // Инженерно-строительный журнал. 2018. № 7(83). С. 222–234.

нагрузки на разных глубинах до и после инъекции смолы достигаются и проанализированы. Также в данной статье описаны результаты процесса инъектирования и распространения смолы в массиве грунта.

1. Introduction

One of the main problems which face the construction engineers is the settlement of the soil beneath foundations during the construction and exploitation processes [1]. Settlements are divided into two main types uniform and differential. In most cases, a uniform settlement causes no problems, when the whole construction is settled. Problems arise when differential settlements occur due to various reasons such as errors in construction design, non-qualitative of geological surveys before construction, poor quality of the soil compaction while construction, the variation of the groundwater level and other reasons [2–4]. Another problem is a weak soil which is not able to carry the applied or designed load of the construction because of many reasons. For instance, the type of the soil is soft and need to be stabilized, changes in the moisture content of soil which leads to changes in the physical and the mechanical properties of it and others[5, 6]. Moreover, the soil might contain organic materials or acids which can have negative influences on the soil properties leading to adverse effects on the foundations. [7]. Furthermore, differential settlements cause adverse consequences on the foundations and other construction parts. It leads to increase the stresses in foundations, walls and other construction parts which lead to cracks, fractures and even collapsing the construction in some cases [8-10]. Also, sometimes it is necessary to increase the bearing capacity of the soil to be able to carry an extra load added to the construction when required to increase the load of the construction or according to clients wishes in case of adding extra floors to the construction [11, 12].

There are many classical methods used to compensate settlements, foundations lifting and soil stabilization such as Jet-Grouting, Root piles, chemical stabilization, and other methods. However, every method has advantages and disadvantages or limitations [13, 14]. Some methods require extensive preparation and instruments, others are high in cost or necessitate huge time to implement until obtaining the desired result in addition to the restrictions of use in the limited construction area. Additionally, most of the existing methods include materials which can react with the soil contents especially if the soil contains acids or other reactive materials. [15, 16].

The density of the soil beds plays a significant role in the design of any foundation. It was proved that the high values of soil density lead to control of the operating conditions of an artificial foundation and what called plate effect can be noticed. Highly compacted soil beds and reinforced soil beds can lead to reduce the thickness of the beds and increase the bearing capacity of the soil which can decrease the designed dimensions of an artificial foundation reducing the cost and the time required [17, 18]. Moreover, the soil might be exposed to high strain conditions where the construction is built on the mountains like in Tajikistan where the mountains and hilly areas cover around 90 % of the areas or for other reasons. Consequently, using a combination of soil stabilization methods lead to ensure the stability of the slope reducing the collapse of the soil as stated in [19].

For all the issues stated above and others, actions need to be taken in order to develop a fast and controlled method for solving various settlements problems and remediation of the foundations. Soil injection technology using an expandable polyurethane resin might offer an optimum solution for most of the mentioned problems either by implementing the technology alone or in a system of methods combination in complex soil problems.

As the modulus of deformation of the soil is a significant parameter to measure the soil stiffness and to design any constructions. The deformation modulus of the soil is affected and variable according to many factors such as the type and the depth of the soil, the soil moisture content and other factors [20, 21]. Therefore, an experiment was conducted in the field to investigate the effect of soil injection technology using an expandable polyurethane resin on different soil properties at different depths and to reduce the soil settlement beside evaluating the performance of lifting a concrete foundation.

2. Methods

2.1. The aim of the experiment

The experiment was conducted for investigating the effect of injecting an expandable Polyurethane resin on different sandy soil parameters such as the soil modulus of deformation (E), settlement reduction and compensation and increasing the bearing capacity of the soil beneath a concrete plate which was exposed to a load in order to behave like a real foundation beside lifting this plate to the pre-designed level. The level of lifting is designed to exceed the value of (1 cm).

2.2. Location of the experiment and the type of the investigated soil

The conducted experiment took place in an open storage area located in the western part of the plant of the company “MC-Bauchemie-Russia” in Kirovsk, Leningradskaya region, Russian Federation as shown in Figure [1]. The type of the investigated soil is non-cohesive sandy soil according to the factory geological report.

Figure 1. The layout of the object (the red Line highlighted the boundary of the plant; red fill indicates the test area) [22]

The soil was investigated in September 2014 by a geotechnical company, and the experiment was conducted based on the geological report given to the factory. According to the geological report of the factory, the soil being investigated in this experiment consists of the following layers: the first layer is a technogenic layer represented by bulk sand of different sizes grading (from small sand to gravels, with gravel, pebbles and building debris) within a depth up to (2 m) and the sediment layer is (1.5–2 m). The Bulk sand is heterogeneous having uneven density and compressibility. The second layer is a glacial soil layer widespread under the bulk sand consist of fine sand medium density and medium degree of saturation. Sediment power is from (3.5–6 m). In the period of geological surveying in September 2014, drilling up to 8m in depth, it was found that the groundwater level located within (2.2–2.5 m). The properties of the investigated soil according to the report are given in Table 1.

Table 1. The properties of the investigated soil as given in the geotechnical report of the factory

Geological Index	Soil Name (type)	Layer No.	Density t/m^3	Porosity factor e	Strength indicators		E, MPa	Calculated resistant R0, kPa	Filtration coefficient, m/day
					C, kPa	Φ, grad			
t IV	Bulk sand different sizes	1	R0=100 kPa						
lg III	Fine sand, medium density and medium degree of saturation and fully saturated	2	1.94	0.65	4**	30**	18**	200**	4.47*

* According to laboratory investigation data, ** According to SP 22.13330.2011 [23].

2.3. Experiment Description and the test site

In the test site, two plots, each measuring 3 m per side, were chosen, covering a total surface area of (3*3 m) as shown in Figure 2. Soil stabilization using an expandable polyurethane resin was applied in one plot while the second plot considered as a reference plot (no injection was carried out in this plot) for the comparison of the results. Then, the concrete plate of the injected plot was cut, and a total load of (11 ton) approximately was placed on it to ensure that the plot acts like a real foundation as shown in Figure 3.

Figure 2. The selected experiment plots

Figure 3. The injected plot under the load during the injection process

The injection of the expandable resin was carried out at five different points along the injected area utilizing injecting tubes which inserted to different depths. The injection of the resin carried out at depths (0.5, 1, 2 m) to assess the effect of the injected resin on the properties of the investigated soil at different layers. The injected geological section with the concrete plate and injection zones are shown in Figure 4. The injected resin consists of two components (component A and component B) of the polyurethane resin (MC-MONTAN INJEKT-LE) produced by the company MC-BAUCHEIME-Russia. The components of the resin were mixed in a hydraulic system under high pressure to control the mixing of the two components of the resin and injected incrementally into the soil using the injection pistol. The pressure of the injection mix was more than 100 bars, and the temperature of the mix was varied and controlled but mostly (15 C°). Then, both plots were excavated to investigate the propagation of the polyurethane resin and to conduct plate load test (plate-bearing test).

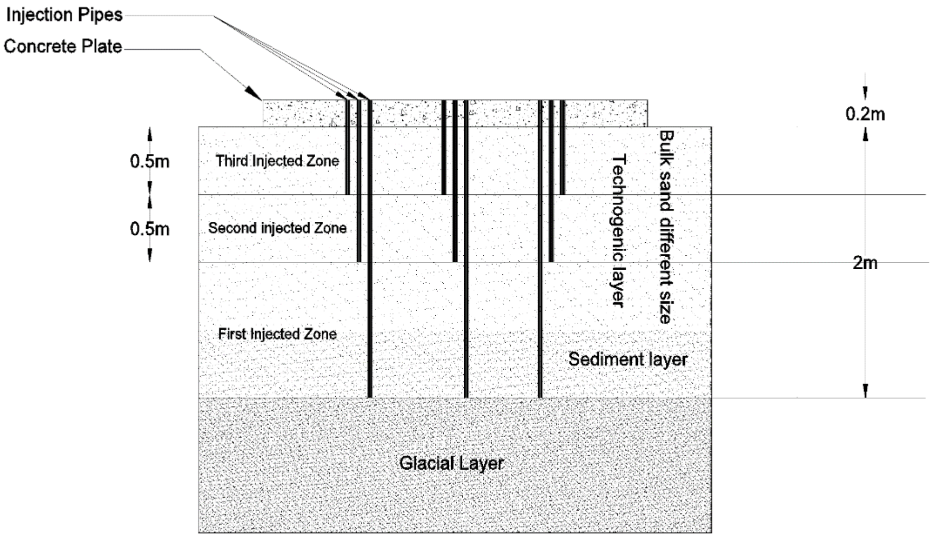


Figure 4. The geological section of the injected area and the in-situ injected zones

2.4. Excavation process and the plate load test

Different depths of excavation were chosen to investigate the effect of the resin on the modulus of deformation (E) by conducting plate load test, and to locate the propagation of the resin in the soil massive at different depths. The Depths of the excavation were selected considering different conditions which can influence the accuracy of the obtained results such as the groundwater level of the tested area. Moreover, the excavation process was carried out manually to avoid any disturbance to the soil which might affect the results of the plate load test and to be able to locate the resin accurately.

Each plot was divided into four quarters and only a quarter of each plot was selected for the investigations at this step. The pre-designed depths of the plate load test (0.5 m) which is the depth of the injection in the first layer of the investigated soil and (1.5 m) for the second layer of the soil as this depth represents the average of the injection depth in the second part of the soil layer (1–2 m). During the excavation process, it was noticed that the groundwater level located at the depth (1.4 m) as shown in

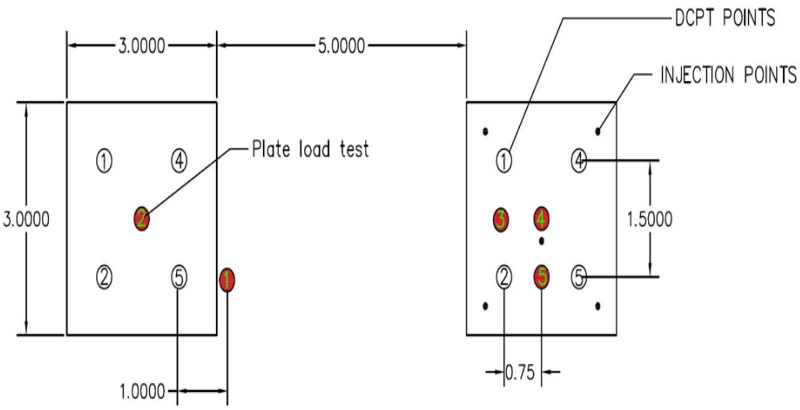
Figure 5. It is the author opinion that the reason behind the groundwater level rise is the seasonal variation of the groundwater as the excavation process was performed in autumn when the water level rises. Thus, the selected excavated points for the plate load test were replaced by another point, and the in-situ depths of the plate load test were taken as explained in Table 2. The concrete plate cutting process is shown in Figure 6.

Figure 5. The groundwater level during the excavation process at a depth of (1.9 m)

(A) The cutting process (B) A section of the injected plot after cutting

Figure 6. The cutting process of the injected plot. (A) The cutting process, (B) A section of the injected plot after cutting

Five different points were chosen for performing the plate load test, two points in the reference plot at depths (0.4,1.2 m) and two points in the injected plot at depths (0.4, 1.1 m) in addition to one point in the injected area on the (resin-soil composition) as shown in figure (7). Furthermore, dynamic cone penetration test DCPT was conducted, and the results of the test are achieved and described in a previous article [22].



Figures 7. The in-situ location of the plate load in the reference and the injected plot

It means that two points at depth in the injected plot were compared to two other points in the reference plot at different soil depths for the comparison of the results, while, the last test was performed separately. In the last test, the center of the steel plate was placed to fit the center of the resin to investigate the modulus of deformation (E) including the resin and the soil together and not only on the soil itself as shown in Figure 8.

Table 2. The excavation zones and the actual depth of the in-situ plate load test

Zones of the test	Number of the test	The depth of the test, (m)
Without injection (Reference plot)	1	0.4
	2	1.2
With injection (Injected plot)	3	0.4
	4	1.1
With injection on the resin-soil (Injected plot)	5	1.1

(A) The location of the steel plate. (B) The soil-resin under the load.
Figure 8. The steel plate as placed in-situ in point number (5). (A) The setting up the plate on the resin-soil composition, (B) The soil-resin under the load in this point

The main aim of the test is the determination the modulus of deformation of the investigated sandy soil (E) at different soil depths and the graphs of load-settlement relationships according to specified load before and after the injection of the expandable polyurethane resin in order to precisely investigate the effect of the injected resin on different soil characteristics and on the bearing capacity of the investigated soil.

Six concrete plates with total load around 25 ton were used for applying the load on a circular steel plate. The load was chosen to ensure that the load applied to the soil area is enough to reach the failure of the soil. The diameter of the chosen steel plate is 27.6 cm, and the area of it is 600 square centimeters. So, the maximum load according to the equation below is around 416 ton/m^2.

$$6 = P/A$$

where P – the load of the concrete plates, A: The area of the steel plate.

In order to transfer and control the load of the concrete plate to the steel plate, an aluminum jack was used with a capacity of loading up to 150 ton. Also, a manual hydraulic jack was calibrated to create and control the load during the testing process. Three sensors connected to the steel plates carefully for reading the settlements of the soil during each process of loading and unloading the soil (release the load and control the settlement). Figures 9, 10 show the plate load test in-situ at different points of the experiment.

Figure 9. The plate load test under the load in point (3)

Figure 10. The plate load test under the load in point (4)

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Furthermore, the diameter effect of the applied load was considered when the locations of the plate load tests were chosen. To ensure that no results are overlapping of the applied load of one tested point to another, the minimum distance between plate load tests was (75 cm) as the diameter effect of the applied load in this test is assumed to be double than the diameter of the steel plate which is (55.2 cm).

3. Results and Discussion

3.1. Results of lifting

The concrete foundation (the plate under the load) was regulated and lifted up to (12 mm) after the injection of the resin. The results were carried out Immediately at each point, then the last elevating of the whole plate was controlled through the middle point (point 3). The injection process was proceeded and monitored using a high accuracy laser level instrument during the injection process until the designed level for this experiment was obtained. The temperature of mixing the components of the resin and the pressure of injection was variated depending on the elevating required for each point. Results of lifting the concrete plate are shown in Figures 11, 12.

(A) Before (B) After

Figure 11. A side section of the concrete plate side of the injected plot before and after the injection of the resin. (A) Before injection, (B) After injection

(A) Before (B) After

Figure 12. The concrete plate of the injected plot before and after the injection of the resin. (A) Before injection, (B) After injection

3.2. Resin propagation

The resin diffused in the soil massive forming shapes similar to walls of foam plates along the injected soil depth from all sides within a distance interval around 30–50 cm and the average thickness of the resin is 2 cm approximately as measured. It was found that the resin propagated through the whole excavated depth of the soil. Moreover, the resin was continuous through the whole excavated depth of the soil and not separated. Figures 13, 14 illustrate different sections of the resin propagation.

Figure 13. Different sections of the resin injection in the injected plot at depth (0.4 m).

Figures 14. Different sections of the resin diffusion in the injected plot at depth (1.1 m)

3.3. Results of plate load test

According to the Russian standard GOST (20276-12) [24], the load must be applied within an interval of loading and unloading (steps) which depends on the type of the soil. Thus, the loading interval was taken in this experiment (0.5 kg/cm^2). Then, waiting for the stabilization of the settlement reading (the release of the load) until it becomes equal or less than (0.1 mm) within a specified time before applying the second load. This interval was used for the first ten steps (till 5 kg/cm^2), then, the interval was increased to (1 kg/cm^2) until obtaining the ultimate load where the failure of the soil occurs or reaching a specified load of (20 kg/cm^2). The cracks of the soil around the steel plate under the ultimate load is a sign of soil failure as shown in figure (15). In point number (4), the soil was very compacted after the injection of the resin, and the failure of the soil did not occur at the maximum specified load for this experiment (20 kg/cm^2). Therefore, the mentioned intervals were taken until reaching the pre-designed load for the comparison of this experiment (20 kg/cm^2), and by exceeding this value the load was increased rapidly without following the requirements of the settlement stabilization intervals (without releasing the load) until the ultimate load where the soil was failed in order to investigate the ultimate load of that point (the failure of the soil) after the injection of the resin.

(A)

(B)

Figure 15. The soil under the ultimate load and cracks shown as a sign of the soil failure. (A) failure in the reference, (B) failure in the injected plot

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Furthermore, the modulus of deformation of the soil was calculated for each step individually according to the following equation:

$$E = (1 - v2)\, Kp * K1 * D\, (\Delta P/\Delta S)$$

where E= modulus of deformation of the soil,

V = 0.3 Poisson's ratio, Kp = 1 as the test done in the pit, $K1$ = 0.79 for circular solid steel plate,

D = 27.6 cm the plate diameter, ΔP = The pressure increment, ΔS = The Settlement increment.

Table 3. The loading stages (steps) and the modulus of deformation (E) obtained from every loading stage

Number of loading stages	The range of loading, Kg/cm^2	The obtained values of the soil deformation modulus (E) at each loading stage				
		Number of the tested points				
		1	**2**	**3**	**4**	**5**
1	0.0-0.5	178.3	951.1	124.1	167.8	124.1
2	0.5-1.0	25.7	226.5	36.0	44.3	34.3
3	1.0-1.5	17.5	20.9	23.6	47.6	26.4
4	1.5-2.0	13.3	12.0	17.7	38.6	25.0
5	2.0-2.5	15.4	11.3	16.9	36.6	22.5
6	2.5-3.0	9.6	12.1	13.6	34.7	23.9
7	3.0-3.5	8.4	10.1	17.3	27.4	19.7
8	3.5-4.0	9.1	10.0	17.1	32.1	20.7
9	4.0-4.5	8.4	11.1	18.3	25.7	18.5
10	4.5-5.0	4.8	7.6	16.4	22.1	14.6
11	5.0-6.0	4.7	10.9	12.9	29.1	16.0
12	6.0-7.0	4.1	10.2	12.1	23.3	12.4
13	7.0-8.0	3.6	10.0	12.1	26.6	6.5
14	8.0-9.0	2.6	10.4	11.5	20.7	7.2
15	9.0-10.0	2.1	9.6	10.0	17.5	2.0
16	10.0-11.0	1.8	6.8	9.6	18.8	
17	11.0-12.0	1.4	3.3	9.0	16.1	
18	12.0-13.0			8.6	16.2	
19	13.0-14.0			7.4	16.7	
20	14.0-15.0			6.3	13.9	
21	15.0-16.0			7.4	13.2	
22	16.0-17.0			4.0	12.6	
23	17.0-18.0			3.0	11.5	
24	18.0-19.0			2.7	10.6	
25	19.0-20.0			1.4	9.9	

The gray color shown in table 3 is the range by which the soil deformation modulus (E) is defined as the total value of the deformation modulus is calculated by taking the average of five stable stages results. Table 4 shows the zones of plate load test and the total soil deformation modulus (E) achieved from each tested point before and after the injection of the resin.

Table 4. The zones of plate load test and the total soil deformation modulus (E) in each tested point

Zones of the test	Test number	Test depth,(m)	Deformation modulus (E), MPa	Maximum load applied, Kg/cm^2
Without injection (Reference plot)	1	0.4	10.6	12
	2	1.2	11.1	12
With injection (Injected plot)	3	0.4	16.4	20
	4	1.1	33.6	27
With injection on the resin-soil	5	1.1	22.3	10

Focusing on Figure 16 which shows the results of load-settlement before and after the injection process at depth (0.4 m) in points (1, 3). Clearly, the soil failed at load (20 kg/cm^2) after the injection of the resin (injected plot), while, the failure point of the soil occurred at a load of (12 kg/cm^2) before the injection of the resin (reference plot) and the settlement of the soil was decreased too during all loading steps. The settlement was around (75 mm) before the injection when exposed to the ultimate load (12 kg/cm^2) where the failure of the soil appeared while it decreased remarkably after the injection of the resin under the same loading and the same test conditions.

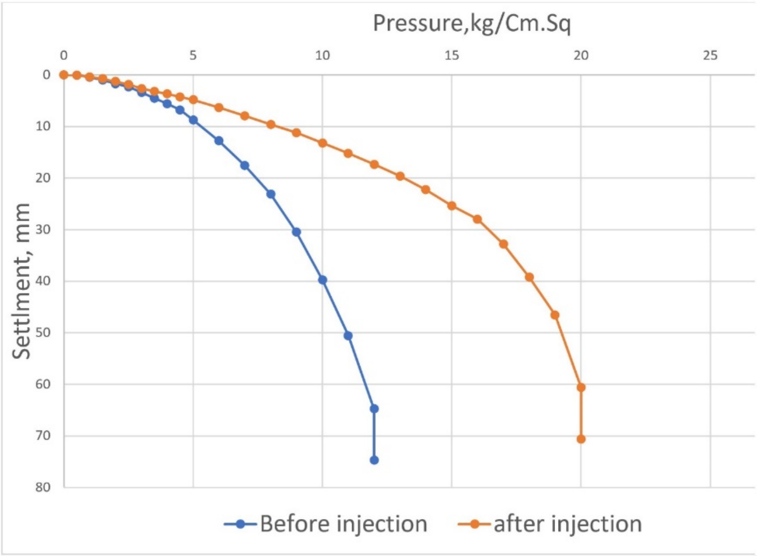

Figure 16. The graph of load-settlement in point number (1,3)) at a depth of 0.4 m before and after the injection of the resin

Furthermore, emphasizing on Figure 17 which shows the results of the load-settlement of the soil in points (2, 4) at depth (1.2, 1.1 m) respectively. Obviously, in point number (4) the soil did not fail under the designed load for this experiment as mentioned above. The soil failed under a load of (12 kg/cm^2) before the injection of the resin (reference plot), while, it exceeded the pre-designed load for the comparison of this experiment and the failure of the soil occurred at a load of (27 kg/cm^2) after the injection of the expandable resin (injected plot). Moreover, the settlement result was around (36 mm) under the failure load (12 kg/cm^2) in the reference area, while, it decreased tremendously under the same loading steps and the same test conditions in the injected area.

Results of both incorporated graphs (16, 17) prove that the soil was more compacted with a high degree of compaction and the settlement of the soil decreased at all comparison depths after the treatment of the soil using the expabdable polyurethane resin.

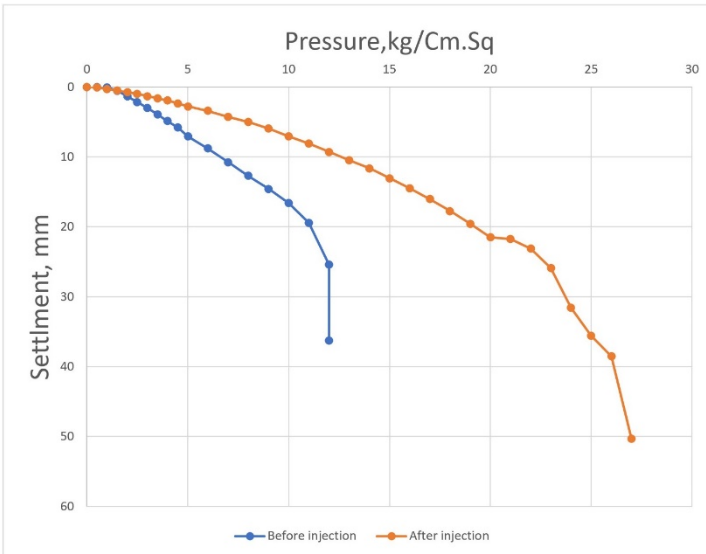

Figure 17. The results of load-settlement in points (2, 4) at a depth of (1.1,1.2 m) respectively before and after the injection of the resin

Focusing on Figure 18 which presents the results of the plate load test in point (5). The result of the soil deformation modulus was increased after the injection of the resin, and the settlement was decreased in comparison to both points (1, 2) in the reference plot, while the failure load of the soil was low (10 kg/cm^2) comparing to the failure load of the reference points. According to the author opinion, the low value of the limit pressure on this tested point (with the inclusion of the resin) is explained by the diversity of the base (soil and resin) under the steel plate. At a particular pressure, the resin which is adjacent to the steel plate is not strictly vertical, began to deform (up to rupture at bending), deforming the surrounded tested soil.

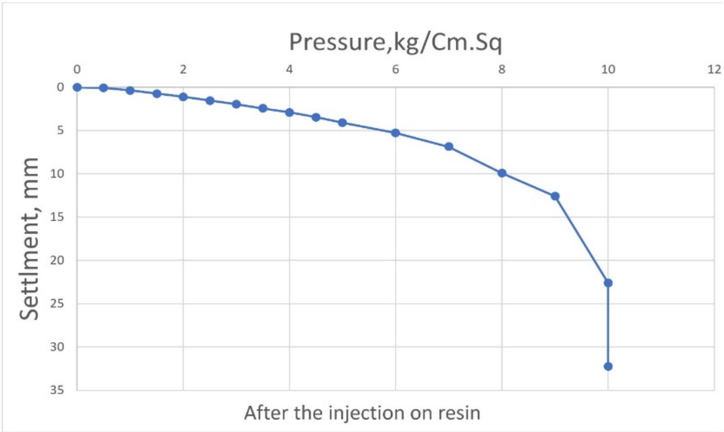

Figure 18. The results of load-settlement in point number (5) at a depth of 1.1 m

The analysis of the results of the plate load test has shown the significant influence of the injected expandable polyurethane resin on the properties of the investigated soil. Results of all graphs (16, 17, 18) improve certainly that the soil in the injected plot became more compacted comparing to the reference plot. Moreover, according to the obtained results, the settlement of the soil decreased in all tested points and at all tested depths after the injection of the resin. Furthermore, the coherent of the plate load test results in each plot at different depths and the diversity of the selected points beside the high accuracy of the selected test in this experiment prove with no doubt the improvement of the properties of the investigated soil which achieved after the injection of the expandable resin.

Moreover, the modulus of deformation of the investigated soil has been increased enormously after the injection of the resin. The effect of the resin on the density of the sandy soil is clearly noticed as the soil in the injected plot became denser in comparison to the soil in the reference plot and the bearing capacity of the investigated soil is improved as the load required for the soil failure increased within a constant area (the area of the steel plate) as illustrated in the graphs of load-settlement.

It is the author opinion that the more load applied on the soil can lead to better results because the resin propagates from the bottom moving towards the upper soil layers exerting pressure on the soil vertically and laterally facing the load of the construction from the opposite direction which leads to an outcome of the pressure applied on the soil and finally leading to strengthening the soil by increasing the cohesion. This opinion is enhanced by focusing on the results of the plate load test at depths of (1.1, 1.2 m) which show that the soil deformation modulus and the soil stabilization was improved after the injection process while less improvement noticed in the same properties at the depth (0.4 m). Moreover, the resin leads to reduce the soil void ratio and extrude the water from the soil decreasing the soil water content beside the presence of the injected resin itself (additional volume of the injected resin is added to the soil while the weight of the resin is small relatively) leading to increase the density and strengthening the soil preventing further future settlements.

4. Conclusion

The paper presents the results of full-scale experimental research carried out before and after the injection of an expandable polyurethane resin consists of two components in non-cohesive sandy soil. An outcome of the results proves the significant improvement of the investigated soil deformation modulus (E) after the injection of the resin in the injected plot while no improvement was observed in the reference plot where no soil treatment carried out. Also, the settlement of the investigated soil was decreased remarkably in the injected plot as demonstrated in the graphs of load-settlement after the injection of the resin. The failure load of the soil occurred at a load of (12 kg/cm^2) in the reference plot while the failure load was increased to be (20, 27 kg/cm^2) in the injected plot proving the increasing of the soil bearing capacity after the injection of the expandable resin. The lifting and regulating of the concrete foundation to the pre-designed level were achieved (up to 12 mm) which proves the efficiency of the injected resin and the effect of it on both applications (foundation lifting and settlement compensation besides strengthening of the injected soil). The resin propagates in baths under high pressure leading to the soil consolidation forming like continues walls of foam plates from all excavated sides and along the whole injected depth of the soil. The obtained results are valid, actual and can be applied in all similar types of non-cohesive sandy soil as the resin increases the cohesion of the treated sand. Furthermore, the outcome of the forces exerted on the soil (load-resin forces) in opposite directions beside the lateral pressure which applies on the soil during the injection process, and the additional volume of the injected resin lead to increase the mass density of the soil (soil compaction). Thus, the soil injection technology using an expandable polyurethane resin might also be applied almost in all soil types except the rocks according to the author opinion and as explained in this article. The injection process is simple and efficient with less equipment and labor required in comparison to other techniques used in this field and with no inherent to the soil ecology and the soil groundwater level.

5. Acknowledgment

The author would like to show gratitude to the company MC-Bauchemie-Russia for funding the experiment and for the great support through the whole experiment especially to Evgenii N. Zakharin, for the significant effort in the injection process and in all the experiment.

Special thanks to Alexey Vladimirovich Ulybin, head manager of the company “OZIS-Venture” for the contribution in the field plate load test and in the whole experiment.

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Mohanad Muayad Sabri,*
+7(905)264-53-57; mohanad.m.sabri@gmail.com

Konstantin Shashkin,
+7(921)916-66-54; cshashkin@yandex.ru

Моханад Муаяд Сабри,*
+7(905)264-53-57;
эл. почта: mohanad.m.sabri@gmail.com

Константин Георгиевич Шашкин,
+7(921)916-66-54;
эл. почта: cshashkin@yandex.ru

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