Iraqi Academic Scientific Journals
Iraqi Journal of Civil Engineering
Available online at https://www.iasj.net/
Journal homepage: https://www.iasj.net/iasj?func=issues&jId=141&uiLanguage=en

Evaluation of the Performance of the Circular Foundation Surrounded by the Diaphragm Wall

Khalid W.Abd Al-kaream[1], Ahmed S.Abdulrasool*[1], Mudhafar K.Hameedi[1], Zainab H.Shaker[1]

[1]*Civil Engineering Department, University of Technology, Baghdad, Iraq.*

ARTICLE INFO

Article history:
Received 05 /03 / 2022
Received in revised form 05 /05 / 2022.
Accepted 09 /05 / 2022.
Available online30 /07 / 2022

Keywords:
Diaphragm Wall,
Bearing capacity,
Settlement,
Stress

ABSTRACT

Increasing the bearing capacity of shallow foundations is a significant challenge in the urban environment due to increased population growth. This paper presents the bearing capacity of circular foundations encircled by a diaphragm wall. In this study, the effects of diaphragm wall depth (0.5 D, D, 2 D) (D is the foundation diameter) of the foundation on the bearing capacity of the foundation are investigated. Varying relative densities of sand soil (loose, medium, and dense) are utilized. The results of the experimental tests show that the diaphragm wall possesses an influence upon the settlement and the foundation bearing capacity. Where, the capacity of bearing increased as the diaphragm wall depth increased. On the other side, increasing the depth leads to a decrease in the settlement ratio of about 57%. The results of experimental work also demonstrated that the best depth is between D and 2D for all types of relative densities.

DOI: 10.37650/ijce.2022.172881

1. Introduction

Several techniques are used for development the bearing capacity of shallow footing. Confinement of soil may have a tremendous impact on improving soil bearing capacity (Abdulrasool et al., 2021). A diaphragm wall shape an enclosure in which the soil is precisely confined.

Terzaghi, (1943) was proposed and some researchers modified such as (Meyerhof,1951); (Meyerhof, 1963); (Hansen, 1970); (Vesic, 1973), it depends on several factors, such as the inclination factors for shape and depth. From the mechanism of shear failure, it is clear that the capacity of bearing of a foundation that rests upon a sand layer rises with the entire length of the surface of failure. The rise in the length of the surface of failure may have resulted from the increase in foundation depth or foundation width (Mahmood, 2018). Therefore, it is possible to increase the bearing capacity by confining the soil under the foundation with a diaphragm wall. Where, the diaphragm wall could be fixed to shallow foundation edges to increase the failure surface length, which may develop under conditions of vertical loading. The work of the diaphragm wall is the same as the skirted foundation work, but the diaphragm wall is better because of its high stability and resistance to soil movement, as well as resistance to corrosion.

Soil confinement technique is very active and it has been used by many researchers such as (Watson and Randolph, 1997); (Byrne et al., 2002); (Al-Aghbari and Mohamedzein, 2004); (EL Wakil,2013); (Tripathy, 2013); (Dawarci et al., 2014); (Al-Aghbari and Mohamedzein, 2018); (Haider and Mekkiyah, 2018), where

* *Corresponding author*. Tel.: +964-771-520-1852.
E-mail address: Ahmed.S.Abdulrasool@uotechnology.edu.iq

studies have investigated the use of coiled foundation on the sand. Mahmood.et al. (2019) The effect of gypsum soil confinement on bearing capacity is studied. Al-qaissy and Muwafak (2013) studied the behavior of confined clay soil under the strip foundation. Some researchers have also studied confined soil under different footings. Khatri et al. (2017) used the rectangular foundation; the square foundation was utilized by (Eid, 2013) and (El Sawwaf and Nazer, 2005) applied the strip foundation, and applied the circular foundation.

Katagiri et al. (1997) conducted 2D and 3D centrifuge model tests to better understand the deformation of slurry trenches and failure behavior in the presence of sand. The most critical variables to study were the effect of trench shape and surcharge load. A strongbox with dimensions of (800x250x400 mm) was utilized. The scale of one to sixty was used for the centrifuge model. To simulate a quarter of the prototype trench, a rubber bag was filled with salty water with a density of (10.5 kN/m^3). The field scale was 15 meters deep by one meter broad, with a variable length between three and six meters, or an indefinite length for 2D analysis, when using the diaphragm wall scale (plane strain). Each experiment used surface water as a source of groundwater.

Symons and Carder (1993) reported the field monitoring findings for the diaphragm and bored pile walls at three separate locations. They determined the distribution of stress and water pressure. In two locations, diaphragm walls were employed. They were T-shaped with dimensions of 4m in length and 0.8m in thickness. The second was 2.7 m in length and 0.8 m thick. In two dimensions, they obtained the depth of T-Shaped at 13.5 m. The lateral stress in one of them was not measured, but the pore water pressure in the other was measured. The lateral ground pressure was measured using spade-shaped pressure cells (1.5 m) from the obverse face of the wall of Tee section diaphragm during the building of several panels. During the trenching procedure, the lateral stress decreased by between 50kN/m^2 and 160 kN/m^2.

Hajnal et al. (1984) conducted an experiment in Hungary's Research Center for Water Resources Development. The experiment's objective has been to determine the influence of the trench width and length, as well as groundwater and slurry levels. Four test series were conducted in the experiment. The initial (2) sequence of experiments being regarded initially and performed in a box (made of glass) filled with the sand and measuring 0.3 x 0.5 m in surface area and 0.3 m in depth. To replicate the trench in the box that's being pulled for causing a failure, a temporary supporting plate was used. During the failure, a surface crack having an arch-like has been noted.

Tse and Nicholson (1993) also discussed the monitoring results of a diaphragm wall installation upon clayey soil (Clay of London). The project of monitoring consisted of (140) rectangular diaphragm wall panels measuring 3.75 meters in length, 0.8 meters in thickness, and approximately 23.5 meters in depth, all of which were determined primarily by their bearing function. The largest horizontal displacement reported as a result of diaphragm wall trenching was 3mm.

2. Research significance

Numerous studies have been conducted on the diaphragm wall and its bearing capacity and settlement effect. However, prior research on the effect of this strategy on the Shallow foundation was limited and did not paint a complete picture of the issue. The primary goal of this research is to ascertain the effect of the diaphragm wall on the bearing capacity and settlement of circular foundations under a variety of conditions. A research program utilizing diaphragm wall attached circular foundation with different depth and embedded in the sandy soil of different relative densities. Three investigation diaphragm wall depths were used: 0.5D, D, and 2D. Furthermore, three soil densities were used, that is 30, 55, and 80%. Corresponding to loose, medium, and dense sand respectively.

3. Material and Experimental Model

3.1. Sandy soil

The soil samples are obtained from Karbala, southwest of Baghdad. Several standard tests have been conducted for determining the soil physical properties, and the information being listed in the Table 1. The distribution of the grain soil particle size utilized is depicted in Fig 1. In accordance with USCS, the sample of soil can be classified as poorly graded sand.

Table 1–Physical properties of sandy soil used.

Test	Results	Specification
Specific gravity (Gs)	2.677	ASTM D854-2010 [25]
Gravel %	0	ASTM D422-2010 [26]
Sand %	93	
Clay and Silt%	7	
D60 (mm)	0.5	
D30 (mm)	0.3	
D10 (mm)	0.17	
Cu (Coefficient of uniformity)	2.94	
Cc (Coefficient of gradation)	1.06	
Classification	SP	USCS
$\gamma_{d\,max}$(Maximum dry unit weight) (kN/m^3)	18.31	ASTM D4253, ASTM D4254- 2010 [27]
$\gamma_{d\,min}$(Minimum dry unit weight) (kN/m^3)	15.91	
Ø (Angle of internal friction) for loose sand	39.2	ASTM D3080-2010 [28]
Ø (Angle of internal friction) for medium sand	42.6	
Ø (Angle of internal friction) for dense sand	44.2	
Ψ (Angle of dialtency)) for dense sand	12	

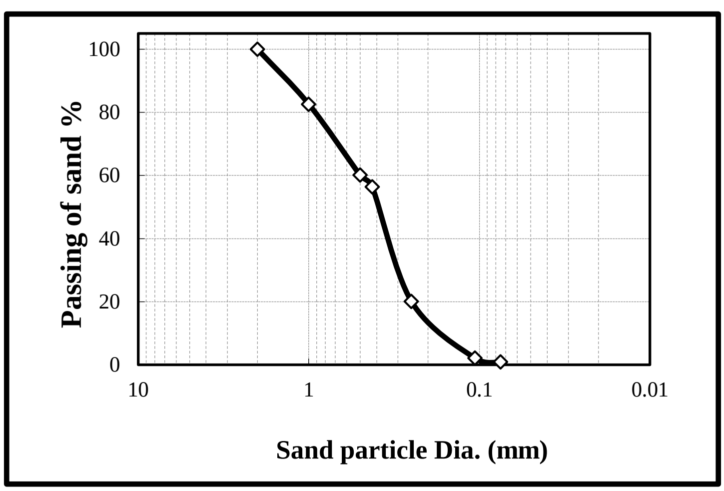

Fig. 1 Grain soil particle size distribution curve.

3.2. Preparation of the diaphragm wall

The diaphragm wall with a thickness of 25 mm is poured using a cement-sand mixture in a ratio (1: 1.5). Portland cement according to BS EN 197-1 (BSI 2011) and natural sand (passing through sieve No. 4 (4.75 mm)) is applied to the casting. The mixture used a sub plasticizer (structure 520) with a wt / g (water-cement ratio) of 0.35 and was treated with water for 7 days. The properties of sub plasticizer (structure 520) listed in the Table 2.

Table 2–The properties of sub plasticizer (structure 520) used.

Test	Results
pH	6.5
Appearance	Light brown coloured liquid
Alkali content	Typically less than 1.5 gm
Chloride content	Nil

3.3. Model footing and instrumentation

A circular foundation was used for the model tests; it consisted of a rigid steel plate, with a diameter of 50 mm. All tests were conducted on the surface of the homogeneous sand layer 250 mm deep with different relative densities (30, 55, and 80%), in a square steel container with an internal dimension of 600 * 300* 300 mm. The container is produced from (6 mm) thick steel plates welded together; this container is adequately stiff and manifested no side deformation through the bed preparation of the sand soil as well as through the test. Figure 2 displays a schematic detail of model setup. The foundation is surrounded by a wall of different diaphragm depths (0.5D, D, and 2D) (where D is the diameter foundation). It is loaded by standard weights until it reaches the required failure weight. Two dial gauges (0.01) mm were applied on the opposite corners of the footing to measure the settlement. The sand in the container is placed with 5 layers. Each layer is 50 mm.

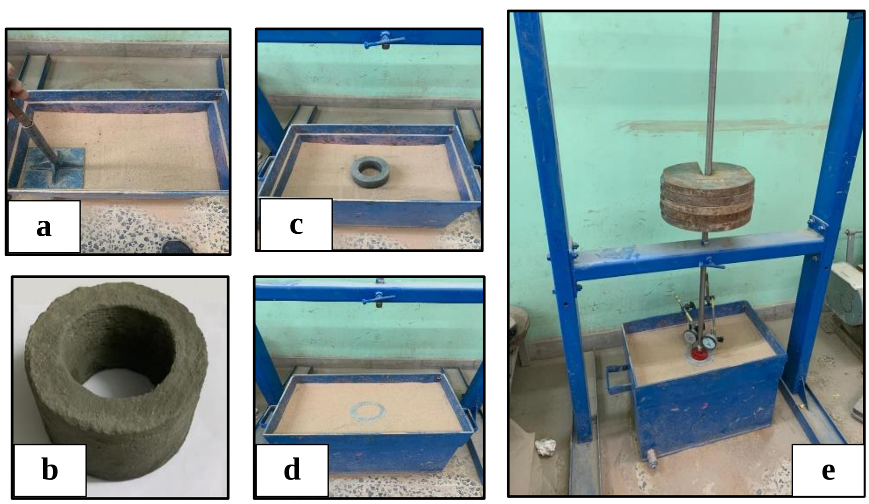

Fig 2. Description of the model setup with diaphragm wall.

4. Discussion of the Test Results

The failure criterion used in all model tests is that proposed by [2], in which the load of failure is described as the load needed to cause a settlement equals (10%) of the diameter of footing. The load-settlement curve obtained from the foundation on sandy soil with different relative densities (30, 55, and 80%) with and without diaphragm wall is presented in Fig. 3. The obtained bearing capacity for various diaphragm wall depths using loose relative density is indicated in Fig. 4. The results shown in Fig.5 explain the efficiency of the diaphragm wall in reducing the settlements ratio (S with walls without walls) and provide an assessment of bearing capacity in different depths of the diaphragm wall.

In general, failure of shallow foundations consists of three types (punching, general shear failure, and local,). As mentioned previously [12], the type of failure is determined by comparing sand and the foundation's ratio of depth to width. This failure mechanism is not applicable in the case of walled foundations, due to the wall connection with the foundation circumference as well as it is prolonging to a depth (d) confining the sand within a skirt cell under the foundation. Therefore, this skirt cell and foundation together have been acting as a single system integrated with the rise in the wall depth, and the shallow foundations become deeper. Consequently, the bearing capacity of foundation increased as the sand relative density rose and the wall depth augmented. From the other side, the failure load is limited by applying vertical and horizontal stresses. The results evinced that for sand having a relative density of 30%, the bearing capacity equal (42.1, 57.4, and 90.1 kN/m^2) at the wall depth (0.5D, D, and 2D), respectively. Such outcomes are well-matched with the [20] results. Figures 6 and 7 depict clearly the diaphragm wall influence on the bearing capacity values when the relative density is medium (55%), according to the results. As it can be observed, the existence of a wall attached to the footing is resisting the side displacement of the particles of soil beneath the footing as well as confining the soil, resulting in an important reduction in the upright settlement and thus increased the capacity of bearing.

It has been found that the more the wall depth, the more the bearing capacity, and hence the more the failure load as illustrated in Figs. 8 and 9. At the specific failure load, the settlement drop for the dense relative density can be observed when increasing the wall depth, as presented in the Fig. 9. Through the obtained results from the relative densities (loose, medium, and dense), it can be seen that the bearing capacity raises when the wall depth is augmented, and the best wall depth is between D and 2D for the all values of relative densities.

The best results obtained are when the soil is dense, as the wall cuts the lines of general failure and turns into a local failure. The results also manifested, that the amount of decrease in the settlement depends in general on the relative densities and the wall depth, as well as the relationship is the opposite between the ratio of settlement and relative densities and wall depth. When increasing the depth of wall with soil at different relative densities is more effective in raising the soil-foundation system stiffness, the sand is confined by the wall and the foundation works as one unit that behaves similar to a deep foundation and controls the vertical and horizontal movement under the foundation.

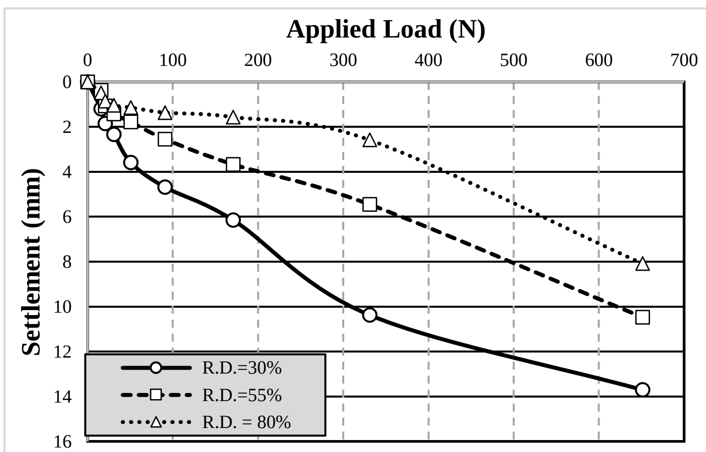

Fig 3. Load -settlement relationships for different relative densities without diaphragm wall.

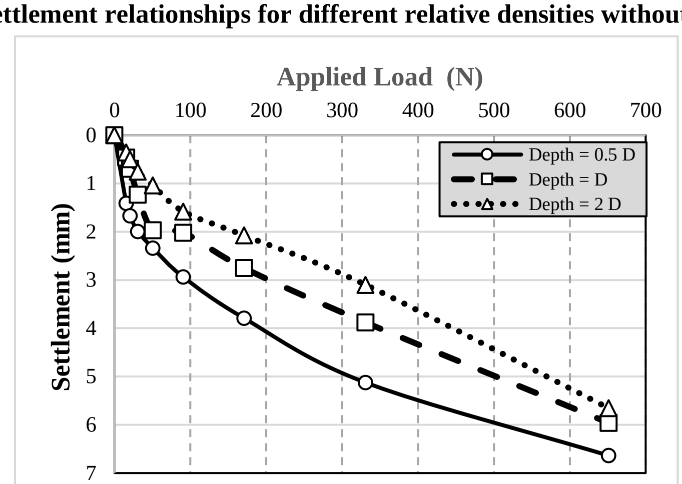

Fig 4. Load - settlement for loose relative density at different diaphragm wall depths.

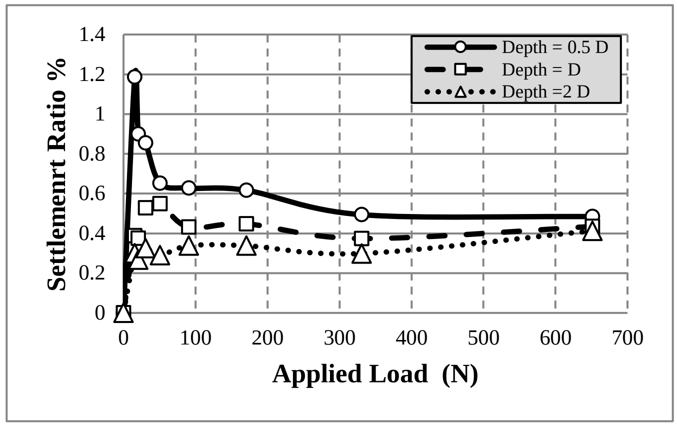

Fig 5. Reduction of settlement ratio vs. load of loose relative density at different diaphragm wall depths.

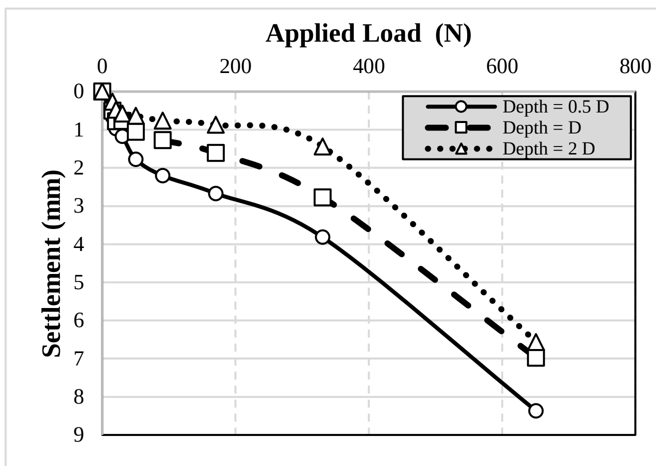

Fig 6. Load versus settlement for medium relative density at different diaphragm wall depths

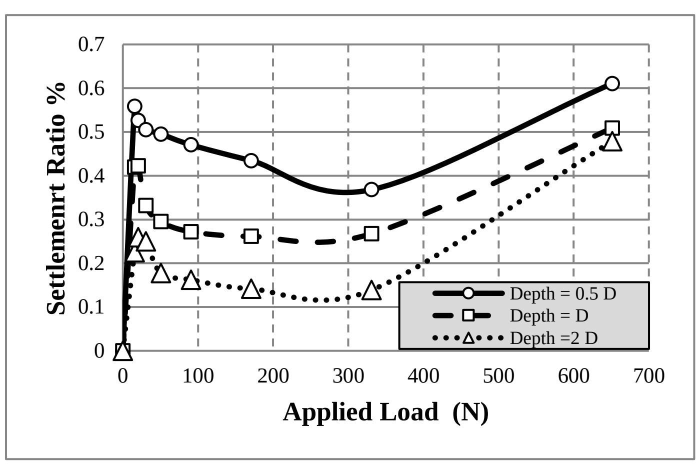

Fig 7. Reduction of settlement ratio vs. load for medium relative density at different diaphragm wall depths.

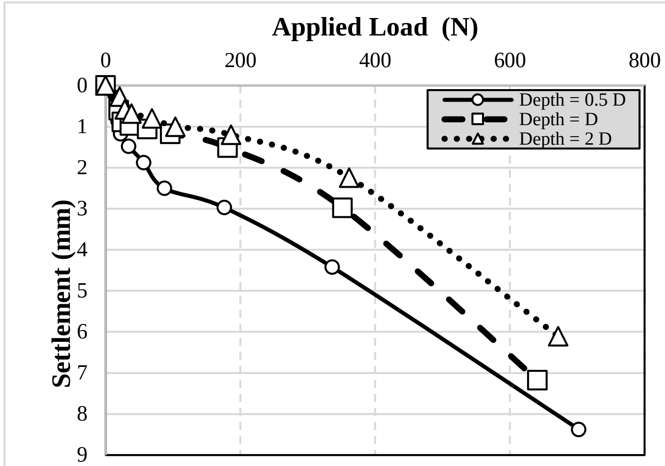

Fig 8. Load versus settlement for dense relative density at different diaphragm wall depths.

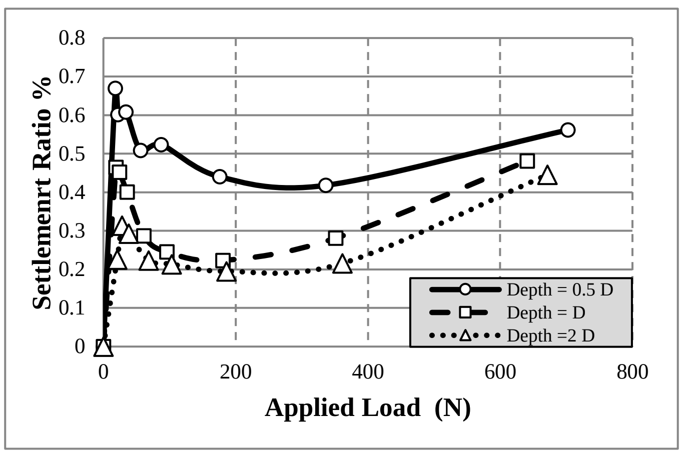

Fig 9. Reduction of settlement ratio vs. load of dense relative density at different diaphragm wall depths.

5. Conclusions

From the experimental investigation of circular foundation surrounded by diaphragm wall, resting embedded in the sandy soil with different relative densities can be summarized as the following conclusions

1. The bearing capacity is improved remarkably by using a diaphragm wall embedded in sandy soil with different relative densities. The maximum bearing capacity is 304 kN/m^2 at relative densities and 2D wall depth
2. The confinement of the soil leads to reducing the settlement ratio depending on the wall depth as well as the soil relative densities to reach about 57%.
3. The bearing capacity increases with increase of wall depth.
4. The bearing capacity is increased about (42.1, 57.4, 90.1 N) at a wall depth (0.5D, D, 2D) in loose soil.
5. The best results can be occurred when the soil is dense.
6. The sand confined by the wall and foundation works as one unit that behaves similarly to a deep foundation, in dense soil, the wall cuts the lines of general failure and turns into a local failure

References

Abdulrasool A. S., Abbas S. A., and Abdulrahman S. M. (2021). Improving Bearing Capacity by Skirted Foundation: A Review Study. *Iraqi Journal of Civil Engineering, 15* (1), 66–71.

Terzaghi, K. (1943). Theoretical Soil Mechanics. 2nd ed. John Wiley and Sons, New York, pp.510

Meyerhof, G.G. (1951). The Ultimate Bearing Capacity of Foundations. *Geotechnique*, 2, 301-332.

Meyerhof, G.G. (1963). Some Recent Research on the Bearing Capacity of Foundations. *Canadian Geotechnical Journal*, *1*, 16-31.

Hansen, J. B. (1970). A revised and extended formula for bearing capacity. *Bulletin of The Danish Geotechnical Institute*, *28*,5-11.

Vesic, A.S. (1973) Analysis of ultimate loads of shallow foundations. *ASCE Journal of Soil Mechanics and Foundation Division*, *99* (1), 45-73

Mahmood, M. (2018). Improvement ratio and behavior of bearing capacity factors for strip skirt footing model resting on sand of different grain size distribution. MATEC Web Of Conferences, 162, 01026. doi: 10.1051/matecconf/201816201026

Watson, P. G., & Randolph, M. F. (1997). Vertical capacity of caisson foundations in calcareous sediments. *International Society of Offshore and Polar Engineers (ISOPE)*, *1*, 784–790.

Byrne, B.W., Villalobos, F., Houlsby, G.T. and Martin C.M. (2002). Laboratory Testing of Shallow Skirted Foundations in Sand. Department of Engineering Science, The University of Oxford, Title, Thomas Telford, London.

Al-Aghbari, M. Y., & Mohamedzein, Y. E. (2004). Bearing capacity of strip foundations with structural skirts. *Geotechnical and Geological Engineering*, *22*(1), 43–57.

EL Wakil, A. Z. (2013). Bearing capacity of skirt circular footing on sand. *Alexandria Engineering Journal*, *52*, 359–364.

Tripathy, S. (2013). Load carrying capacity of skirted foundation on sand. MS Thesis, *National Institute of Technology*, Rourkela, India.

Dawarci, B., Ornek, M., & Turedi, Y. (2014). Analysis of multi-edge footings rested on loose and dense sand. *Period Politech Civil Engineering*, *58*(4), 355–370.

Al-Aghbari, M., & Mohamedzein, Y. (2018). The use of skirts to improve the performance of a footing in sand. *International Journal Of Geotechnical Engineering*, *14*(2), 134-141.DOI: 10.1080/19386362.2018.1429702

Haider, L., & Mekkiyah, H. M. (2018). Response of skirted foundations resting on dry medium dense sand. *Civil Engineering Journal*, *4*(6), 1193-1205.

Mahmood, M. R., Fattah, M. Y., & Khalaf, A. (2019). Experimental investigation on the bearing capacity of skirted foundations on submerged gypseous soil. *Marine Georesources & Geotechnology*, *38*(10), 1151-1162.

Al-qaissy, M., & Muwafak, H. (2013). Experimental study on the behavior of skirted foundation rested on soft clayey soils. *Engineering and Techechnology Journal*, *31*(20), 435- 443.

Khatri, V. N, Debbarma, S. P, Dutta, R. K, & Mohanty, B. (2017). Pressure- settlement behavior of square and rectangular skirted footings resting on sand. *Geomechanics and Engineering*, *12*(4), 689–705.

Eid, H. T. (2013). Bearing capacity and settlement of skirted shallow foundations on sand. *International Journal of Geomechanics*, *13*(5), 645-652.

El Sawwaf, M. and Nazer, A. (2005). Behavior of Circular Footings Resting on Confined Granular Soil. *Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 131*(3), 359-366.

Katagiri, M.; Saitoh, K.; Masuda, T.; Aizawa, F.; Ugai, K. (1997): Shape effect on deformation behaviour and stability of slurry trench walls constructed in sandy ground. In Proceedings of the International Symposium on Deformation and Progressive Failure in Geomechanics. Nagoya, Japan, 665–670.

Symons, I. F. and Carder, D. R. (1993). Stress changes in stiff clay caused by the installation of embedded retaining walls. *In Proceedings of the Conference on Retaining Structures*. Robinson College, Cambridge, United Kingdom, pp. 227–236.

Hajnal, I.; Márton, J.; Regele, Z. (1984). Construction of diaphragm walls. Budapest: Akadémiai Kiadó.

Tse, C. M.; Nicholson, D. P. (1993). Design, construction and monitoring of the basement diaphragm wall at Minster Court, London. In Retaining Structures, Edt. C.R.I.Clyton, Thomas Telford. London, pp. 323–332.

American Society of Testing and Materials (ASTM) (2010). Standard Test Method for Specific Gravity ASTM D 854, West Conshohocken, Pennsylvania, USA.

American Society of Testing and Materials (ASTM) (2010). Standard Test Method for Particle Size Analysis of Soils. ASTM D 422, West Conshohocken, Pennsylvania, USA.

American Society of Testing and Materials (ASTM) (2010). Standard Test Method for Maximum and Minimum Index Density and Unit Weight of Soils Using a Vibratory Table. ASTM D 4253-4254, West Conshohocken, Pennsylvania, USA.

American Society of Testing and Materials (ASTM) (2010). Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions. ASTM D 3080, West Conshohocken, Pennsylvania, USA.

BS EN 197-1, (2011). Cement. Part 1. Composition. Specifications and Conformity Criteria for Common Cements. BSI, London, UK.