Strength of chemically grouted micro pile model in Calcareous sand

M. Hassanlourad
Islamic Azad University- Zanjan Branch

H. Salehzadeh & H. Shahnazari
Iran University of Science and Technology

ABSTRACT

In this paper, at first the improvement susceptibility of calcareous sand is investigated using grouting method. The calcareous sand was obtained from Kish Island, located in Persian Gulf in south of Iran. The grouting process of sand was conducted using injection of a sodium silicate grout. It was observed that the maximum unconfined compressive strength, initial tangent modulus and failure strain of grouted samples are obtained in water/sodium silicate ratio of 0.5. Based on unconfined compressive test results, a model of micro pile was constructed, grouted and loaded axially. Results show that the sodium silicate grout increases the compression bearing capacity of micro pile model. The bearing capacity of grouted model of micro piles using a relatively moderate grout in loose sand is about 35 to 5.4 times of the un-grouted one located in loose and dense soil respectively. Also, the grouted model micro pile bearing increment is proportional to unconfined compressive strength of the grouted samples.

RÉSUMÉ

Dans cette recherche, d'abord l'augmentation de la pénétrabilité de sable à chaux en utilisant la méthode de l'injection du mortier liquide est étudiée. Le sable calcaire provient de l'île Kish, située au Golfe persique, sud de l'Iran. Le processus de l'injection de sable s'effectue avec l'injection du mortier liquide du silicate de sodium. Les constatations ont prouvé que le maximum de la résistance de la pression illimitée, module préliminaire tangent et la fêlure des modèles injectés est atteint avec la proportion de 0.5 de silicate de sodium/eau. Selon les résultats du teste de la pression illimitée, un modèle de micro bougie a été construit, le mortier liquide y est injecté et chargé. Selon les résultats, le mortier liquide du silicate de sodium augmente la résistance du modèle de micro bougie. La capacité de la résistance du modèle de mortier de micro bougie en utilisant une injection relativement diluée dans le sable mou respectivement est 35 et 5.4 fois plus élevé que le modèle non injecté du mortier liquide dans le sol mou et dense. De même, l'augmentation de la résistance du micro bougie du modèle injecté est en proportion avec la résistance de la pression illimitée des modèles dans lesquels le mortier liquide est injecté.

Keywords : Calcareous sand, crushing, chemically grout, unconfined compressive test, micro pile model

1 INTRODUCTION

Calcareous sands are different from noncalcareous sands considering of both source of generation and reaction against loads from structures such as driving piles and so on. Calcareous sands with biological source are very crushable, especially against shear stresses. During pile driving in loose biological calcareous sands, large dynamic shear stresses strains crush the sand particles that cause the fall of skin friction resistance of pile. Often, calcareous sands are cemented naturally. Degree of cementation could be very weak to very strong. Driven piles in calcareous sands may have only a small fraction of the capacity of driven piles in noncalcareous sands (Murff 1987). It has been shown that piles driven in to weakly cemented and compressible carbonate soils mobilize as low as %15 of the capacity predicted by conventional methods for siliceous soils (API, 2000). According to the reported documents, calcareous soils are different in other conditions from noncalcareous soils, such as shallow foundation bearing capacity, deformation settlement and so on (ARGEMA, 1994).

Improvement of calcareous soils, with the aim of reduction the grain or cement crushing effects on the driven pile bearing capacity has been begun in recent years. Grouted pile is an option to overcome crushing effects on pile skin friction resistance (Lee and Poulos 1991, Carter et all 1991).

In grouted piles and caste in place piles, grout penetrates to the between sand particles and creates cohesion and unifies them. In fine sand and silt, injection of cements grout such as Portland cement grout is very hard or sometime impossible due to its coarse grains. Micro fine cements or chemicall grouts are good options to overcome this problem.

In this paper, at first, improvement susceptibility of carbonate sand is investigated using unconfined compressive tests on grouted samples. Samples were prepared using different initial relative densities. Then a model micro pile is grouted based on results of the unconfined compressive tests. Sodium silicate was used for injection in to the sand.

2 PHYSICAL PROPERTIES OF SAND

The sand for this research was obtained from Kish Island, located in north of Persian Gulf in south of Iran. It should be noted that some parts of Persian Gulf and its Islands have covered with calcareous soils. To determine of calcareous portion of the selected sand, carbonate content test were performed based on BS-1377. The SEM image and particle size distribution of the sand are shown in Figures 1 and 2 respectively. As it can be seen in Figure 1, some of sand particles are skeletal with porous shapes. Also Figure 2 shows the used sand is a relative medium well grained. In this figure, the particle size distribution of the sand after a triaxial test is shown. It can be seen that particles have experienced some breakage during shear loading. Other properties such as maximum and minimum void ratio and specific gravity of sand

Proceedings of the 17th International Conference on Soil Mechanics and Geotechnical Engineering
M. Hamza et al. (Eds.)

doi:10.3233/978-1-60750-031-5-801

particles are summarized in Table 1. Calcium carbonate percent of sand is about 95. This shows that a high percent of sand is calcium carbonate.

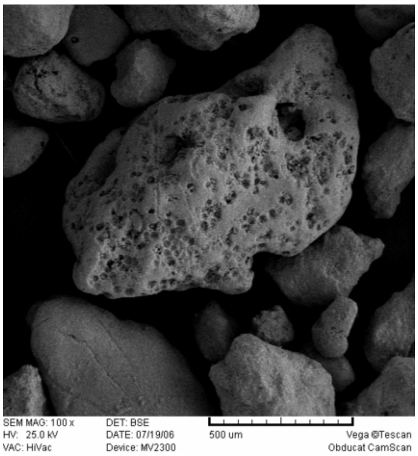

Figure 1. The microscopic image of the studied sand

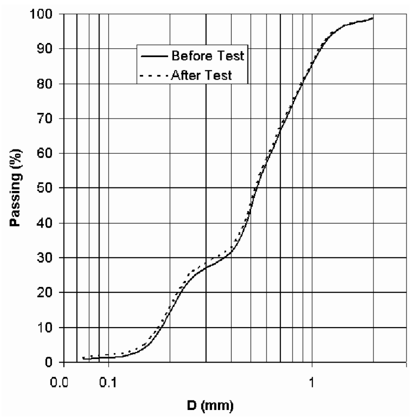

Figure 2. Particle size distribution of the studied sand

Table 1. Physical properties of sand

Gs	e_{max}	e_{min}	CaCo3 (%)
2.9	0.72	0.51	95

3 GROUT

In this study, a chemically based grout named sodium silicate was used. For this, different combinations of sodium silicate (Na2O2SiO2) and water were used as grout. To start the reaction between sodium silicate and water, an additive is necessary. Formamide (HCONH2) was used as an additive for this porpuse. In orther to accelerate and control of reactions rate, there is need other additive. Sodium aluminate (NaAlO2) was used for this porpuse. The different combinations of the mentioned materials used in this research are listed in Table 2.

This grout is a known chemically gout that is used for strength improvement and water cutoff. This system has been successfully used for solidification of materials below the water table. It is dimensionally stable to temperature, permanent under freezing and thawing, resistant to acidity, alkalinity, salinity and bacteria. It is non-corrosive to metals. It has low damage to environment and high groutability potential (EM-1110-1-3500, 1995; Alaa and Cumaraswamy, 1998, 1999).

Table 2. Combinations of the used grout

W/S	From Amid (%)	Sodium Aluminate (%)
0.33-3.33	2-7	0.58-1.5

4 GROUTING SET-UP

For grout of samples and model of micro pile in laboratory, an apparatus was designed and constructed. Figure 3 shows the apparatus and set up of grouting. Grouting process is performed by applying of air pressure on top of the grout in a reservoir. The sample moulds, pipes and reservoir were constructed from a bright Plax glass, so that it is possible to see the grouting process.

Samples were prepared with different relative densities (Dr=20, 50 and 80 percent) by dry deposition method and then grouted. The soil including model micropile was prepared in loose state having Dr=%20. After grouting, the samples and model were maintained for 7, 14 and 30 days by keeping of grouted water content inside of plastic membranes. Figure 4 illustrates the grouted sand SEM image. As shown in this figure, sand grains have been stick to each other by grout.

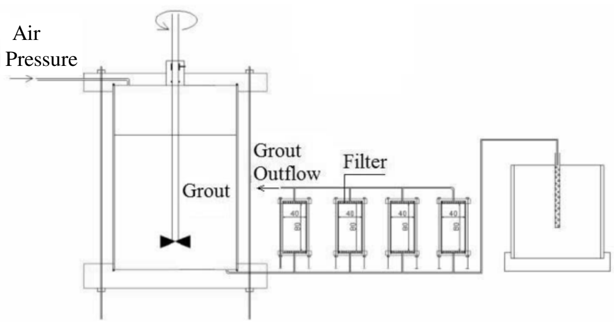

Figure 3. Designed and used grouting set up; (a) grouting of samples and (b) grouting of model micro pile

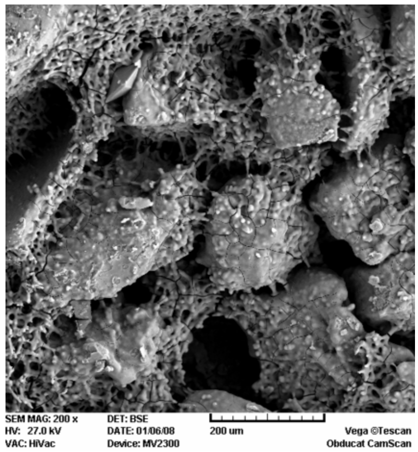

Figure 4: The microscopic image of the groutedsand

5 UNCONFINED COMPRESSIVE TESTS

Prepared sand samples were grouted using different combinations of grout according to the Table 2. Unconfined compressive strength of grouted samples was determined after 14 days curing time. Different water/sodium silicate ratio, content of additives and initial relative densities of samples on unconfined compressive strength and initial tangent modulus were investigated. The results of unconfined compressive tests are shown in Figures 5 and 6. In Figure 5, the envelope of unconfined compressive strength, initial tangent modulus and failure strain are illustrated. As shown in this Figure, decreasing the water/sodium silicate ratios, increases the mentioned three parameters. However in W/S=0.5, the mentioned process is inversed. In other words, this ratio is a kind of optimum point and after that; reducing the W/S ratio reduces all the mentioned parameters.

As shown in Figure 6, there is apparently a linear relation between the unconfined compressive strength and failure strain as bellow:

$$q_u = 991\varepsilon_u - 1540 \quad (1)$$

Therefore it seams that the calcareous sands have a good compatibility with sodium silicate grout and the used additives. Using this grout, the 14 days unconfined compressive strength and initial tangent modulus have been increased up to 4MPa to 150MPa respectively.

6 EFFECT OF INITIAL RELATIVE DENSITY

Samples were prepared with different initial relative densities and then grouted. It was seen that increasing the initial relative density increases the unconfined compressive strength and initial tangent modulus and reduces the failure strain. It was observed that the effect of initial relative density on unconfined compressive strength is reduced by reducing the W/S ratio (Figure 7).

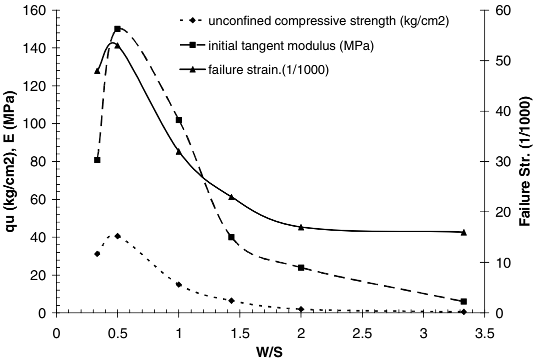

Figure 5. Unconfined compressive strength, initial tangent modulus and failure strain envelope against water/ sodium silicate ratio.

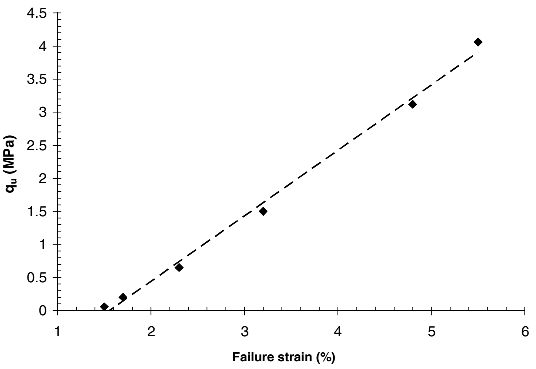

Figure 6. The relationship between unconfined compressive strength and failure strain of grouted sand

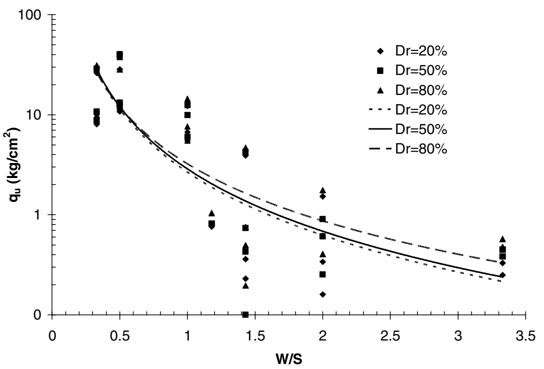

Figure 7. Unconfined compressive strength versus water/sodium silicate ratio

7 MICRO PILE MODEL

A model of micro pile was constructed with porous skin surface. Diameter and embedded length of the model were 8mm and 100mm respectively. Initial relative density of sand containing the model of micro pile was selected as 20, 50 and %80. The thickness of the sand layer under the model of micro pile was considered as 5cm. The models of micro piles were loaded axially. Loading set up is shown in Figure 8. The loading process was performed with displacement control. Load-displacement behavior of the micro pile model is illustrated in Figure 9. As it can be seen in Figure 9, the bearing capacity of the model of micro pile is increased with increasing the sand initial relative density.

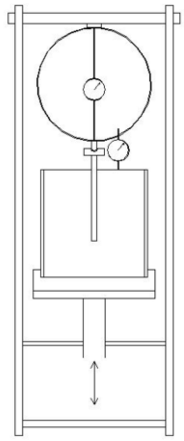

Figure 8. Loading set up of model micro pile

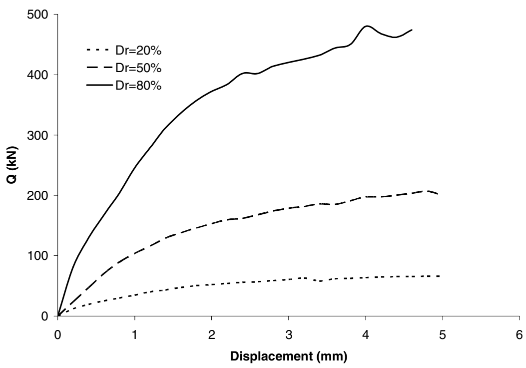

Figure 9. Load-displacement behavior of the model micro pile in sand with different initial relative density

8 MICRO PILE MODEL IN GROUTED SAND

Effect of grout on bearing capacity was investigated by grouting of the micro pile model located in plain and grouted sand. Relative density of plain sand was selected as %20 and then was grouted using a relatively moderate grout. The combination of grout was chosen as: W/S=0.5, Form-amid=%5 and Sodium-silicate=%1.

The unconfined compressive stress-strain behavior of the grouted sand is shown in Figure 10. As shown in this Figure, the 30, 14 and 7 days unconfined compressive strength of the grouted sand is about 1010, 1004 and 520kPa respectively. It is seen that increasing of curing time increases the unconfined compressive strength up to 14 days. After that, the unconfined compressive strength is not increased, however, the grouted samples become brittle and fail in a small axial strain.

Load-displacement graph of the grouted micro pile model in grouted sand is demonstrated in Figure 11. Models of micro piles were loaded like un-grouted models with strain rate of 0.7%mm/min. As shown in Figure 11, the 30, 14 and 7 days compression bearing capacity of the grouted model micro pile is about 2504, 2385 and 1914kPa respectively. Like unconfined compressive tests, the bearing capacity of the micro pile model in grouted sand is increased with curing time up to 30. However, the load-displacement behavior becomes brittle and failure happens in a small displacement (lower than 1mm).

As shown in Figure 12, the bearing capacity of the grouted micro pile model in loose sand is about 35 and 5.4 times of the un-grouted one with relative densities of %20 and %80 respectively.

In grouted model of micro pile, ultimate bearing capacity is developed in displacement of 4, 2.2 and 0.8mm in curing times of 7, 14 and 30 days respectively. In other words, like unconfined compression stress-strain behavior, increasing the grout strength and curing time make the load-displacement behavior of the grouted micro pile model brittle.

However, as the results show, chemically grouted micro pile model is a good option in calcareous sands with crushable particles. Using this option, the reduction effect of sand particles breakage on driven piles bearing capacity is compensated.

9 CONCLUSIONS

Based on the unconfined compressive tests of a grouted carbonate sand and un-grouted and grouted micro piles models using sodium silicate grout, it was found out that:

1. Different water/sodium silicate ratio, content of additives and initial relative densities of soil result in various unconfined compressive strength and initial tangent modulus. Reducing of W/S ratio to 0.5 increases the unconfined compressive strength and initial tangent modulus. Lower than the ratio of W/S=0.5, the mentioned process is turned.
2. Increasing the grouted sand initial relative density increases the unconfined compressive strength and initial tangent modulus and reduces the failure strain. However, reduction of the W/S ratio decreases the effect of initial relative density on the unconfined compressive strength.
3. Chemically grouted micro pile model is a suitable option as a deep foundation in calcareous sands. So that, it compensates the sand particle crushing and even cement destruction effects on driven piles bearing capacity.
4. Investigations revealed that the bearing capacity of grouted micro pile model in loose sand is about 35 to 5.4 times of the un-grouted one in loose and dense states respectively. Also, the grouted model micro pile bearing increment is proportional to unconfined compressive strength of the grouted samples.

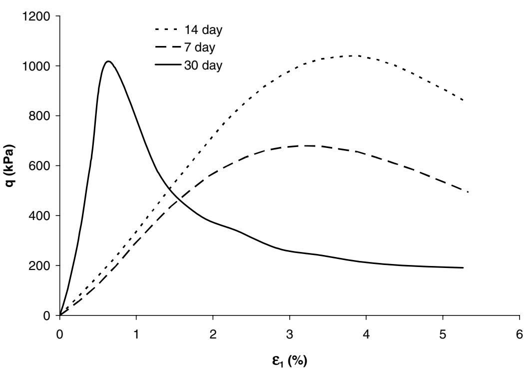

Figure 10. Unconfined compressive stress-strain of the grouted sand

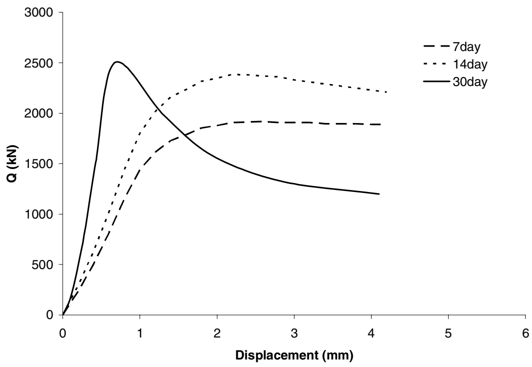

Figure 11. Load-displacement behavior of micro pile model in grouted sand

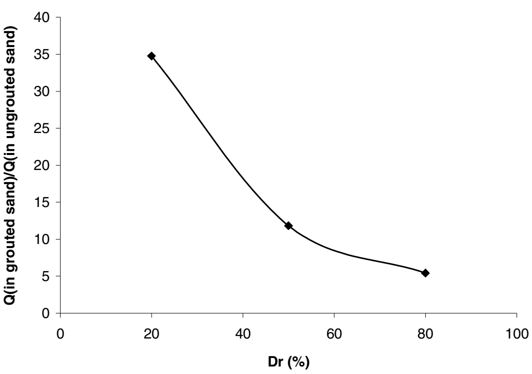

Figure 12. Bearing capacity of the micro pile model in grouted sand to un-grouted sand versus relative density

REFERENCES

API. 2000. *Recommended practice for planning, designing and constructing fixed offshore platforms*. American Petroleum Institute, API RP-2A.

ARMEMA-CLAROM. 1994. *Design guides for offshore structures-foundations in carbonate soils*. Ed. Le Tirant and Nauroy, 204 pages.

Ata, A. & Vipulanandan, C. 1998. Cohesive and adhesive properties of silicate grout on grouted-sand behavior. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 124(1): 38-44.

Ata, A. & Vipulanandan, C. 1999. Factors affecting mechanical and creep properties of silicate-grouted sands. Journal of Geotechnical and Geoenvironmental Engineering, 125: 868-876.

Carter, J.P. Airey, D.W. & Fahey, M. 1999. A review of laboratory testing of calcareous soils. Proceedings of the Second International Conference on Engineering for Calcareous Sediments, Bahrain, 21-24 February.

Hassanlourad, M. 2008. Thriaxial shear behavior of non-cemented and chemically grouted carbonate sands, Ph.D. Thesis, Iran University of science and Technology, Iran.

Lee, C.Y. & Poulos. 1991. Tests on model instrumented grouted piles in offshore calcareous soil. Journal of Geotechnical Engineering, 117: 1738-1753.

Murf, J.D. 1987. Pile capacity in calcareous sand: State-of-the-Art. Journal of Geotechnical Engineering, 113: 490-507.

US Army Corps of Engineers. 1995. *Chemical grouting*. EM 1110-1-3500.