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# Experimental Investigation of Square Footing Resting on Sand over Gypseous Soils

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**ABSTRACT**

This study included (40) tests of loading a square footing (100*100 mm) resting on two layered soils (sand over gypseous soils) using a steel box with the dimensions of (900*900*500 mm). Gypseous soil was brought from Tikrit-University with gypsum content 61%. The tests were divided into two groups. The first groups included (4) tests for gypseous soil only by using the field and maximum densities (14.5, 18.75 kN/m3) respectively, without soaking and with soaking where gypseous soil lost a great value of its resistance. The second group included (36) tests of loading two layers of soil by replacing a layer of gypseous soil by sandy soil with relative density (30%, 60%, and 80%) and depths (B/2, B and 3/2 B). The results showed that the replacement process gave an improvement in the bearing capacity when the gypseous soil was compacted to field density and soaked with a relative density of sand (80%) while the other cases did not have any improvement. The results of loading the two layers of soil also show that the soaking of gypseous soil under the sandy layer affects on the resistance of sand through reducing it especially when the depth of sand was (B/2) this effect decreased gradually with increase in the depth of the sandy layer.



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# دراسة تجريبيه لأساس مربع مستند على تربة رملية فوق تربة جبسية

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**الخلاصة**

هذه الدراسة تضمنت اجراء (40) تجربة من تجارب تحميل أساس مربع (100*100 مم) مستند على طبقتين من التربة (تربة رملية فوق تربة جبسية) باستخدام صندوق حديد بأبعاد (900*900*500 مم). تم جلب التربة الجبسية من جامعة تكريت وبنسبة جبس (61%). تم تقسيم التجارب الى مجموعتين. المجموعة الأولى تضمنت (4) تجارب للتربة الجبسية فقط باستخدام الكثافة الحقلية والعظمى (14.5، 18.75 كيلو نيوتن\م3) على التوالي وبدون غمر ومع الغمر حيث خسرت التربة الجبسية جزءا كبيرا من مقاومتها. المجموعة الثانية تضمنت اجراء (36) تجربة من تجارب تحميل طبقتين من التربة وذلك باستبدال طبقة تربة جبسية بأخرى رملية بكثافة نسبية (30%، 60%،80%) وأعماق (B/2, B, 3/2 B). النتائج بينت أن عملية الاستبدال أعطت تحسن في المقاومة عندما كانت التربة الجبسية مرصوصة بالكثافة الحقلية ومغمورة بالماء مع كثافة نسبيه لرمل (80%) بينما الحالات الأخرى لم يلاحظ أي تحسن. النتائج بينت أيضا ان عملية غمر التربة الجبسية بالماء الموضوعة تحت طبقة التربة الرملية أدت الى نقصان في مقاومة الرمل خصوصا عندما كان سمك الطبقة الرملية (B/2)وهذا التناقص في المقاومة يقل بازدياد سمك طبقة الرمل.

**الكلمات الدالة:** اساس ضحل، طبقتين من التربة، تربة جبسية، تربة رملية، غمر.

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## 1. Introduction

A shallow foundation is one of the major categories of foundations. Individual footings Plate (1), square or rectangular in-plane, that support columns and strip footings that support walls and other similar structures are generally referred to as shallow foundations [1].

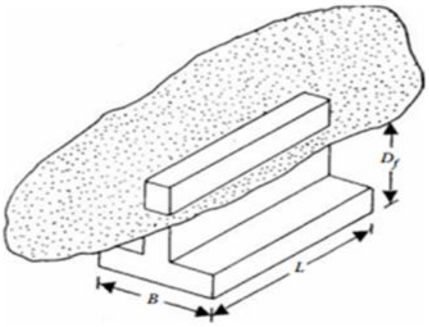


**Plate (1)** Individual footings

The design of foundation depends on the ultimate bearing capacity of soil beneath the foundation and the tolerable settlement that footing can suffer without any adverse result on the superstructure. Studying the characteristics and behavior of soil beneath the structure is a very important matter to ensure that no problems occur in the structure resulting from the lack of knowledge about the soil. Gypseous soil is a type of soil that covers large areas of Iraq (more than 20%), [2]. It is concentrated in Mosul, Baiji, Tikrit, Samarra, North West of Baghdad, Anna, Heet, Ramadi, Fallujah and it may be found in other regions [3]. This soil contains adequate quantities of gypsum (hydrated calcium sulfate $CaSO_4.2H_2O$) and is considered as a collapsible soil or metastable soil.

Many researchers studied the behavior of shallow foundation resting on two layers of soil as Button [4] studied the bearing capacity of a strip footing resting on two layers of clay, Reddy and Srinivasan [5] which extended the work of Button [4], Brown and Meyerhof [6] studied stiff clay layer overlying a soft clay layer and a soft clay layer overlying stiff clay layer, Meyerhof [7] investigated sand layer overlying clay layer.

Many researchers studied the improvement of the gypseous soil. Abid Awn [8] studied the improvement of gypseous soil by pre-wetting and the result shows a large decrease in percentage of (foundation settlement / foundation width) specially in the third recycle of soaking with water and the value of this reduction is (91)%. Ibrahim and Schanz [9] studied the improvement of gypseous soil using Silica oil, the results show that this material improves the compressibility and shear strength of soil. Zedan, et. al. [10] used the mixture of (concrete waste and asphalt waste) as addition to the gypseous soil, they found that, the values of cohesion and angle of internal friction increase with the increase of concrete wastes, in which the cohesion increases in a magnitude of 100% and angle of internal friction in a magnitude of 14%, the value 8% represents the optimum percentages. When asphalt mixture wastes are added, the cohesion increases in a magnitude of 112% with a decrease in the angle of internal friction in a magnitude of 2% and the optimum percentage is 108% with an increase in the angle of internal friction in a magnitude of 14%.

## 2. Experimental Program

### *2.1 Apparatus and Procedures*

#### 2.1.1 The text box

The soil beds are prepared in a steel box with inside dimensions (900 mm* 900 mm* 500 mm) in height as shown in the Plate (2).

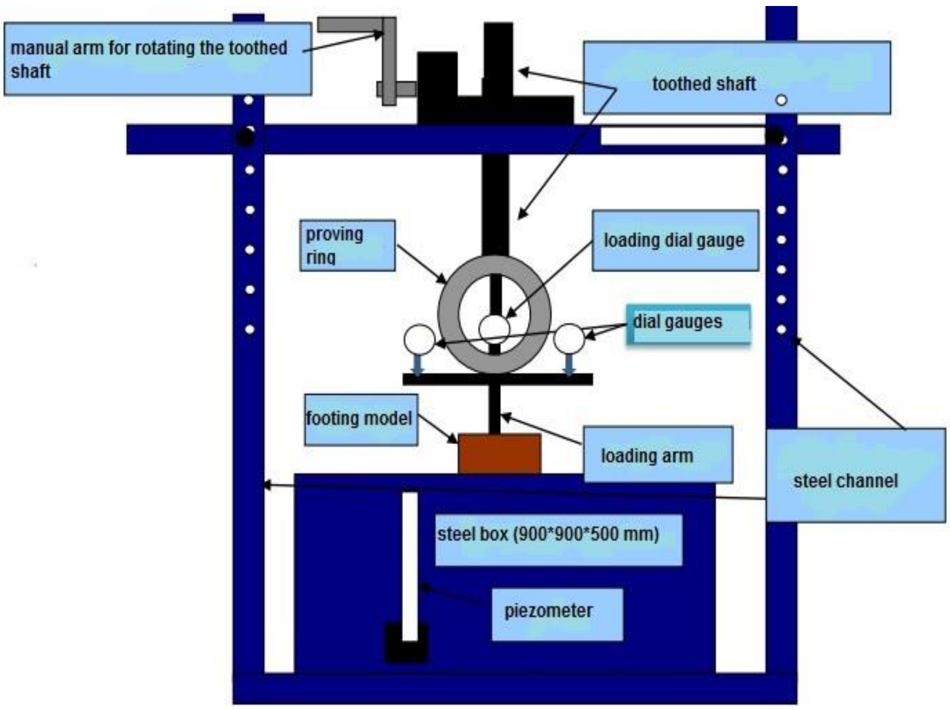


**Plate (2)** The test box

The sides and the bottom are made of 6 mm thickness plate. A valve is fixed in the lower part of the box. This valve is connected with 500 mm vertical plastic cylinder tube. This tube is used to notice the level of water, the bed of soil as a piezometer, and as an indication when the soil becomes at the saturating stage. The filter material is placed at the lower part of the steel model to allow the soaking water to infiltrate through the filter material without the loss of soil particles. A perforated steel plate of 4 mm thickness is placed under the filter material. The plate is supported by four steel channels, with 150 mm high from the base of the steel box. Mark lines are drawn to give the required thickness of the layers.

### 2.1.2. The soil's samples

Gypseous soil was collected from Tikrit University from depth ranging (1.5-2.0) m below the natural ground level after removing the upper soil strata. The sand used in the tests was brought from Tikrit city. The sandy soil sieved through sieve No.4 (4.75 mm) to make sure that no gravels will remain in the sand. The properties of both soils were found and the results were obtained in the Table (1) and Table (2). Gypsum content is found by using Al-Mufty and Nashat method [11]. All classification tests were done according to (ASTM) [12].

**Table 1**
Properties of soils

| Properties | | Gypseous soil | Sandy soil | Specification |
|---|---|---|---|---|
| | Moisture content,(ω%) | 5.5 | 2.00 | ASTM D-2216 |
| | Specific gravity,(Gs) | 2.48 | 2.61 | ASTM D-854 |
| Atterberg limits | Liquid limit L.L | N.L | N.L | ASTM D-4318 |
| | Plastic limit P.L | N.P | N.P | ASTM D-4318 |
| M.I.T Classification | Gravel | 6.92 | 0.00 | _ |
| | Sand | 86.35 | 97.29 | _ |
| | Fines | 6.72 | 2.71 | _ |
| | Coefficient of uniformity (Cu) | 3 | 2.71 | ASTM D-421 |
| | Coefficient of curvature (Cc) | 1.2 | 0.86 | ASTM D-421 |
| | Unified soil classification | SP | SP | _ |
| | Minimum dry unit weight, ($\gamma_{min}$) kN/m$^3$ | _ | 13.88 | ASTM D-4254 |
| | Field unit weight, ($\gamma_{field}$) kN/m$^3$ | 14.5 | _ | ASTM D-1556 |
| Compaction characteristics | Max unit weight (kN/m$^3$) | 18.75 | 17.44 | ASTM D-1557 |
| | Optimum moisture content | 12.5 | _ | ASTM D-2216 |
| | Gypsum content % | 61 | _ | [11] |
| | Total sulfate content % | 68 | 0.48 | _ |
| | PH value | 7.98 | _ | _ |

**Table 2**
Direct shear results

| | | Cohesion c (kN/m$^3$) | | Internal angle of friction ϕ° | | Specification |
|---|---|---|---|---|---|---|
| | | Dry | Soaked | Dry | Soaked | |
| Gypseous soil density | At field unit weight | 15.67 | 7.5 | 26.23 | 13.21 | ASTM D-3080 |
| | At maximum unit weight | 24.58 | 14.43 | 31.52 | 22.5 | |
| Relative density of sand % | 80 | 0 | | 36 | | |
| | 60 | 0 | | 32 | | |
| | 30 | 0 | | 28 | | |

### *2.2. Experimental Procedure*

50 mm thick layers of soil are put in the box and compacted until the required height is reached. A hand hammer is designed for this purpose contains a circular disc of iron with a diameter of 200 mm and a thickness of 12.5 mm is associated with a metal tube diameter 25 mm, the total hammer weight 5 kg. For each layer, the height of the drop of the hammer to realize the demand density is determined. The soil placed in the box in different cases. The first time only gypseous soil is placed and the second time a layer of sandy soil is placed above the gypseous soil. The thickness of these layers varied depending on the width of the foundation, (B). The process of compaction of sandy soil is made by using an electrical vibrator. Small cans are put at the different places to ensure the achieved relative density. The difference in densities measured at various locations was found to be less than 1%. The footing is situated at the center of the box.

## 3. Results and Discussion

### *3.1. Results of the first stage*

These results are listed in Table 3 where the theoretical and experimental values for all tests were obtained. The theoretical values were calculated according to Meyerhof's equation (1963) [13], and were calculated in order to make a comparison with the experimental results.

This stage consists of sandy soil and gypseous soil with field density (without soaking). The results of loading did not show any improvement as shown in Figs. 1-3.

**Table 3**
Ultimate bearing capacity for the first stage

| Gypseous soil | Sandy soil | | Ultimate bearing capacity (kPa) | |
|---|---|---|---|---|
| Density | Relative density | Thickness | Theoretical | Experimental |
| Field density (14.5 kPa) | 30% | 50 mm | 77.38 | 84 |
| | | 100 mm | 10.52 | 34.12 |
| | | 150 mm | 10.52 | 21 |
| | 60% | 50 mm | 92.9 | 147 |
| | | 100 mm | 23.06 | 52.5 |
| | | 150 mm | 23.06 | 31.5 |
| | 80% | 50 mm | 109.2 | 201.07 |
| | | 100 mm | 51 | 99.75 |
| | | 150 mm | 51 | 52.5 |

This stage consists of sandy soil and gypseous soil with field density (without soaking). The results of loading did not show any improvement as shown in Figs. 1-3. This is because that gypseous soil had a good resistance when it was in a dry state and there was no need to replacement with sandy soil which has small cohesion between its particles.

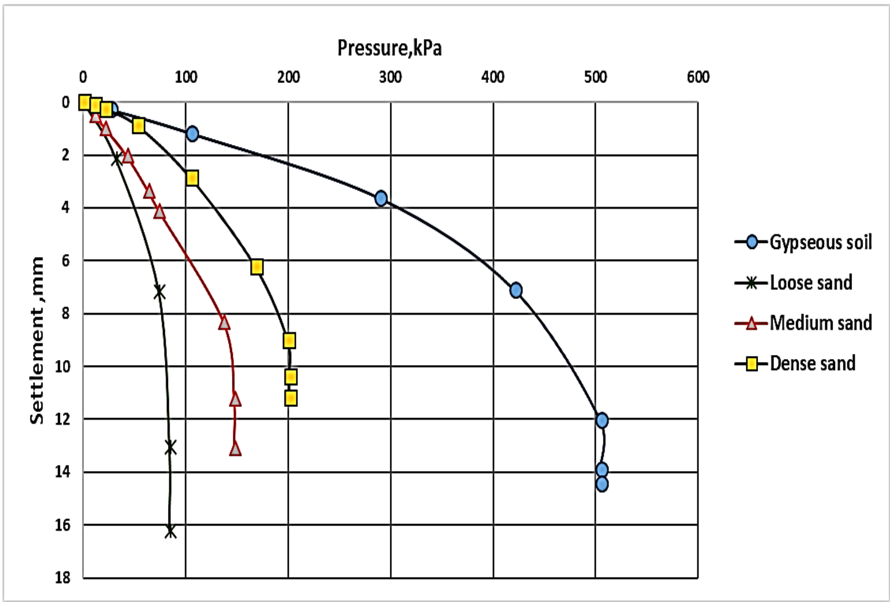


**Fig. 1.** Pressure-Settlement relation for gypseous soil with field density (without soaking) before and after replacement with sandy soil with depth B/2

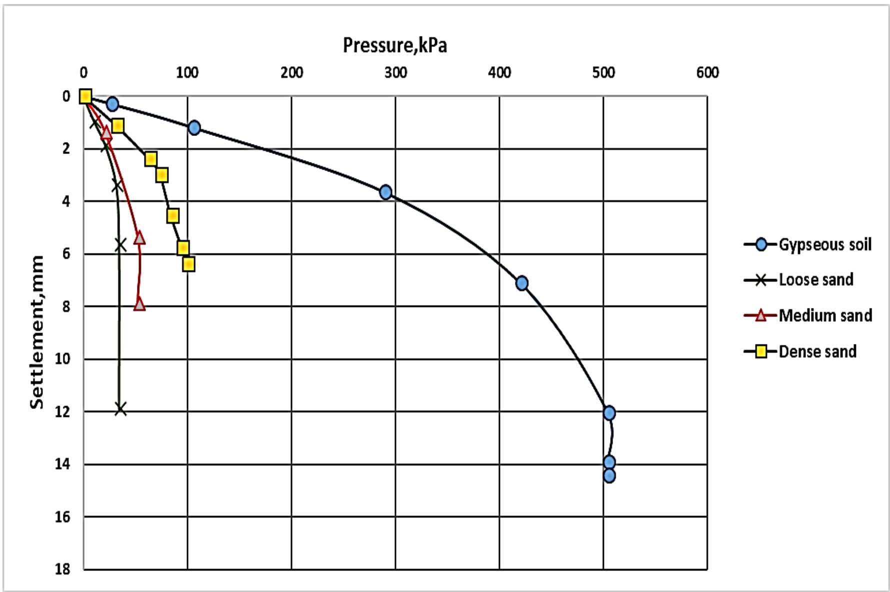


**Fig. 2.** Pressure-Settlement relation for gypseous soil with field density (without soaking) before and after replacement with sandy soil with depth B

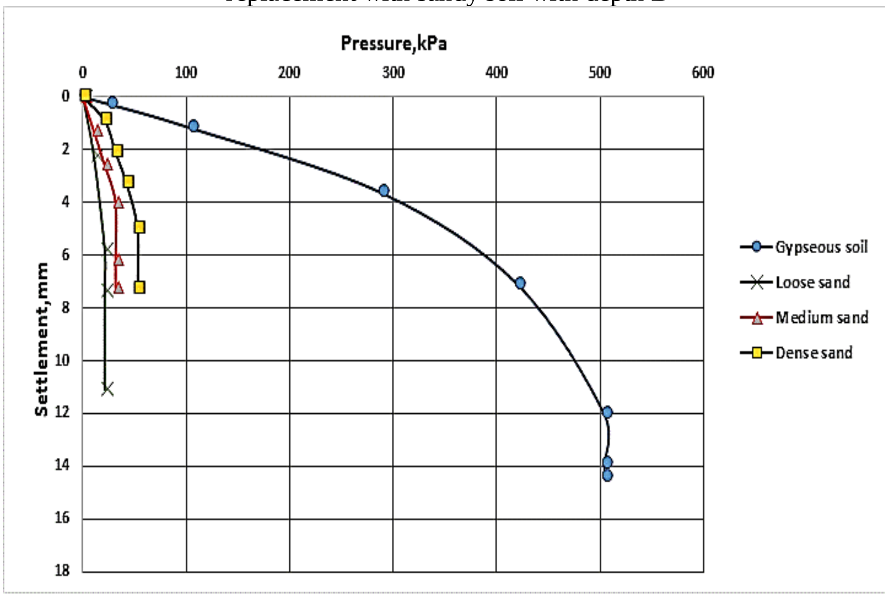


**Fig. 3.** Pressure-Settlement relation for gypseous soil with field density (without soaking) before and after replacement with sandy soil with depth 3/2 B

### *3. 2. Results of the second stage*

The second stage was sandy soil and gypseous soil with field density (with soaking). The theoretical and experimental results are obtained in the Table 4.
In this stage, the results did not show an improvement in the bearing capacity when the sandy soil was in a loose state. This because that gypseous soil with soaking lost (93.5%) of its resistance by losing the bonding between its particles due to the dissolution of gypsum which consisted of a great percentage of soil and the relative density of sand was small (30%). With a medium state, the bearing capacity after the replacement was approximately equal to the bearing capacity before replacement and still no improvement. With dense state and relative density (80%) the results show an improvement with depth (B/2) this improvement increases with an increase in the depth of the sandy layer reaching to a maximum value (63kPa) with depth (3/2 B). This improvement is due to high relative density (80%) which leads to close particles and that means a few voids, also an increase in the depth of sandy layer keeps the foundation away from the collapsed soil layer. Figs. 4 to 6 show the relationship between the pressure and settlement for this stage.

### *3.3 Results of the third stage*

The third stage was sandy soil and gypseous soil with maximum density (without soaking). Table 5 shows the theoretical and experimental results of bearing capacity.

The results for this stage did not show any improvement as shown in Figs. 7-9, this was due to the fact that gypseous soil with the maximum density in the dry state has great resistance and the resistance of sand is very small if compared with gypseous soil because of small cohesion between sandy particles.

**Table 4**
Ultimate bearing capacity for the second stage

| Gypseous soil | Sandy soil | | Ultimate bearing capacity (kPa) | |
|---|---|---|---|---|
| Density | Relative density | Thickness | Theoretical | Experimental |
| Field density (14.5 kPa) | 30% | 50 mm | 29.83 | 21 |
| | | 100 mm | 10.52 | 26.25 |
| | | 150 mm | 10.52 | 10.2 |
| | 60% | 50 mm | 36.56 | 31.5 |
| | | 100 mm | 23 | 42 |
| | | 150 mm | 23 | 31.5 |
| | 80% | 50 mm | 56 | 52.5 |
| | | 100 mm | 51 | 60.37 |
| | | 150 mm | 51 | 63 |

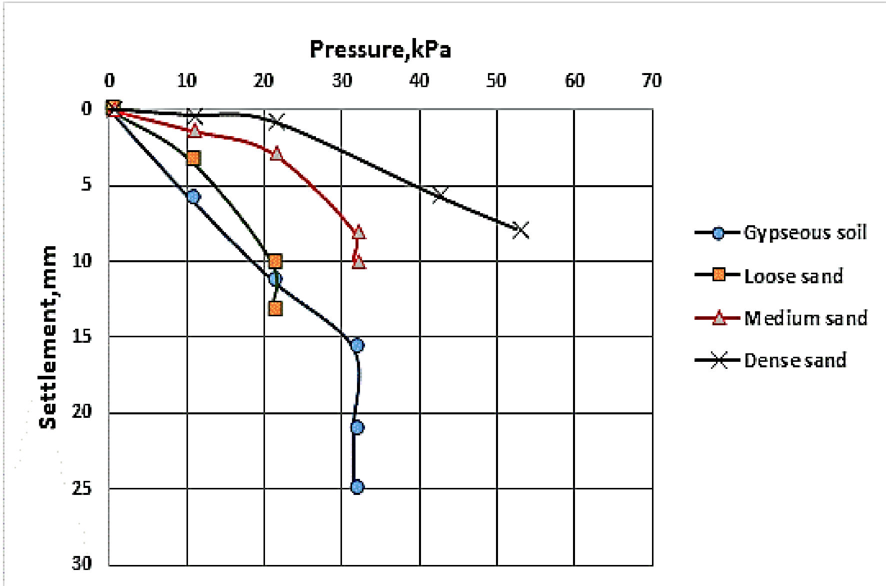


**Fig. 4.** Pressure-Settlement relation for gypseous soil with field density (with soaking) before and after replacement with sandy soil with depth B/2

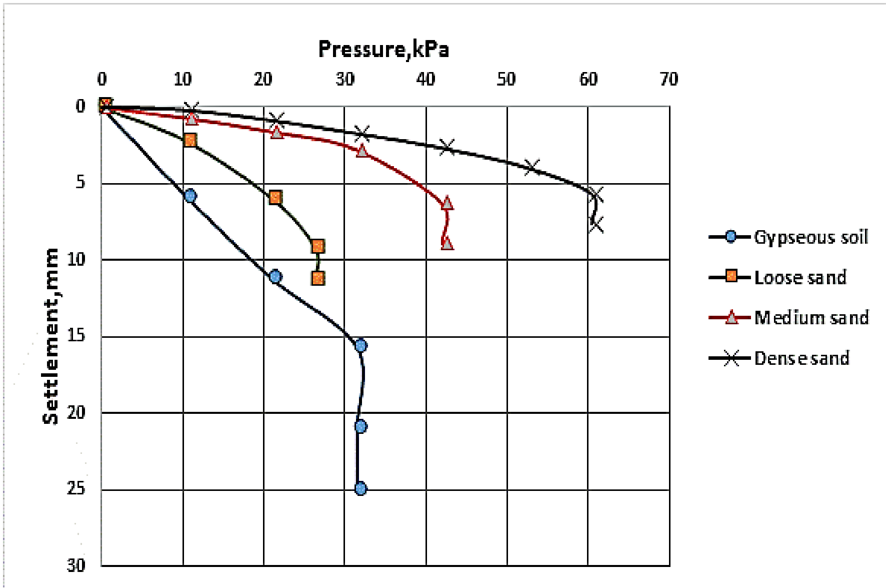


**Fig. 5.** Pressure-Settlement relation for gypseous soil with field density (with soaking) before and after replacement with sandy soil with depth B

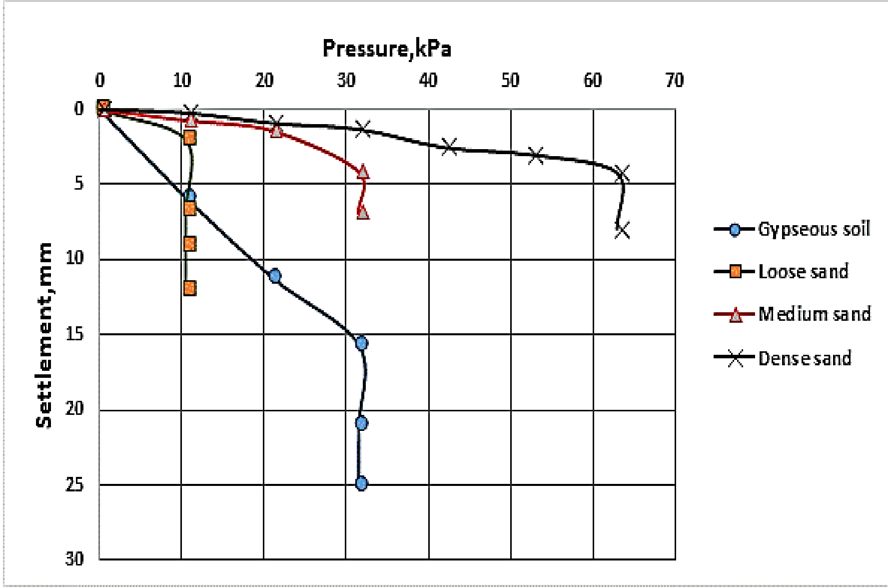


**Fig. 6.** Pressure-Settlement relation for gypseous soil with field density (with soaking) before and after replacement with sandy soil with depth 3/2 B

**Table 5**
Ultimate bearing capacity for the third stage

| Gypseous soil | Sandy soil | | Ultimate bearing capacity (kPa) | |
|---|---|---|---|---|
| Density | Relative density | Thickness | Theoretical | Experimental |
| Maximum density (18.75 kPa) | 30% | 50 mm | 144.3 | 126 |
| | | 100 mm | 10.5 | 31.5 |
| | | 150 mm | 10.5 | 23.62 |
| | 60% | 50 mm | 181.45 | 210 |
| | | 100 mm | 23 | 49.87 |
| | | 150 mm | 23 | 31.5 |
| | 80% | 50 mm | 201.3 | 316 |
| | | 100 mm | 51 | 115.5 |
| | | 150 mm | 51 | 57.75 |

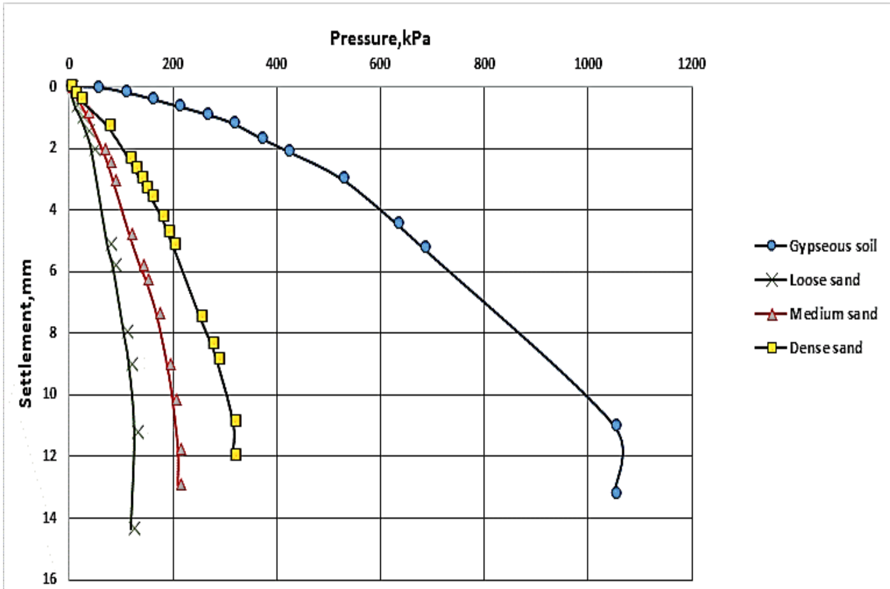


**Fig. 7.** Pressure-Settlement relation for gypseous soil with maximum density (without soaking) before and after replacement with sandy soil with depth B/2

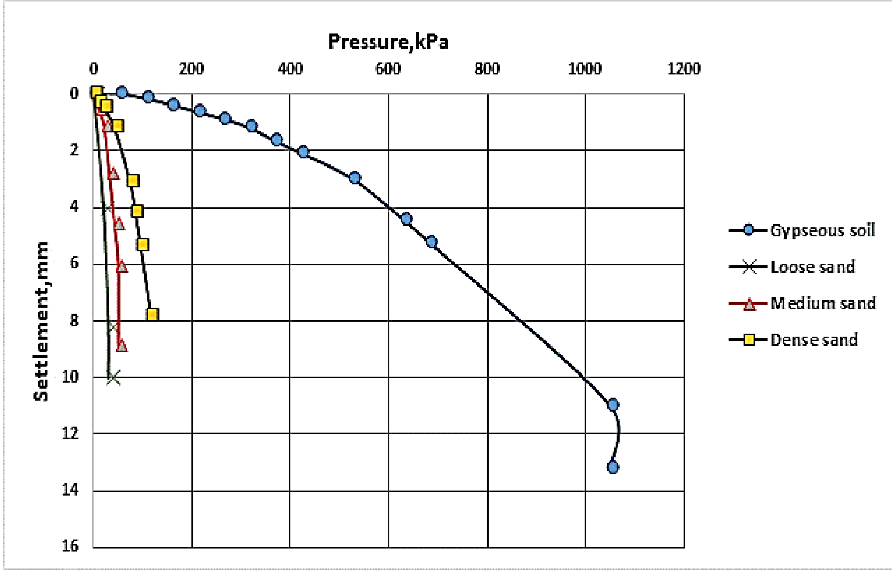


**Fig. 8** Pressure-Settlement relation for gypseous soil with maximum density (without soaking) before and after replacement with sandy soil with depth B

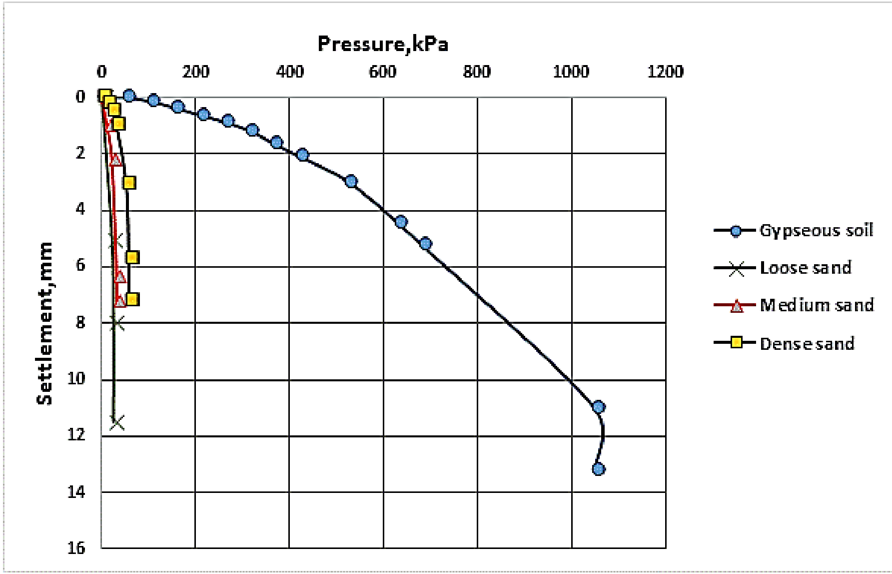


**Fig. 9.** Pressure-Settlement relation for gypseous soil with maximum density (without soaking) before and after replacement with sandy soil with depth 3/2 B

### *3.4 Results of the final stage*

The final stage was sandy soil and gypseous soil with maximum density (with soaking). The results for this stage did not show any improvement as shown in Figs. 10-12. With soaking the gypseous soil lost a high percentage of its bearing capacity but remained larger than the value of the bearing capacity after replacement because the cohesion between the particles of gypseous soil is greater than the cohesion between particles of sandy soil. The theoretical and experimental values for this stage were obtained in Table 6.

## 4. Conclusions

The main conclusions of the present study could be summarized as follows:

1- After soaking the gypseous soil (compacted with field density) with water till the saturation, this soil lost 93.5% of its bearing capacity and when the gypseous soil compacted with maximum density and soaking with water, the soil lost 85% of its bearing capacity.

2- The process of replacing a layer of gypseous soil (without soaking) with a sandy soil does not improve its bearing capacity due to the resistance that gypseous soil has when it is in a dry or a semi-dry condition. Also the process of replacing a layer of gypseous soil compacted with field density (with soaking) with a sandy soil showed an improvement in the bearing capacity especially when the relative density of sand was (80%) and the thickness was (3/2B mm).

3- The process of replacing a layer of gypseous soil compacted to the maximum density (with soaking) with sandy soil does not improve the supporting of the soil.

4- The soaking of gypseous soil affected the bearing capacity of sandy soil and made it decrease especially when the depth of the sand layer was (B/2).

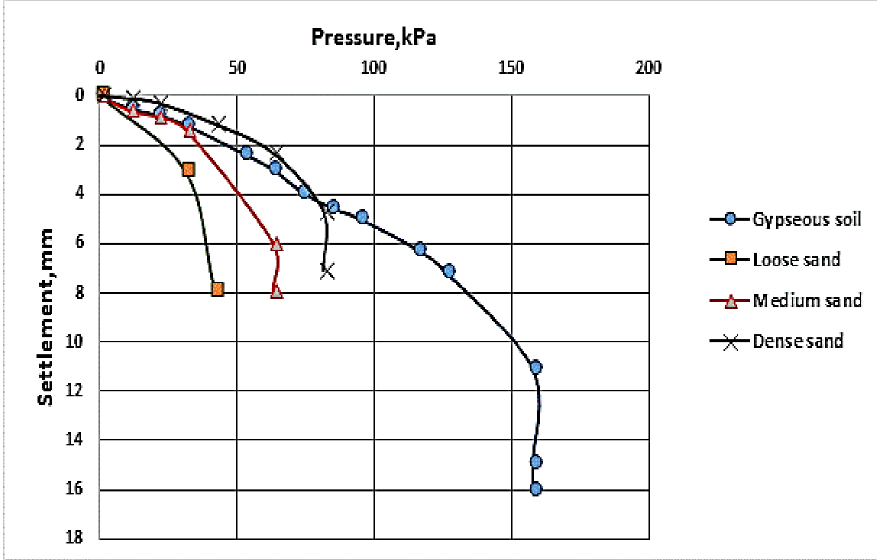


**Fig. 10.** Pressure-Settlement relation for gypseous soil with maximum density (with soaking) before and after replacement with sandy soil with depth B/2

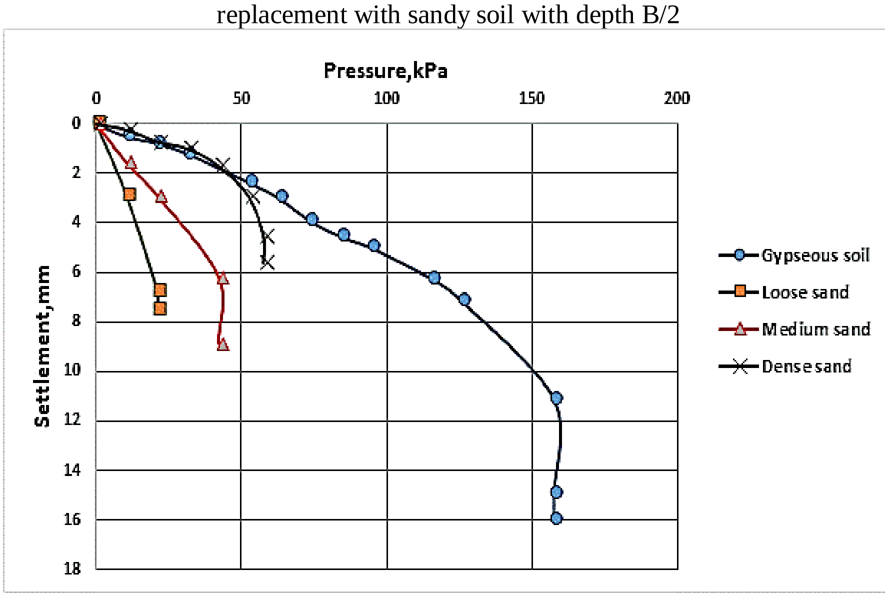


**Fig. 11.** Pressure-Settlement relation for gypseous soil with maximum density (with soaking) before and after replacement with sandy soil with depth B

**Table 6**
Ultimate bearing capacity for the fourth stage

| Gypseous soil Density | Sandy soil Relative density | Sandy soil Thickness | Ultimate bearing capacity (kPa) Theoretical | Ultimate bearing capacity (kPa) Experimental |
|---|---|---|---|---|
| Maximum density (18.75 kPa) | 30% | 50 mm | 66 | 42 |
| | | 100 mm | 10.52 | 21 |
| | | 150 mm | 10.52 | 10.5 |
| | 60% | 50 mm | 79.4 | 63 |
| | | 100 mm | 23 | 42 |
| | | 150 mm | 23 | 39.37 |
| | 80% | 50 mm | 94 | 81.37 |
| | | 100 mm | 51 | 57.75 |
| | | 150 mm | 51 | 65.62 |

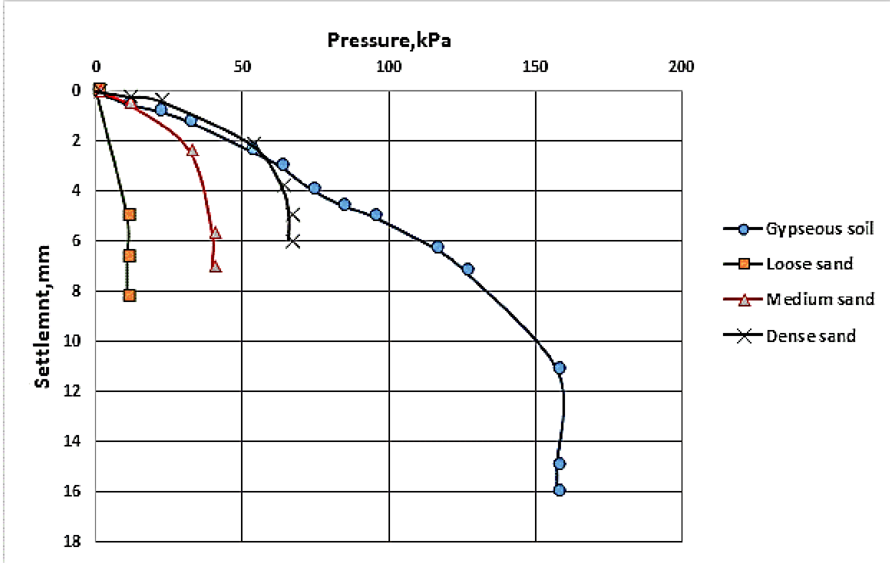


**Fig. 12.** Pressure-Settlement relation for gypseous soil with maximum density (with soaking) before and after replacement with sandy soil with depth 3/2 B

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