Journal of Engineering and Applied Sciences 12 (Special Issue 6): 7959-7964, 2017
ISSN: 1816-949X
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Experimental Study on using Different Shapes of Sand Cushion in Weak Soil

[1]Sura Saadoon, [1]Ali Al-Robay and [2]Kadhim A. Al-Abbas
[1]Department of Civil Engineering, College of Engineering, Al-Qadisiyah University, Al-Diwaniyah, Republic of Iraq
[1]Department of Civil Engineering, College of Engineering, Thi-Qar University, Nasiriyah, Republic of Iraq

Abstract: In the center and South regions of Iraq (Mesopotamia) the soil is weak, that has low bearing capacity and high settlement. Considerably the sand cushion is one of the best techniques used frequently to treat the weak soil and enhance its mechanical properties such as bearing capacity and consequently reduce its settlement. In this research an experimental study has been carried out to study the load-settlement behaviour of two groups of footings.The first group consists of footing on natural soil (weak soil) and footing on the flat sand cushion, the second group consists of footing on a curvilinear sand cushion and the footing on the reinforced curvilinear sand cushion. Test results showed that, the use of a sand cushion, reduce the soil settlement and increase the load applied capacity. The measurements of settlement are taking place for the first and second groups at the average load of P = 75 kPa. It has been indicated that, the use of flat cushion is allowed to reduce the soil settlement up to 13%, the curvilinear sand cushion reduced the settlement up to 16% while the curvilinear sand cushion that has been reinforced with geotextile reduced the settlement by 34% compared with the natural soil base settlement under the same load.

Key words: Weak soil, sand cushion, reinforcement, bearing capacity, settlement, curvilinear, consists

INTRODUCTION

Effect of soil reinforcing: Methods of reinforcing soil with geosynthetic materials have now become a widespread. The main advantage of this type of reinforcement is: strengthening and increasing the stability of the foundations, reduction of deformations in the ground base and exclusion of ground excavation beneath the foundations. On the other hand, despite the wide use of reinforcing materials, the issues of design and design of reinforced substrates are relevant because of insufficient knowledge, considerable labour and cost and in some cases, insufficient reliability. In addition, the problem of the development of reinforcement for soil bases is the lack of technical design standards and experience in the use of reinforcing materials.

Stability and bearing capacity of weak soil with the sand cushions: When the soil beneath the foundation is a weak soil, the required dimensions of the foundation may be produced excessively large. In a number of cases, the size of the foundation can be significantly reduced if the bearing capacity of the soil is artificially enhanced. One way to increase the stability and bearing capacity of the weak soil is the use and arrangement of sand cushions. In the practice of construction on weak water saturated soils, two types of sand cushions are frequently used:

- The partial replacement of the weak soil layer
- The replacement of the week soil with well compacted layer

The use of flat cushions becomes economically impractical if the thickness of the weak layer exceeds the width by a factor of 1.5-2 in which case hanging sand cushions are used (Francius, 1930).

In the practice of construction, it is customary to use cushions of coarse-grained sand, gravel and sand-gravel mixture. The use of sands with admixtures of silt and clay particles as well as waste from stone-crushing production from soluble and rapidly eroding rocks is not allowed.

The first systematic course was published in 1869, on the scientific substantiation of the theory of the use of sand cushions in weak soils by Litvinov (1934) and Ahmed (1990). In this research, it was explained the expediency of using sand to replace the weak soil due to the ability of sand to transfer pressure to a large area of the base, distribute the pressure more evenly and also in

Corresponding Author: Sura Saadoon, Department of Civil Engineering, College of Engineering, Al-Qadisiyah University, Al-Diwaniyah, Republic of Iraq

view of the simplicity and availability of the base. The main issue when designing a sand cushion is to determine its geometric dimensions. According to the experiments carried out by Mangusher (Standard ASTM., 2007), the ball shape showed the high ability of sand to redistribute the pressure over a large area of the base. It has been proved that, the sand pressure extends to the sides at an angle of about 45°C. Proceeding from this, the width of the sand cushion along the bottom is determined (Gudehus and Kolymbas, 1979; Ophrichter, 2013).

To ensure that, the soil, withstand the pressure of the structure safely, the value of this pressure must not exceed the soil resistance over the area in the level of the cushion base.

The subsequent calculations of the size of the sand cushions were also based on the angles of pressure transfer in the sand layer and different researchers took their values different. In accordance with this, the width of the cushion on the lower part and its thickness were determined.

Results provided by Francius (1930), devoted to the calculation of sand cushions for massive (hard) foundations on highly compressible soils, concluded that the use of a sand cushion thicker than 0.2 of the base width removes the plastic regions along the edges of the base and moves them to the middle.

Dalmatov (2006) in his research, determined that, the dimensions of a sand cushion must meet the condition that, the average pressures along the base of the foundation and the base of the sand cushion are close or equal to their limiting values.

Abelev and Krutov (1962) and Krutov (2009) noted that, due to the shortcomings in the methods for calculating sand cushions, either material over expenditures or unacceptable deposits of foundations occur as a result of the creeping of the pillows to the sides.

The method closest to the method of base amplification used in this study is the method of replacing the isobaric zones of local overvoltages as shown in Fig. 1, that has been proposed and published in 1934 by Litvinov (1934).

In this method and proceeding from the actual distribution of stresses along the base of the foundation along the bell-shaped curves (instead of the rectangular law adopted in practice) and using isobaric zones, it is proposed to replace the over-stressed zones with denser low-compressible ground (sand, gravel). Noting that, beyond the vertical line passing through the face of the foundation, isobars pass through with approximately 50% of the applied load, it is proposed to replace the weak ground within the contour limited by the chosen isobar (Fig. 1). In this case, a smooth transition from the foundation material to the soil material is ensured due to the involvement of ground masses along the perimeter of the cushion. Further study of this method showed that the arrangement of sand cushions only within the zone of propagation of the maximum compressive stresses can not be extended to weak, strongly compressible soils. Since, in the construction of cushions in these soils, their width should be taken on the basis of the condition of limiting the lateral expansion of the soil which in turn confirms the effectiveness of the proposed solution in the form of inserting a reinforcing element along the sand cushion contour in order to limit its transverse deformations (ASTMI., 2012).

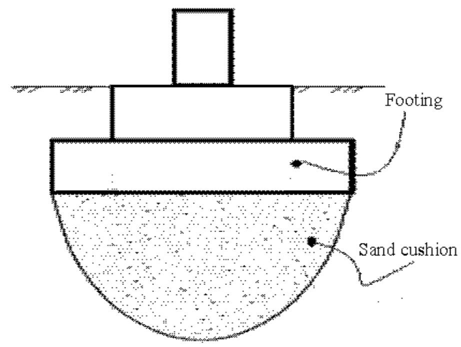

Fig. 1: Replacing the natural soil with a sand cushion

Increasing the bearing capacity and the stability of weak soil by reinforcement: Reinforcing the bases leads to strengthening and hardening of the soil massifs by including special elements in their composition that are in close interaction with the soil but not connected with the foundation constructively.

Soil reinforcement is widely used in the construction of buildings and structures on structurally unstable soils, such as: highly compressible, weak clay soils, etc.

In soil massifs, the structural arrangement of reinforcing elements can be vertical, horizontal, inclined in one direction or in two or more directions, solid, intermittent and in the form of a different series of cellular structures. Depending on the physical and mechanical characteristics of soils and tasks that are solved during reinforcement, the character of the location of reinforcing elements is chosen as well as the technology for their implementation.

Reinforcing of the clay soil base can be carried out in two main directions: use of reinforcing elements having high rigidity and taking part or all of the load directly to themselves, like piles, micro-piles; Steel reinforcement located in the thickness of the ground, steel mesh, expansion walls and georgics with fillers or use of reinforcing elements that do not have their own high strength characteristics but increase the dimensions of the core and change the stress-strain state of the substrate, like non-woven synthetic material (geotextile),

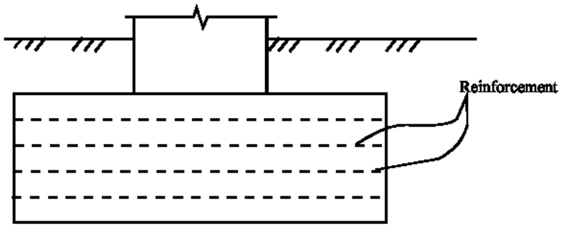

Fig. 2: Reinforced sand cushion with the foundation and the soil backfill

straw, basalt fiber. Restrictive factors in the use of reinforcing materials with the soil construction are the lack of experience in the use of these materials as well as the difficulty of taking into account the research of the reinforcing material in the calculation base model.

Ahmad (1990) in his research considered the method of reinforcing of a clay foundation with basalt fibers. The researcher examined an array of soil with a multilayer arrangement of reinforcing elements. On the basis of the numerical and semi-detailed conducted model, the following regularities are revealed: the maximum effect of single-stage reinforcement depends on the width, length, depth of the reinforced layer and the size of the columnar foundation. The reseacher found that, the most effective option in his study is the two-layer reinforcement option.

A study on the sand cushions reinforced with geotextiles in the contact layer of the soil was engaged by Tazhigulov (1993). The research deals with the reinforcement of the soil in the zone of contact with the foundation. As a result the following conclusions have been conducted: The ability of the reinforcing element to incorporate an additional primer in the horizontal direction is revealed which leads to a decrease in settlement and an increase in the bearing capacity of the base.

In the research of Roscoe and Burland (1968), Gudehus and Kolymbas (1979) and Ophrichter (2013), noted that the reinforced foundation cushions as a rule are used in case of need to replace the ground. The replaced bulk soil is laid layer by layer and the reinforcement is installed in the horizontal direction as shown in Fig. 2.

In this research, it is concluded that the number of reinforcing layers located in sand cushion is determined by static requirements. Nevertheless, it is necessary to provide at least two reinforcing layers. When using geosynthetic materials with different design strength in the longitudinal and transverse directions, the distribution of design strength of the reinforcement is performed according to static requirements.

MATERIALS AND METHODS

Soil samples used in this study have been taken from Al-Qadisiyah City located in the middle of Iraq (Mesopotamia) which is characterized by sedimentary soil, therefore, this soil has cohesion of 19 kN/m^2 and bulk unit weight of 13.9 kN/m^3, using Terzaghi's bearing capacity equation for square footing q_{all} = 5.3 ton/m^2 (Das, 2009; Joseph, 1996). In this study three materials have been used: weak soil, sand and geotextile. Several tests have been carried out on the natural soil and sand used in cushion to determine the soil characteristic as shown in the following.

Table 1: Construction test results

Pressure (p) (kN/m^2)	Settlement reading (mm)
25	0.29
50	0.40
100	0.60
200	0.92
400	1.66
800	2.66
400	2.52
100	2.25

Table 2: Chemical properties

SO_3	TSS	OM	Gypsum
0.089	0.191	0.051	0.218

Grain size distribution: A sieve analysis has been made on a 0.5 kg of natural soil as per ASTM (Standard ASTM., 2009, 2011), then a hydrometer analysis is made on the soil passing sieve No. 200. A Unified Soil Classification System (USCS) is used to classify soils and to find the soil of type Low Plasticity Clay (CL). For sand only sieve analysis is made and a Well-Graded Sand (SW) is achieved with the accordance of USCS.

Atterbeg limit: The liqiud limit of the soil samples is equal to (34.5%) and the plastic limit is (21%) as per ASTM (Standard ASTM., 2010).

Compaction: The standard Procter test for natural soil was used to determine the compaction properties as per ASTM (Mangushev, 2012; Standard ASTM., 2007). The maximum dry density of the soil was (18.2 kN/m^3) and the optimum moisture content was (22 %).

Consolidation test: from this test find the initial void ratio (0.87) and the result of the test shown in Table 1.

Chemical analysis: Made an analysis of the chemical properties shown in the Table 2.

Bulk unit weight: The bulk unit weight of sand was 17.2 kN/m^{3}and his angle of internal friction was 33°C.

Testing program: To study the settlement of the natural soil (weak soil) of the base and the development of stresses in the it, an experimental investigation on several

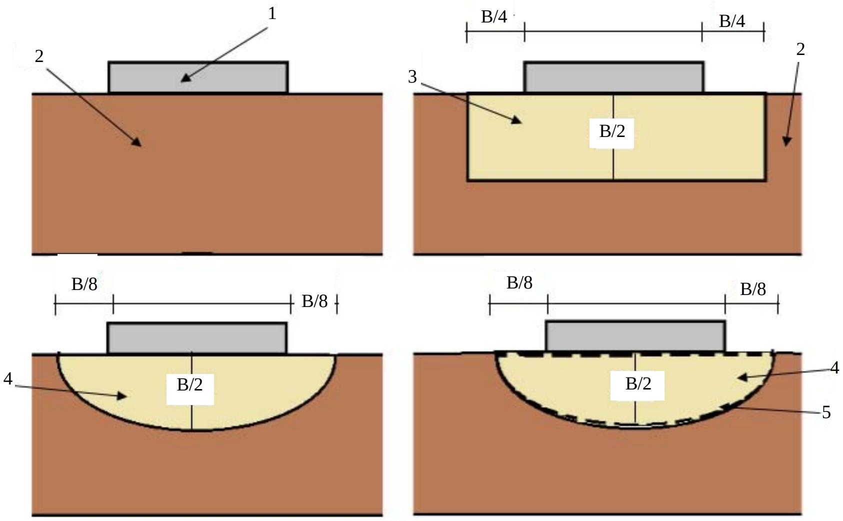

Fig. 3: Different shapes study for base under footing; 1) Footing (300×300×50) mm; 2) Natural soil (weak soil); 3) Flat sand cushion; 2) 4 Curvilinear sand cushion; 5) Curvilinear sand cushion with reinforced (geotextile)

shapes of the soil base were carried out as shown in Fig. 3. For the research purposes to simulate the soil base a tank with dimensions of (1500 mm length 2000* mm width 1000* mm depth) was used. The load on the footing was transferred incrementally by using a cantilever lever system. The dimensions of footing were (300×300×50 mm).

To study the load-settlement behavior two groups of footings were considered:

First group:
- Footings on the natural soil
- Footings on the flat sand cushion

Second group:
- Footings on curvilinear sand cushion
- Footings on curvilinear sand cushion reinforced with geotextile

RESULTS AND DISCUSSION

Figure 4 shows the load-settlement relationship for the samples of the first group (footing on natural soil and footing on sand flat shape). From this figure it can be easily seen that at the average load of 75 kPa, the settlement of the footing with natural soil base is 20 mm, while for that with sand flat shape base is 18 mm in other words the settlement of the second one is decreased by 13%. The final settlement of 50 mm was occurred at the loads of 83 and 87 kPa for both bases, respectively. Examination the figure also shows that the line of load-settlement is equal up to the load of 25 kPa, beyond this point the difference began between the behavior of two types of bases.Therefore, it can be concluded that, the arrangement of sand cushion only within the zone of spreading of the maximum compressive stresses without any additional engineering measures does not lead to obtain any significant effect, this can be

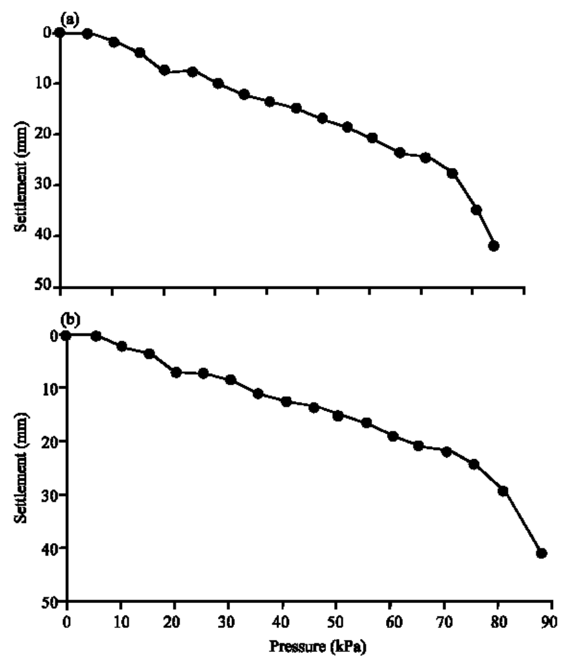

Fig. 4: Load settiement resuits for first serial; a) Nautrad soil based and b) Flat sand cushion based

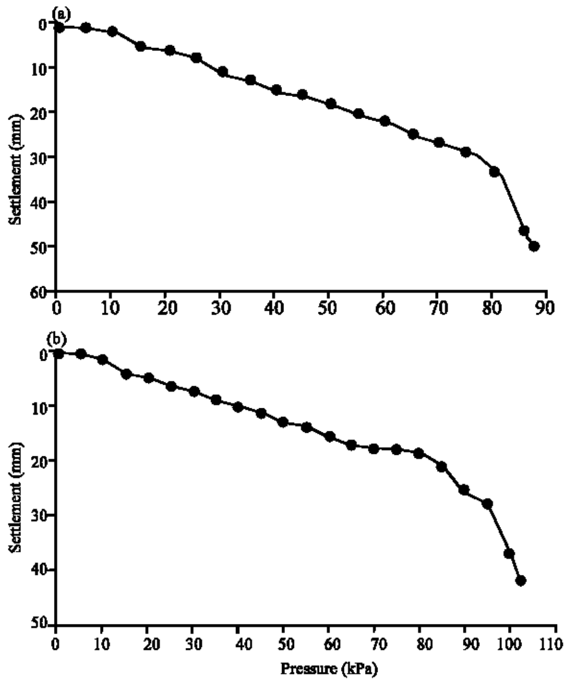

Fig. 5: Load settlement results for first serial; a) Curvilinear sand cushion and b) Curvilinear sand cushion with reinforced

attributed to the fact that at the model of the foundation cushion is crushed under high loads which is accompanied with significant transverse cushion body deformation and extrusion of the sandy soil beneath the base of the model of foundation. Figure 5 shows the load-settlement results of the second group of the footings with a curvilinear sand cushion base and footing on curvilinear sand cushion reinforced with geotextile base. Analysis the results, shows that at the first stages of the loading up to about 45 kPa, the same curve trend achieved in both types of footings. With load increasing a gradual inclusion in the work of the geotextile reinforcing element was observed when the load increasing the difference in settlement increases consequently.

From the test results of the first and second groups, it can be observed that the settlement decrease and the applied load increase. Figure 6 shows the differences between the first and second groups and it can be concluded that the settlement at average load of 75 kPa, the use of flat cushion is allowed to reduce 13% while for curvilinear sand cushion the settlemen reduce by 16 %, and for reinforced curvilinear sand cushion reduce by 34 % compared with that of the natural soil.

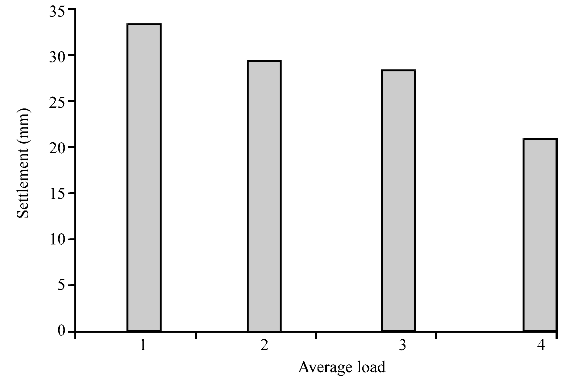

Fig. 6: Comparison among all case studies at average load 75 kPa; 1) Natural soil base; 2) Flat sand cushion; 3) Curvilinear sand cushion and 4) Curvilinear sand cushion with reinforced

CONCLUSION

Complex experimental studies of the stress-strain state of natural soil, flat sand cushion, curvilinear sand cushion and reinforced curvilinear sand cushion, revealed the following; Use curvilinear sand cushion provides a more even distribution of stress under footing which leads to decrease in the settlement and an increase in the bearing capacity of the base under the footing.

The use of curvilinear sand cushion with geotextile is allowed to reduce he settlement by 34% compared with that of the natural soil and 16% when curvilinear sand cushion without geotextile is used. Use geotextile around curvilinear sand cushion restricts it transverse deformation and reduces the settlement by reducing the compression strain. To increase the effect of the method used to strengthen the base by the sand cushion, it is proposed to exclude the zones of early development of plastic deformations that form along the edges of the footing on a weak soil by increasing the size of the sand cushion at the base of the footing.

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