International Journal of Engineering

Intrusion of Geomesh in Gypseous Soil Under Single Footing

W. A. Zakaria*

Engineering College, Civil Department, University of Diyala, Iraq

PAPER INFO

ABSTRACT

Methods to improve bearing capacity of footing resting of collapsing soil can, in fact, take two approaches, improving soil strength properties and intrusion of reinforcing sorces into soil. The footing is modeled by a square steel plate 0.1 by 0.1 m. The footing is loaded as to have a stress of 40 kPa and settlement is receded in dry and in soaking conditions. Two depths of the geo-mesh reinforcement are used, one B (B is width of footing) and 0.5B. For one B depth, three different square sizes of geo-mesh are used, 4B, 6B, and 8B. For the reinforcement depth of 0.5B the three sizes of the geo-mesh used are, 3.5B, 5.5B, and, 7.5B. Results reveal that the best improvement obtained is the case of square geo-mesh width of 7.5B and located at depth of B/2 under footing, with an improvement in terms of collapse settlement of 35%, and a settlement reduction in dry condition of 50%. The least improvement is the case of square geo-mesh with width of 4B and depth of one B, and it was really negligible, about 4% decrease in collapse settlement. Other cases varied between the two mentioned ratios. For findings of study, author recommends not to use geomesh size less than size of footing and not to place it in a depth more than half footing width. As such, in a whole, the effectiveness of geomesh in reducing the settlement of collapsing soil is obvious if used in proper way.

doi: *10.5829/ije.2020.33.09c.05*

1. INTRODUCTION

The concept of reinforcing waek soil is rather old and had come into effect to touch the collapsing soil. Gemesh or geogrid had been well perfected into use here in this country and abroad. Problematic soils are widely exist in the dry surface of the global. In this type of soil, the soil grains are attached by bridges of salts acting as a cementing or bonding material, as the case of the gypseous soil [1, 2]. The salts bridging soil exists in countries such as China, Australia, and also in Europe [3]. Some Arab Countries are also include in the list, such as, Iraq, Iran, Algeria, Syria, and, Bahrain. In these places the gypsum may range between 10-70%. The fundamental property of such soils is that it can bear large loads when dry and run out in large reduction in volume, without additional stress, when water finds its way to the soil grains and by dissolution breaking out the bonding bridges of gypsum [2]. It is worth to mention that gypsum dissolves at a rate of 2.6 gram per liter at 25°C and the rate of dissolution increases by three-fold as the temperature changes from 5 to 23°C [4]. According to literature [5] mainly water can get to soil from top by raining, for instance, or it can penetrate from bottom as there is a rise in water table. The methods for improving the gypseous soil can take three aspects; the first is deal with the soil without the intrusion of any type of materials or reinforcement into soil, such as using heavy compaction or even deep detonation using small and safe charges. The second aspect is to introduce effective stabilizing materials or some types of reinforcement [6]. The last aspect is to carry out a soil replacement. Each method of the three aspects has its own limitations and condition for use. The use of the geo-grid reinforcement has been in progress for many decades in normal soil. It was used not only in soil foundation engineering, but also in highways and so on. The reinforcement of soil has a long tradition. Already 3500 years ago the Sumerians

*Corresponding Author Email: *waadzakariya@yahoo.com* (W. A. Zakaria)

under King Kurigalzu erected the temple of Aqar Quf in Mesopotamia near Bagdad/ Iraq. They used reed mats to stabilize the foundations and the brick walls [7]. The main function of geo-grids is reinforcement. Depending on the application under consideration, reinforcement could either be uniaxial (strength in one direction) or biaxial (strength in all directions). They are graded by a number of performance properties for instance tensile strength, junction efficiency, and so on. The best depth of first geogrid layer in granular soil was found at depth of 0.15 from thickness and from height of soil layer [8]. On the other hand, that the permanent strain soil reinforced geogrid samples have decreased by 44% compared to that in unreinforced soil samples [9].

According to karim et al. [10], studied the effect of cyclic loading on foundations for different engineering structures constructed on soft ground. They improved soil by fly ash, geogrid and both. They demontrated that settlement of footing resting on treated models with fly ash and geogrid layers performed better than other improving techniques. Using PLAXIS FE program, the study conducted by Emeka et al. [11] recommended of 30%of existing soil should be replaced by mixture of lateritic soil and quarry dust. They stated that it is advisable to replace some quantities of problematic soil with mixture stated for purposes of soil improvement. The study conducted by Al-Amli et al. [12] carried out a non-linear analysis for reinforced concrete members on saturated and unsaturated soil using the FE ABAQUS program. They showed that plastic strains in reinforced concrete members in unsaturated soil was about 54, 58, 53, and 52% when geogrid ratios are (without geogrid 60, 40, 20%) respectively with some value of applied stress. It is worth to mention that size and depth of empedment of geogrids had not been mathematically formulated and standarized, and design formula did not flaot to surface yet. Additional knowledge to such subject is still sticking to the state-of-the-art review.

2. METHOD

2. 1. Properties of Soil Used   The soil used in this study is totally brought by a pickup car from the western desert, Al-Anbar governorate, about 200 km west of the capital Baghdad. Al-Anbar governorate, in addition to Salahuldeen north of Baghdad, is quit famous with its soil as being rich in gypsum content, (as such, those places have great issues in their engineering facilities). The mass of soil is brought from a depth of 0.60 m below the natural ground level and packed into double nylon bags and transported to the laboratory in Baghdad. It is believed that the top soil does not represents a homogeneous soil as it was much contaminated with other materials, as such, a depth of 0.6 m is found adequate for study. These bags are dumped together as a mass on to a large sheet of thick nylon, remixed

thoroughly as to get homogeneous soil, packed again into nylon bags, and stored in place in concern ready to be used when needed. To determine the gypsum content in soil, four specimens are taken from different random bags (after thorough mixing). Another three specimens are tested for collapsibility test using the consolidation apparatus (one dimensional compression) and following the Knight method (namely, compressing soil in dry state until 200 kPa then completing in saturated state) [13]. And finally two specimens are tested for shear strength using the direct shear device. The two collapsibility tests using the Knight Method reveal collapse potential of 7.5 and 8%, which is rather high. On the other hand, shear strength for the two tests show an angle of friction of 32 and 34° tested in soaked state, and 34 and 36° tested in dry basis. According to literature [14], there was a little decrease in friction angle of gypseous soil tested using the shear box as soil is tested in dry and soaked states. Also, similar results are reached regerding soaked and unsoaked friction angle of gypseous soil by other authors [15, 16].

One specific gravity test using the white spirit is conducted, and Gs is 2.39. Ordinary Proctor test show that the maximum Proctor dry density (unit weight more precisely) is 15.98 kN/m³. The maximum and minimum unit weight are 16.32, 11.81 kN/m³, respectively. The last tests are conducted once per each test. Table 1 shows summary of the average test results.

A primitive look on Table 1 shows that soil has high and dangerous collapse potential. This is because soil has low specific gravity, maximum dry unit weight, and high gypsum content, and collapse potential. As stated before this type of soil has high strength when in dry condition and experiences high immediate settlement upon wetting.

2. 2. Laboratory Testing Model   The testing model is totally manufactured by author using components available in local market in Baghdad, the setup is quite simple and has no complicated parts. It is shown schematically in Figure 1. Most of the parts are made of steel and the major components are described for convenience.

TABLE 1. Summary of soil test results

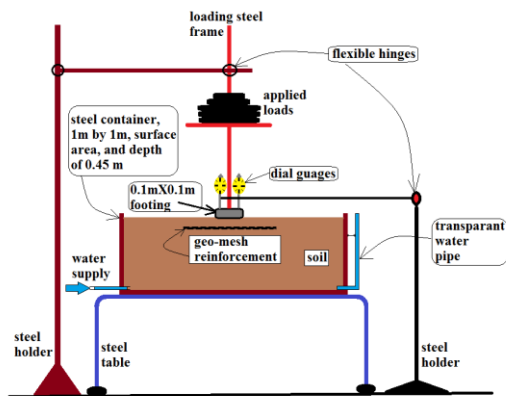| Test	Result
Gypsum content	66 %
Shear strength (Ave.)	33° soaked, 35° dry
Collapse potential	8%
Soil type	Sandy
Specific gravity	2.351
Maximum Proctor dry unit weight	15.98 kN/m³
Maximum dry unit weight	16.32 kN/m³
Minimum dry unit weight	11.81 kN/m³

Figure 1. Setup used in this study

The soil is placed into the steel container, densified in layers of 100 mm each using portable-electrical compactor. Also, it is intended to place the geo-mesh (or geo-grid) into two depth positions. The first is embedded at depth of one width dimension of footing (B) beneath the bottom surface of footing, the second is at depth of embedment of (B/2) below footing level. And since the footing is placed directly on soil surface, the geo-grid is now understood to be embeded at depths of B and (B/2) below soil surface. The soil is continued to be compacted easily layer after layer until the level of placement of the grid reinforcement is reached. The geo-grid is placed, (in a specified lateral dimensions for each test), and soil is continued to be compacted until the surface of soil, and that is a total depth of soil equals 0.5 m. At each specified depth of the geo-mesh reinforcement, three dimensions (sizes) of the grid are used, please care for Figure 2 for details.

Three extensions are used for each geo-mesh depth, namely, 1B, 2B, and 3B. Table 2 shows the relationship between the extensions of the geo-mesh, their depths, and the total lateral length of the grid.
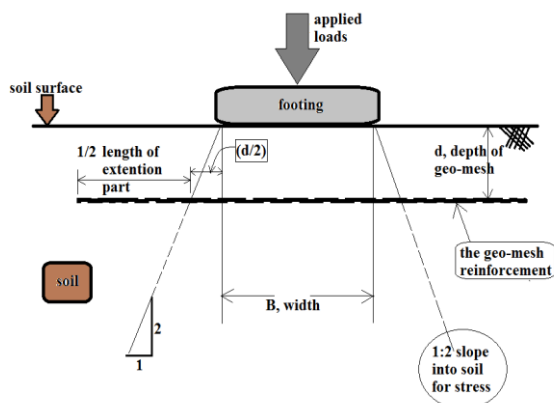
TABLE 2. Depth of geo-mesh versus extension and its size

Extension of geo-mesh	Depth of geo-mesh	Total length (size) of the mesh
1B	B**	4B by 4B
2B	B	6B by 6B
3B	B	8B by 8B
1B	B/2	3.5B by 3.5B
2B	B/2	5.5B by 5.5B
3B	B/2	7.5B by 7.5B

**B is the width of the square footing = 100 mm

The basic idea of this research is to investigate the effect of depth and size of the geo-mesh reinforcement in getting a notable improvement in reducing the collapse potential of the gypseous soil. It worth to mention that one type of geo-mesh reinforcement is used for the totality of the study as author believes that changing the geometry of the grid will have some changes on the results.

2. 4. Testing Method   The testing procedure for the laboratory model can be listed through the following points.

1. After completing the job of compacting the soil in tank, carefully levelling off the soil surface, the footing is placed onto soil and the two dial gauges are positioned and set to zero.
2. Now the soil is in its air-dried condition. Loads are applied gradually onto the loading steel frame up to a stress of 40 kPa. The settlement recording is initiated with time until no further depression in footing is taking place. The gypseous soil has the property of owning a high strength when dry, thus little footing settlement is expected in this stage. The water inlet valve is opened to let soil to be saturated. The soaking stage is now just started and the settlement of footing begins to increase. This settlement is recorded until the dial readings runs out to a negligible settlement. This takes about 3 days. It is worth to mention that no leaching process is carried out and only soaking process is conducted. The water level is monitored through a transparent pipe installed for that purpose in the container. When water level reaches soil surface, water inlet valve is closed off.
3. Upon ending of test, soil in container is removed and not be used again in any test, that is, always new soil is used in each test.
4. Very low head of water is utilized to saturate the soil as to avoid soil boiling condition, since water inlet is located in the bottom on the container.
5. The dial readings is recorded for the first ten hours, in increments of one reading per hour. Then after the settlement reading is recorded for each next 24

Figure 2. Schematic diagram for footing and location of geomesh reinforcement

hours. It has been observed that at the initial stages of soaking, dial readings changes considerably with time, and only experience little changes then after.

6. In case of footing rotation, the average dial readings is recorded. On the other hand, if large differential settlement (rotation of footing) takes place then the whole test is stopped, ignored, and repeated once again with new soil.

7. For connivance, the test in which no geo-grid is used, has been repeated twice and the average settlement is taken into account. This test is the reference test for measuring any improvement in the soil, as it will be compared with it. Thus the reference test is considered important.

3. RESULTS AND DISCUSSION

Figures 3 to 8 show the cases plotted individually, in each figure two curves are plotted, one is for the unreinforced (untreated) soil, and the other belongs to the case of geo-mesh reinforcement in concern. The curve for the untreated soil is inserted in each figure for convenience as a measure for improvement. In each of the forgoing figures, the settlement which is presented as a ratio of s/B (settlement/width of footing) is plotted versus Time in minutes and in logarithmic scale. A primitive look on the mentioned figures indicates that the general trend of behavior is quite similar for all tests. The settlements regarding the initial (pre-soaked) stage are quite small compared to the total settlement. This stage lasted for as hour at most for all cases. The case of (3B, B/2) is exceptional, and by (3B, B/2) it is meant and extension of geo-mesh reinforcement equal to 3B and located at depth of B/2 under soil surface. Again, the case (3B, B/2) show the least initial settlement. It is half the settlement recorded compared to the other cases. In other words, extending the geo-mesh for 3B seems to be effective in reducing the dry stage of loading by about 50%. The other cases do not show such significant differences in any reduction of initial settlement. After one hour of dry loading, the soaking stage comes after by allowing water to preclude and saturate the gypseous soil directed from bottom to top of soil. The water rise is monitored in the container via a transparent pipe as mentioned earlier. As can be seen in all figures, there is a drastic increase in the settlement, namely the collapse settlement, for all cases. The best case for obtaining a reduction in the settlement is the case of (3B, B/2). The percentages of improvement recorded with respect the untreated soil is show in Table 5. These percentages are based on the final settlement measured (after 72 hours) for the case in concern divided on that for the untreated soil. There is a reduction in settlement by 35% and by settlement it is meant the collapse settlement. In foundation engineering terminology, it is considered good improvement. The next in improvement comes the case of (2B, 0.5B), which

was successful in reducing the collapse potential by a ratio of 16%. The case of (B, B), which has an improvement ration of 4% only, is regarded as insignificant and ineffective in reducing the collapse potential of a footing. The use of such size and death of reinforcement is immaterial. Also, the two curves in Figure 8 seems to converge in the initial stages of test and in its final. The curves convergence of untreated soil and the reinforced soil, indicates that the type of reinforcement in concern is ineffective in reducing the collapse potential and has no impact in real engineering live.The case of (3B, B), shown in Figure 6, has improvement ratio of 10% which is rather a low number. It can be realized from Table 3 that decreasing the geo-grid by 0.5B reduced the settlement improvement ratio from 35 to 10%. This indicates that large amount of the collapse settlement is actually taking place in the zone beneath the footing and the improvement ratio for all cases of depth B are less than all cases of depth 0.5B, although the size of the mesh is little larger. Similar results are noticed by Hassan [17] on the sabkha soil (salty) when using geomesh. This insures the forgoing conclusion. Also extending the geo mesh increases the improvement (which is physically understood) and the extension of 1B is not effective in reducing the collapse settlement. Now referring to Figures 3 to 8, it can be seen that the curve of case 3B, 0.5B is in a higher position than the others, meaning that the collapse settlement is always and all the time is well below the other cases. All curves are rather smooth and do not intersect of overlap each other (in general), except the case of (1B, B/2). There is

TABLE 3. Percentage of collapse potential improvement with respect to the untreated soil

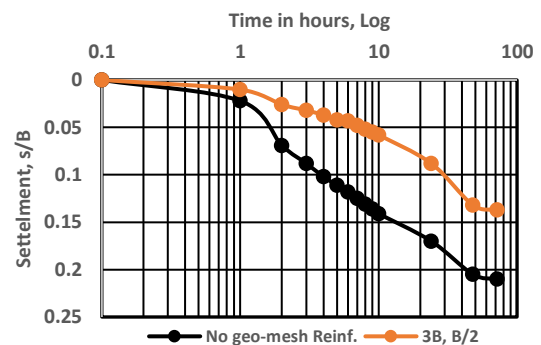| Length of geo-grid Reinforcement	d = Depth of geo-grid Reinforcement	
	B/2 (%)	B (%)
3B	35	10
2B	16	7.5
1B	7	3

Figure 3. Settlement in terms of s/B versus time in logarithmic scale, for (3B, B/2)
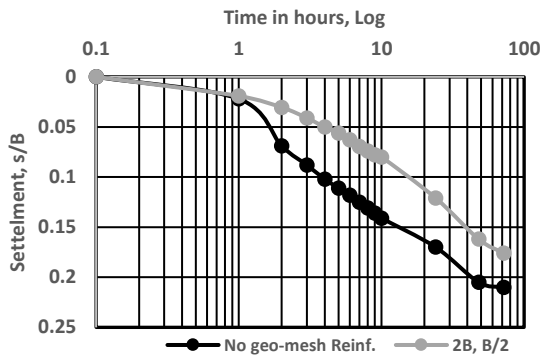
Figure 4. Settlement in terms of s/B versus time in logarithmic scale, for (2B, B/2)
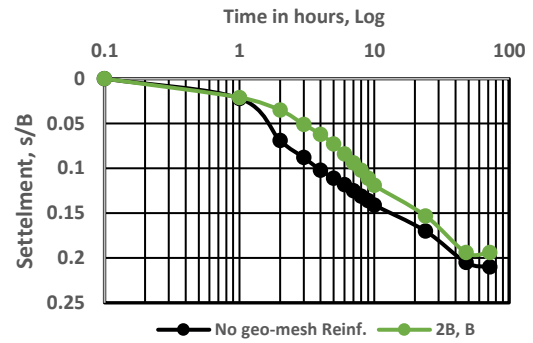

Figure 7. Settlement in terms of s/B versus time in logarithmic scale, for (2B, B)
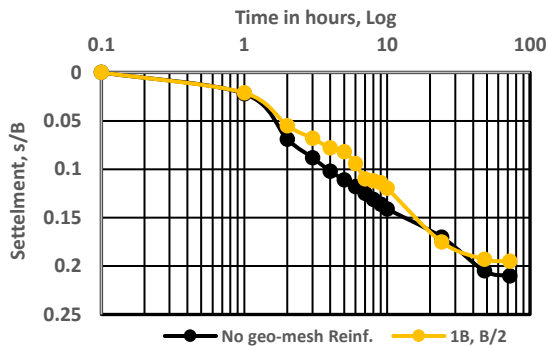

Figure 5. Settlement in terms of s/B versus time in logarithmic scale, for (1B, B/2)
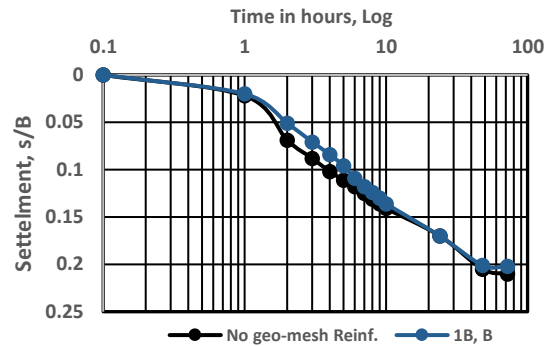

Figure 8. Settlement in terms of s/B versus time in logarithmic scale, for (1B, B)
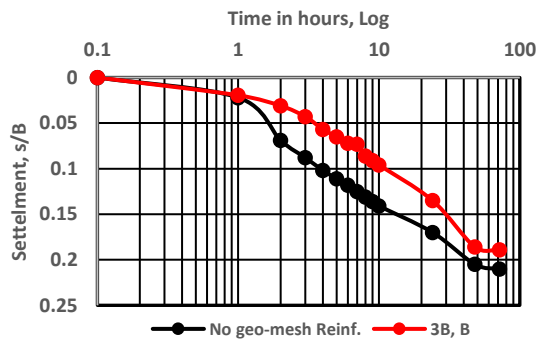

Figure 6. Settlement in terms of s/B versus time in logarithmic scale, for (3B, B)

a fluctuation in this curve as it intersects other curves and not in a trend of harmony like the other cases. Author believes that this is attributed to (maybe) experimentation error as it is the only one that deviates from the general trend of the other cases. So as stated earlier, very small initial settlement is recorded as a whole when soil is almost dry (and as curves in figures show) and a sharp increase in settlement is mesured uopn wetting, it is worth mentioning that quit similar resluts were obrained by Ibrahim and Zakaria [18].

4. CONCLUSIONS

Conclusions of this study are summarized as follows:
1. The settlement of footing in dry gypseous soil is quite small, and all cases of reinforcement and the case of untreated soil experience almost the same initial settlement except the cace of (3B, 0.5B), in which footing show about half the depression experienced by the other cases.
2. The best collapse settlement improvement ratios recorded is for the case of (3B, 0.5B) and it is 35%. The improvement is measured with respect to settlement of the untreated soil. The worst case for improvement ratio measured is the case (1B, B), with only 4%. This is an immaterial improvement ratio and thus this detail of reinforcing the gypseous soil should not be followed off.
3. Next in improvement ratio is the case (2B, 0.5B) with a value of 16%. The other types of reinforcements have improvement ratios confined between 4-16%.
4. All reinforcement cases for the depth of 0.5B show higher improvement ratios than the similar cases for depth one B, indicating that the majority of collapse potential is taking place in the zone of soil almost directly beneath footing. In addition to that the sizes of the geo-mesh in the first case are smaller than that for the latters.

5. All settlement-time curves plotted show similar trend of behavior and settlement almost seized after 72 hours of the start of tests.

6. The settlement in soaking stage is very much higher (considered drastic) compared to the dry stage. This is physically normal since gypseous soil has high strength properties when dry, loses bond and collapse when saturated, or even wetted.

5. REFERENCES

1. Al-Jumaily, F., "Gypsum and its mechanical effect on the engineering properties of soil", *Journal of Arab Universities*, Vol. 1, (1994), 40-50.

2. Clemence, S.P. and Finbarr, A.O., "Design considerations for collapsible soils", *Journal of the geotechnical Engineering Division, ASCE*, Vol. 107, No. GT3, Proc. Paper, 16106, (1981), 305-317.

3. Ismail, H., "The use of gypseous soils", in Symposium on the Gypseous Soils and Their Effect on Strength, NCCL, Baghdad.

4. James, A. and Lupton, A., "Gypsum and anhydrite in foundations of hydraulic structures", *Geotechnique*, Vol. 28, No. 3, (1978), 249-272. doi:10.1680/geot.1978.28.3.249

5. Noor, S.T., Hanna, A. and Mashhour, I., "Numerical modeling of piles in collapsible soil subjected to inundation", *International Journal of Geomechanics*, Vol. 13, No. 5, (2013), 514-526. doi:10.1061/(asce)gm.1943-5622.0000235

6. Awn, S.H.A. and Abbas, H.O., "Improvement of gypseous soil by compaction and addition of cement", *Journal of Engineering and Sustainable Development*, Vol. 16, No. 2, (2012), 74-88.

7. Ziegler, M., "Application of geogrid reinforced constructions: History, recent and future developments", *Procedia Engineering*, Vol. 172, No., (2017), 42-51. doi:10.1016/j.proeng.2017.02.015

8. Fakhraldin, M.K., "Improvement of loose granular soil by using geogrid reinforcement", *Kufa Journal of Engineering*, Vol. 7, No. 3, (2016), 66-79.

9. Ahmed Kamel, M., Chandra, S. and Kumar, P., "Behaviour of subgrade soil reinforced with geogrid", *International Journal of Pavement Engineering*, Vol. 5, No. 4, (2004), 201-209. https://doi.org/10.1080/1029843042000327122

10. Karim, H.H., Samueel, Z.W. and Jassem, A.H., "Behaviour of soft clayey soil improved by fly ash and geogrid under cyclic loading", *Civil Engineering Journal*, Vol. 6, No. 2, (2020), 225-237. doi:10.28991/cej-2020-03091466

11. Emeka, A.E., Chukwuemeka, A.J. and Okwudili, M.B., "Deformation behaviour of erodible soil stabilized with cement and quarry dust", *Emerging Science Journal*, Vol. 2, No. 6, (2018), 383-387. http://dx.doi.org/10.28991/esj-2018-01157

12. Amli, A., Sabah, A., Al-Ansari, N. and Laue, J., "Study numerical simulation of stress-strain behavior of reinforced concrete bar in soil using theoretical models", *Civil Engineering Journal*, Vol. 11, No. 5, (2019), 2349-2358. doi:10.28991/cej-2019-03091416

13. Lutenegger, A.J. and Saber, R.T., "Determination of collapse potential of soils", *Geotechnical Testing Journal*, Vol. 11, No. 3, (1988), 173-178. doi:10.1520/gtj10003j

14. Muarik, H.O.A.S.M., "Behavior of compacted gypsiferous sandy soil during soaking and leaching process", *Journal of Wassit for Science & Medicine*, Vol. 5, No. 1, (2012), 165-176.

15. Al-Busoda, B.S. and Al-Rubaye, A.H., "Bearing capacity of bored pile model constructed in gypseous soil", *Journal of Engineering*, Vol. 21, No. 3, (2015), 109-128.

16. Noman, B.J., Abd-Awn, S.H. and Abbas, H.O., "Effect of pile spacing on group efficiency in gypseous soil", *Civil Engineering Journal*, Vol. 5, No. 2, (2019), 373-389. doi:10.28991/cej-2019-03091252

17. Abbas, H.O., "Improvement of sabkha soil by using geomesh and addition of polycoa", *Engineering and Technology Journal*, Vol. 30, No. 4, (2012), 568-576.

18. Ibrahim, S.K. and Zakaria, W.A., "Effect of vibrating footing on a nearby static–load footing", *Civil Engineering Journal*, Vol. 5, No. 8, (2019), 1738-1752. doi:10.28991/cej-2019-03091367

Persian Abstract

چکیده

در حقیقت روشهایی برای بهبود ظرفیت تحمل استراحت کف پا در حال فروپاشی خاک می تواند دو رویکرد را بهبود بخشد ، از این رو بهبود خصوصیات استحکام خاک و نفوذ سوراخهای تقویت شده به خاک است. پایه توسط یک صفحه فولادی مربع ۰.۱ در ۰.۱ متر مدل سازی می شود. پایه بارگذاری می شود که دارای استرس ۴۰ کیلو پاسکال بوده و محل استقرار در شرایط خشک و در حالت خیساندن اصلاح می شود. از دو عمق تقویت جغرافیایی مش استفاده می شود ، یک B (B عرض پا) و B۰.۵ است. برای یک عمق B ، از سه اندازه مربع مختلف از ژئو مش استفاده می شود ، ۴ B، ۶ B و B۸ برای عمق تقویت شده از B۰.۵، سه اندازه از جغرافیایی مش استفاده شده ، B ۳.۵ ، 5.5B و ، B۷.۵ است. نتایج نشان می دهد که بهترین پیشرفت به دست آمده ، مورد عرض جغرافیایی مربعی با عرض B ۷.۵ و در عمق B/2 در زیر پایه است ، با پیشرفت از نظر حل و فصل سقوط ۳۵٪ و کاهش تسویه در شرایط خشک ۵۰٪ کمترین پیشرفت در مورد ژئو مش مربع با عرض B۴ و عمق یک B است و واقعاً بسیار ناچیز بود ، حدود ٤٪ کاهش در تسویه در نسبت به سقوط. موارد دیگر بین این دو نسبت متفاوت بود. برای یافته های مطالعه ، نویسنده توصیه می کند از اندازه ژئومش کمتر از اندازه پایه استفاده نکند و آن را در عمق بیش از نیمی از عرض پایه قرار ندهد. به همین ترتیب ، در کل ، تأثیر ژئومش در کاهش محل استقرار خاک در حال فروپاشی واضح است اگر به روش مناسب استفاده شود.