Journal of Engineering

journal homepage: www.joe.uobaghdad.edu.iq

Volume 29 Number 5 May 2023

Evaluation the behavior of Ring Footing on Gypseous Soil Subjected to Eccentric and Inclined Loads

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ABSTRACT

An extensive program of laboratory testing was conducted on ring footing rested on gypseous soil brought from the north of Iraq (Salah El-Deen governorate) with a gypsum content of 59%. There are limited researches available, and even fewer have been done experimentally to understand how to ring footings behave; almost all the previous works only concern the behavior of ring footing under vertical loads, Moreover, relatively few studies have examined the impact of eccentric load and inclined load on such footing. In this study, a series of tests, including dry and wet tests, were carried out using a steel container (600×600×600) mm, metal ring footing (100 mm outer diameter and 40 mm inner diameter) was placed in the middle of the container top surface that filled with the gypseous soil. Subject to (vertical and inclined) (concentric and eccentric) loads was carried out for dry and soaking soil to discover the differences in bearing capacity as well as ring behaviors. According to the results when the load eccentricity increases on the ring footing from the rate (e = 0B, e = 0.04B e = 0.08B, e = 0.16B) and the inclination load increases as (0°, 5°, 10°, 15°) respectively the ring footing ultimate loads will be reduced.

Keywords: Gypseous soil, ring footings, bearing capacity, eccentric load.

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2023.05.06

Article received: 19/09/2022
Article accepted: 29/04/2023
Article published: 01/05/2023

تقييم تصرف الاساس الحلقي المرتكز على تربة جبسية والمعرض لاحمال مائلة وغير مركزية

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الخلاصة

تم اجراء فحوصات مختبرية مكثفة على اساس حلقي مستند على تربة جبسية تم جلبها من شمال العراق (محافظة صلاح الدين) بنسبة جبس 59%. هناك عدد محدود وقليل من البحوث المختبرية المتوفرة بخصوص اداء الاساس الحلقي , الدراسات السابقة كان تركيزها على اداء الاساس الحلقي تحت تاثير الحمل العمودي , وقليل من الدراسات الموجودة اخذت بنظر الاعتبار تاثير الحمل الغير مركزي والحمل المائل على هكذا اساس. في هذا البحث , سلسلة من الفحوصات المختبرية متضمنة الفحوصفات الجافة والرطبة للتربة تم اجرائها باستخدام صندوق من الحديد بابعاد(600×600×600) ملم , اساس حلقي بابعاد (100 ملم قطر خارجي × 40 ملم قطر داخلي) تم وضعه في منتصف اعلى سطح الصندوق المملوء بالتربة الجبسية .وتم تعريضه الى الاحمال التالية (عمودي ومائل) (مركزي وغير مركزي) نفذت الفحوصات باستخدام تربة جافة ومغمورة لمعرفة اختلاف قابلية التحمل وكذلك اداء الاساس الحلقي , اظهرت النتائج عند زيادة انحراف الحمل المركزي من (e = 0B, e = 0.04B e = 0.08B, e = 0.16B) وكذلك زيادة الحمل المائل من (0°, 5°, 10°, 15°) بالتوالي فان قابلية التحمل للاساس الحلقي تقل.

الكلمات الرئيسية: تربة جبسية , اساس حلقي , قابلية تحمل , حمل غير مركزي.

1. INTRODUCTION

The term "gypseous soil" describes soils that contain gypsum. Gypseous soils are tough when the soil dries because the gypsum materials significantly affect the cementation as well as the strengthening of soil particles. Due to the melting of the gypsum between soil particles, large strength losses and increases in compressibility occur quickly when soils are exposed to water or leaching (**Albusoda, 1999; Albusoda, 2008; Al-Taie, et al., 2019; Mohsen and Albusoda, 2022).** Gypseous soils are considered collapsible soils, which contain a high proportion of hydrated calcium sulfate ($CaSO_4.2H_2O$) and consider problematic soils because of the metastable structures when the gypsum melt **(Nashat, 1990; Al-Yasir and Al-Taie, 2022)**. Large sections area of Iraq, especially in the west and north, are covered in gypseous soils. Gypseous soils are widely spread, particularly in Iraq, where gypsum accounts for nearly 12% of the country's total area. According to previous studies the gypseous soils cover 31.7 % of Iraq's total area **(FAO, 1990**; **Ismail, 1994).**
The foundations are the lowest parts of structures that carry their weight to the essential soil. Different types of foundation bases are used for construction. Shallow foundations can carry the structural weight and loads to the earth's surface, which is relatively close to the ground. In a shallow foundation, the ground depth ranges from 1.5m to 3m. Amongest the numerous types, the suitable type is chosen depending on the structure that the footing will support **(Abd-Alhameed and Albusoda, 2022)**.

Ring footings are commonly used to support tower silos, storage tanks filled with oil or water, radio or television towers, bridge piers, offshore buildings, and tall and large structures with axisymmetric geometry. Ring footings have an advantage over circular footings in that the volume reduces the cost of construction. Furthermore, when compared to a circular footing with the same area, the ring footing gives a higher stabilizing moment arm. Under dynamic stresses, ring footing can also act as an anchorage against slip **(Sargaziand and Hosseininia, 2017; Kadhum and Albusoda, 2020A).** The construction which built on ring footing, subject to loads such as vertical load, horizontal load, and eccentricity load. Inclined load is generated by the combination of horizontal (as wind load) and vertical loads on a ring foundation. In structures built on ring footing, eccentricity load is caused by the placement of the horizontal load at any point through the height of the structures **(Kadhum and Albusoda, 2020B).**

This research will be unique because extensive laboratory testing programs were conducted using a small physical model. Ring footing model test was subjected to (vertical and inclined) (concentric and eccentric) loads, and carried out for dry and soaked soil to discover the difference in bearing capacity and ring footing behaviors.

2. MATERIALS AND METHOD

2.1 Gypseous Soil

A disturbed natural gypseous soil sample was used in this investigation, brought from the governorate of Salah El-Deen in the north of Iraq, with gypsum content (59 %) from a depth of (1.0) m. The sample was collected, air-dried, pulverized, and well-mixed before being prepared in double nylon bags. The physical, mechanical, as well as chemical properties of the soil are determined through a series of laboratory tests. The physical and mechanical properties of the soil which were tested summarizes in **Table 1.**

2.2 Small-Scale Physical Model

Experimental works have been performed by using a small-scale physical model to comprehend how the ring footing resting on gypseous soil performs and behaves. The manufactured setup is clear from **Fig. 1,** and consists of a box made of glass of interior dimensions 600 mm * 600 mm and 600 mm high, the thickness of the glass is 10 mm. The box's sides have glassy sides to enable the observation of gypseous soil's behavior throughout the loading stages. The loading system consists of the metal arch as a frame and the mechanical manual jack connected to the load cell to gauge the load applied on the ring footing. This load cell was made from stainless steel (LS300) material with a maximum capacity reached one ton. Two (LVDT) with a capacity of 50 mm, were placed at an equal distance at the right and left on both sides of the jack to measure the settlement of the ring footing. The two LVDT will connect with the load cell to the data logger and use a lap view program to record data. It is important to mention that the small physical model is manufactured by (**Kadhum and Albusoda, 2020B).**

The following are the essential components of the complete setup:

1. Soil container 600mmx600mm and 600mm height with glassy side.
2. Frame made from steel and hydraulic compression handle jack used to apply the load.
3. Load cell with (1 ton) capacity, it is clear from **Fig. 2**.
4. LVDT of 50 mm capacity, which is clear from **Fig. 3**.

5. Metal footing with (100 mm) external diameter and (40 mm) internal diameter, which is clear from **Fig. 4**.
6. Steel tamper (13 kg) to prepare the dense layers with 25 blows dropping from (400-500 mm) for each layer.
7. The load cell and LVDT are connected with a data logger and use a lap view program, which is clear from **Fig. 5**.

Table 1. Gypseous soil's physical and mechanical properties

Property	Value	Specification
D 10	0.05	ASTM D 422
D 30	0.13	
D 60	0.4	
Coefficient of uniformity (Cu)	8	
Coefficient of curvature (Cc)	0.84	
Specific gravity (Gs) With water With kerosene	2.34 2.32	ASTM D 854
The angle of internal friction (ϕ) Relative density	29.7 53%	ASTM D 3080
Maximum dry density (γd max)	1.31 g/cm^3	ASTM D 4253
minimum dry density (γd min)	1.11 g/cm^3	ASTM D 4254
Stander Procter test optimum moisture content max dry density	12.5 1.71 g/cm^3	ASTM D 698
Modify Procter test optimum moisture content max dry density	12.4 1.77 g/cm^3	ASTM D1557
Soil classification	SP-SM	ASTM D 2487

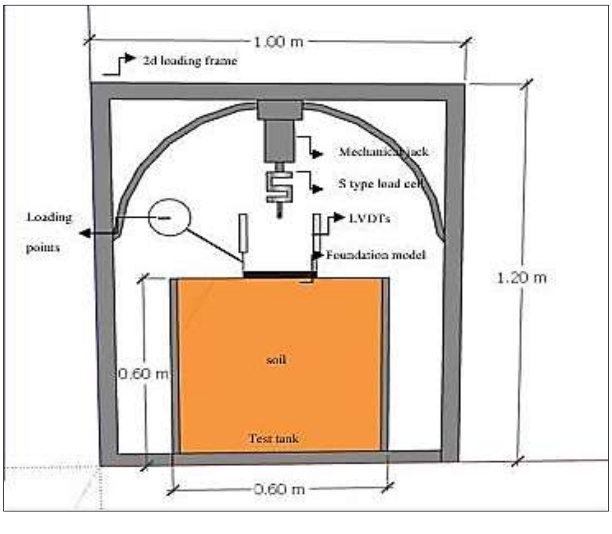

Figure 1. Physical model Manufactured by (**Kadhum, 2020).**

Figure 2. A digital image of the Load cell

Figure 3. A digital image LVDT

Figure 4. Metal footing with (100 mm) outer diameter and (40 mm) internal diameter.

Figure 5. Data logger

2.3 Tests Preparation

2.3.1 Preparation of the Soil

In this work, the popular "raining sand method" has been used in the preparation of gypseous soil (**Al-Yasir and Al-Taie, 2023)**. The model tests were prepared by using the raining technique, the soil prepared at field density and relative density that corresponds to RD of 53 % (medium dense state). After the raining technique has stopped, level the soil surface at the final depth. A leveling tool is used to evaluate the level of the soil layers.

2.3.2 Preparation of Model Test

The gypseous soil amount used to fill the container was determined based on the soil relative density (53%) obtained from the test. The steel container of depth 600 mm was separated into six layers, and the height of each layer was 100 mm. In the container, the uniform dry gypseous soil was placed. Using the raining technique and compacting within six layers until it reached the surface. Steel tamper was specially designed for this purpose with 13 kg weight, it is employed to compact the gypseous soil in the box until it reaches the desired density. Each layer was scraped with a spatula to ensure proper contact between all the compressed layers. The ring foundation was positioned in the middle of the soil surface after the last soil layer in the container was finished. Two (LVDT) were installed at the footing's edges and magnetically linked to the container's sides. The loads were applied by using a mechanical jack per the specified conditions (concentric or eccentric loading as well as inclined load) gradually at a rate of 1 mm per min until the load reached 20% strain. (48) model testing for ring footing was carried out using eccentricity 0B, 0.04 B, 0.08 B, and 0.16 B. For inclined load, the load was subject to angles (5°,10°,15°), each with eccentricity (0B, 0.04B, 0.08B, 0.16B) for both dry and soaked cases.

3. RESULTS AND DISCUSSION

3.1 The Behavior of Ring Footing Rested On Natural Gypseous Soil

There is limited research available on the main behavior of ring footings rested on gypseous soils. In this study, many tests have been conducted using ring footing resting on natural gypseous soil and subject to concentric and eccentric loads. It can be shown from **Fig. 6** that the initial loading with zero centricity (concentric load) generates uniform settlement. Also, the bearing capacity decreased with the increase of the eccentricity of the loads, and local shear failure occurred. The differential settlement rises linearly as the eccentricity rises. A similar result was discovered by (**Al-Mosawe, et al., 2009; Al-Mosawe, et al., 2011; Albusoda and Hussein, 2013; Hosseininia, 2018)**. As well as, the results show that the tilt increases with the increase in a settlement. This result agrees with the finding of **(El-Sawwaf and Nazir, 2012).** Additionally, as eccentricity increases, the amount of friction that happened between the footing's base and the soil reduces. Ring footing at e= 0B, 0.04B, 0.08B, 0.16B (where B is the ring footing's outside diameter) shows that bearing capacity decreases respectably with eccentricity. This is a logical behavior because of the decrease in the effective area of footing with the increase in eccentricity value.

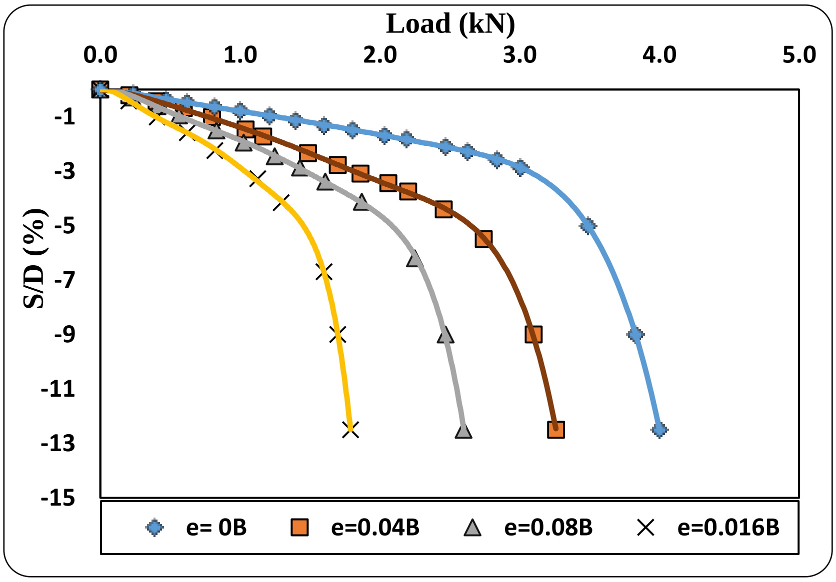

Figure 6. Load-settlement ratio curves for ring footing resting on untreated gypseous soil and subjected to centric and eccentric loading.

3.2 The Behavior of Ring Footing Resting On Gypseous Soil Subjected To Inclined Loadings

The constructions appropriate for ring footings are tall transmission towers, chimneys, silos, and storage of oil. These structure types are subjected to horizontal loads (wind loads) in addition to their dead weight. Inclined load is generated by the combination of horizontal and vertical loads on a ring foundation. The main purpose of this study is to understand how to ring footing behaves when resting on gypseous soil subject to inclined loads (0°, 5°, 10°, 15°) as is clear from **Fig. 7.**

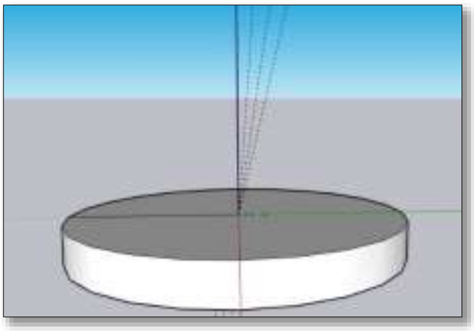

Figure 7. Ring footing subject to inclined loading 0°, 5°, 10°, 15°

Ring footings may experience eccentric or inclined loadings. Numerous researchers have examined how footing behaves when resting on improved or unimproved soil beds, other than ring footings that are loaded eccentrically and inclined. In this work, **Fig. 8** shows Load and settlement (load in kN that is subject to ring footing and soil settlement in mm) curves for ring footing subject to inclined loading at 5° with a vertical axis, **Fig. 9** shows the same footing subject to inclined loading at 10°, and **Fig. 10** shows the footing subject to inclined loading 15°. With eccentric loadings (e = 0B, e = 0.04B e = 0.08B, e = 0.16B) respectively.

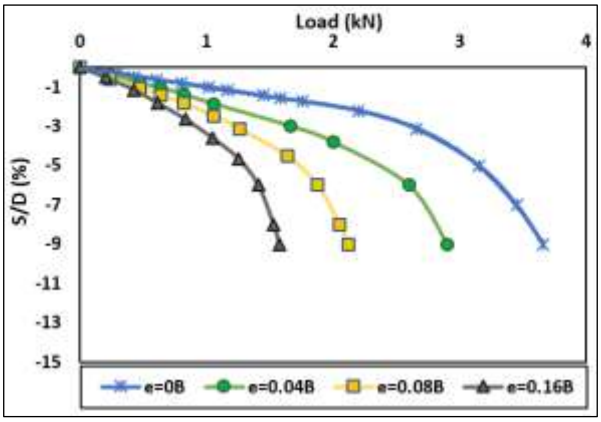

Figure 8. Load-settlement ratio curves for ring footing subjected to inclined loading by 5°.

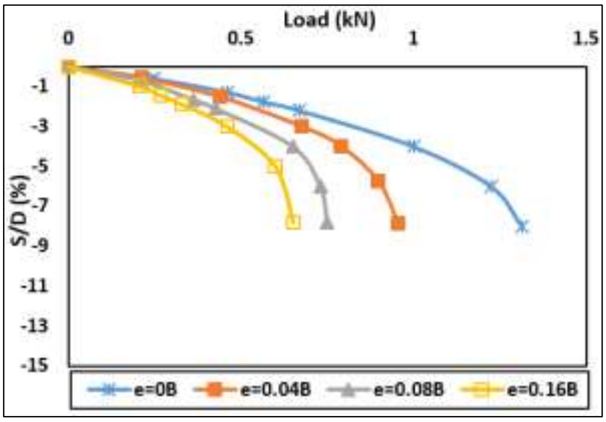

Figure 9. Load-settlement ratio curves for ring footing subjected to inclined loading by 10°.

From these tests, it is obvious that as the load's eccentricity rose, the footing's bearing capacity considerably decreased, and more tilting of the footing was also observed.

Increasing load inclination from 0° to 15°, the ultimate load of footing resting on gypseous soil is reduced. When the eccentricity of the subject load increases from 0 to 0.16, the ultimate bearing load was decreased, similar to results found by **(Sharma and Kumar, 2018)**.

3.3 The Behavior of Ring Footing Resting On Soaked Gypseous Soil

A series of many model loading tests were conducted to study the effect of soaking on the collapsible soil bearing capacity as well as the behavior of ring footing resting on soaked gypseous soil exposed to vertical, inclined, and eccentric-inclined loadings (e= 0B, e= 0.04B, e= 0.08B, and e= 0.16B) where B is the ring footing's outside diameter, inclination angle (5°, 10°, 15°). **Fig. 11** shows the relationship between the applied load and (S/D) (where S is the soil settlement and D is the ring diameter) of the gypseous soil in a dry and soaked state. Gypseous soil is soaked for (2) hours and loaded to failure, a significant drawdown in bearing capacity was observed, additionally, a pattern of behavior approximating local shear failure was observed. This behavior may result from bonds breaking when soil soaking. High decrease in bearing capacity after soaking if compared with the dry state. This is referred to as the collapse and softening of gypsum bonds and generating voids which lead to reducing the friction areas between particles of the gypseous soil and then decreasing the shear strength and deforming to a new structure.

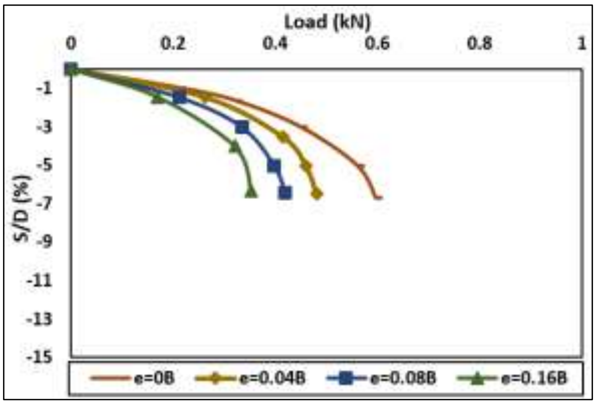

Figure 10. Load-settlement ratio curves for ring footing subject to inclined loading by 15°.

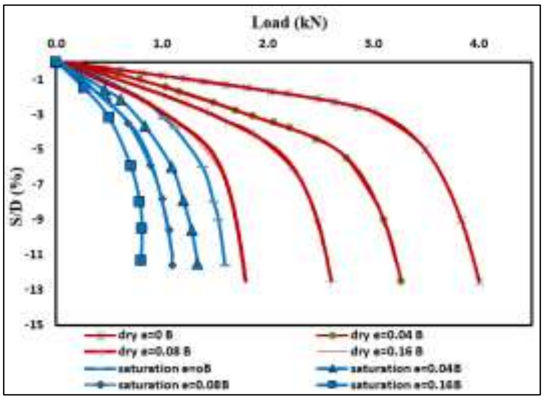

Figure 11. Load - settlement curves for ring footing rested on gypseous soil at a dry and soaked state.

Figs. 12 to 14 show the behavior of ring footing rested on soaked gypseous soil and subject to loading with eccentricity (e=0B, e=0.04 B, e=0.08B, e=0.16 B) respectively, each load inclined with (5°, 10°, 15°). Values of gypseous soil's bearing ability decreased as eccentricities increased in both dry and saturated conditions. This is a logical result because of the decrease in the effective area of ring footing with the increase in the value of eccentricity. That agrees with the findings of **(Albusoda and Hussein, 2013)**. As the load inclination rises from 0° to 15°, the ultimate load of ring footing resting on (dry or soaked) gypseous soil is reduced. When the load eccentricity will increase from e= 0B to e= 0.16B, the ultimate bearing load is reduced also. The maximum load of ring footing rested on gypseous soil higher in dry than the soaked state, and the settlement increased in soaked soil if compared with dry soil.

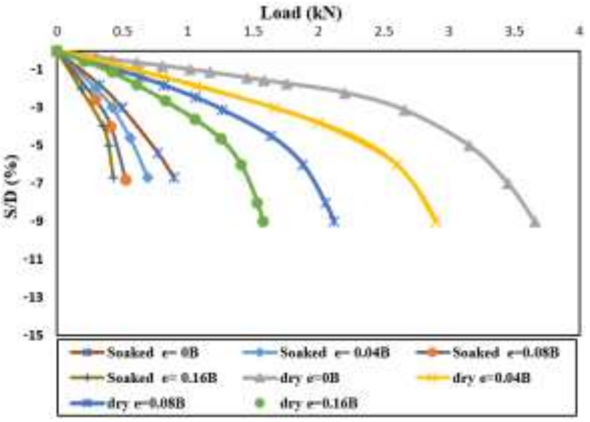

Figure 12. Load - settlement curves for ring footing rested on gypseous soil at a soaked state subjected to an inclined load of 5°.

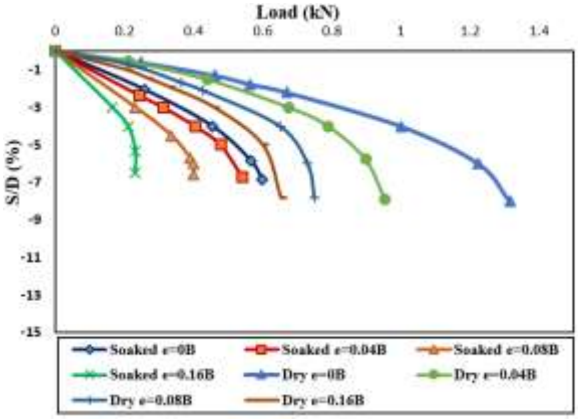

Figure 13. Load - settlement curves for ring footing rested on gypseous soil at a soaked state subjected to an inclined load of 10°.

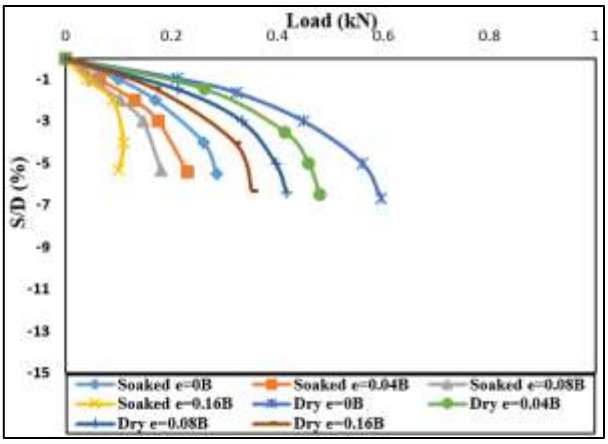

Figure 14. Load - settlement curves for ring footing rested on Gypseous soil at a soaked state subjected to an inclined load of 15 °.

4. CONCLUSIONS

1. When the load eccentricity of that subject on ring footing resting on gypseous soil increases from the rate of 0 to 0.16, the ultimate load is reduced by 87% because the ring footing affective area reduces.
2. When the inclination loads that subject on ring footing resting on gypseous soil increase from 0° to 15°, the ultimate load is reduced as well as the bearing capacity, this reduction range was 56%. Generally, the bearing capacity of dry soil is more than soaking soil under the same conditions.
3. High decrease in bearing capacity after soaking if compared with the dry state. This is referred to as the collapse and softening of gypsum bonds and generating voids which lead to reducing the friction areas between particles of the gypseous soil and then decreasing the shear strength.

REFERENCES

Abd-Alhameed, H.J., and Albusoda, B.S., 2022. Impact of eccentricity and depth-to-breadth ratio on the behavior of skirt foundation rested on dry gypseous soil. *Journal of the Mechanical Behavior of Materials*, 31(1), pp., 546-553. doi:10.1515/jmbm-2022-0057

Al-Busoda, B.S., 2008. Treatment of collapsibility of gypseous soil. *Journal of Engineering*, 14(3), pp. 444-457.

Albusoda, B. S., 1999. Studies on the behavior of gypseous soil and its treatment during loading, MSc. Thesis, Civil Engineering Department, University of Baghdad.

Albusoda, B., and Hussein, R., 2013. Bearing capacity of shallow footing on compacted dune sand underlain Iraqi collapsible soil. *Engineering and Technology Journal*, 31(19), 13-28.

Al-Mosawe, M. J. A., Albusoda, B. S., and Yaseen, A. S., 2009. Bearing capacity of shallow footing on soft clay improved by compacted cement dust. *Journal of Engineering*, 15(4), pp. 4417-4428.

Al-Mosawe, M. J. A., Albusoda, B. S., and Yaseen, A. S., 2011. Bearing capacity of shallow footing on soft clay was improved by compacted fly ash. *Journal of Engineering*, 17(6), pp. 1473-1482.

Al-Taie, A. J., Albusoda, B.S., Alabdullah, S.F.I., and Dabdab, A.J., 2019. An experimental study on leaching in gypseous soil subjected to triaxial loading. *Geotechnical and Geological Engineering*, 37(6), pp. 5199–5210. doi:10.1007/s10706-019-00974-2

Al-Yasir, A., and Al-Taie, A., 2022. Geotechnical review for gypseous soils: properties and stabilization. *Jurnal Kejuruteraan* , 34 (5)785-799. doi:10.17576/jkukm-2022-34(5)-04

Al-Yasir, A., and Al-Taie, A., 2023. A new sand raining technique to reconstitute large sand specimens. *Journal of the Mechanical Behavior of Materials*, 32. doi:10.1515/jmbm-2022-0228

ASTM, D 422., 2007. *Standard test method for particle-size analysis of soils*. ASTM Annual Book

ASTM D854, 2016. *Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer*. ASTM Annual Book.

ASTM, D3080., 2011. *Standard test method for direct shear test of soils under consolidated drained conditions*. D3080/D3080M, 3, 9.

ASTM Annual BookASTM, D4254., 2006*. Standard test methods for minimum index density and unit weight of soils and calculation of relative density*. ASTM Annual Book

ASTM D698., 2021. *Standard Test Methods for Laboratory Compaction of Soil Standard Effort*. ASTM Annual Book

ASTM D1557-12., 2021. *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort*. ASTM Annual Book

El-Sawwaf, M., and Nazir, A., 2012. Behavior of eccentrically loaded small-scale ring footings resting on reinforced layered soil. *Journal of Geotechnical and Geo environmental Engineering*, 138(3), 376-384. doi:10.1061/(ASCE)GT.1943-5606.0000593

FAO. 1990. Management of Gypsiferous Soils. Food and Agriculture Organization of United Nations, Rome, Internet, Http.//Fao.Org/Doc Rep/To 323e/Ro323e03.Htm.

Hosseininia, E. S., 2018. Effect of load eccentricity on the bearing capacity of ring footings. International Conference: Fundamentals of Soil Behaviours, GSIC 2018, Proceedings of GeoShanghai, 2018, pp. 490–497. doi:10.1007/978-981-13-0125-4_54.

Ismail, H. N. 1994. The use of gypseous soils. In Symposium on the Gypseous Soils and Their Effect on Strength, NCCL, Baghdad.

Kadhum, M.Q., and Albusoda, B., 2020A. Behaviours of Ring and Circular Footings Subjected to Eccentric Loading: a comparative Study. IOP Conference Series: Materials Science and Engineering, 1067(1), p. 012056, 4th International Conference on Engineering Sciences (ICES 2020) 5th-6th Dec. 2020, Kerbala, Iraq. doi:10.1088/1757-899X/1067/1/012056

Kadhum, M.Q., and Albusoda, B., 2020B. A Review on the performance of ring foundations resting on reinforced and unreinforced soil. IOP Conference Series: Materials Science and Engineering, 1105 (1), p. 012086, The Fifth Scientific Conference for Engineering and Postgraduate Research (PEC 2020) 21st-22nd Dec. 2020, Baghdad, Iraq. doi:10.1088/1757-899X/1105/1/012086

Mohsen, A., and Albusoda, B. S., 2022. The collapsible soil, types, mechanism, and identification: a review study. *Journal of Engineering*, 28(5), pp. 41–60. doi:10.31026/j.eng.2022.05.04

Nashat, I. H. 1990. Engineering Characteristics of Some Gypseous Soils in Iraq. Ph.D. Thesis, Civil Engineering Department, University of Baghdad.

Sargazi, O., and Hosseininia, E., 2017. Bearing capacity of ring footings on cohesionless soil under eccentric load. *Computers and Geotechnics*, 92, pp. 169-178. doi:10.1016/j.compgeo.2017.08.003

Sharma, V., and Kumar, A., 2018. Behavior of ring footing resting on reinforced sand subjected to eccentric-inclined loading. *Journal of Rock Mechanics and Geotechnical Engineering*, 10(2), 347-357. doi:10.1016/j.jrmge.2017.11.005