International Journal of Civil and Structural Engineering Research ISSN 2348-7607 (Online)
Vol. 12, Issue 1, pp: (133-143), Month: April 2024 - September 2024, Available at: www.researchpublish.com

STUDY THE BEHAVIOR OF ELECTRICAL TOWER FOOTING SUBJECTED TO UPLIFT AND LATERAL LOADS

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DOI: https://doi.org/10.5281/zenodo.13310832

Published Date: 13-August-2024

Abstract: **The construction of high voltage electrical network in Egypt requires the construction of thousands of lattice towers of different shapes and sizes. Generally, the foundations of such towers are subjected to three types of loads, the downward trust (compression), the pullout (tension) and the side trust (horizontal shear). The soil above and surrounding a tower foundation has to resist a considerable amount of tension force and lateral force. In the current research, the effect of different parameters, such as the soil type, footing dimension, relative compaction and the ratio between the foundation depth to footing width on the pullout capacity of shallow horizontal footings subjected to uplift force and lateral force were studied. A detailed series of laboratory tests were carried out considering the footing dimensions (3.5*7 cm, 5*10 cm and 7.5*15 cm), the relative dentists (100% and 92%) were used. The ratio between foundation depths to footing width is (1, 1.5 and 2.5). A detailed series of laboratory tests were carried out to expect the behavior of the footing of electrical towers. A parametric study is performed to investigate the load displacement curve and the ultimate pullout load of shallow footings under tension force and lateral force.**

Keywords: **Uplift resistance, Lateral load, Anchor footing, Footings of lattice towers.**

1. INTRODUCTION

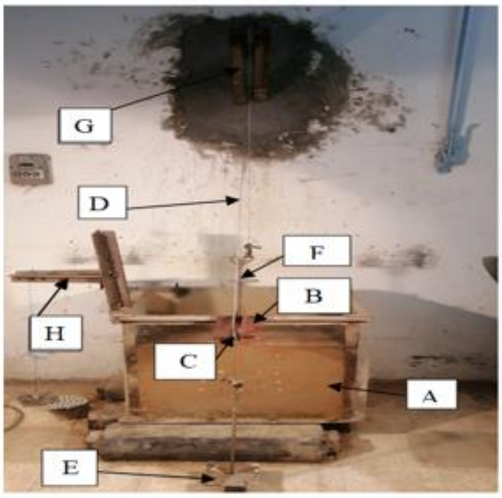
In this study, details of the experimental program consisting of testing 36 on footing subjected to uplift load and horizontal load are presented. The main objectives of the experimental program are: 1) Investigate experimentally the behavior of the load displacement curve under tension force and lateral force. 2) To studding the effect of different parameters on the value of pullout load. 3) To compare the different between the value of ultimate bearing capacity for footing under tension force only, under tension force and lateral force. 4) Expect the ultimate uplift value for footing under vertical load and lateral load are the most realistic since it is similar to what happens in nature.

2. EXPERMINTAL STUDY

This research work involves a laboratory testing program carried out to study experimentally the load displacement curve and the ultimate pullout load of shallow footings subjected to compression force, uplift force and shear force. The shear force will consequently cause bending moment on the footing. The experimental program is presented together with a full description of the laboratory model which was used in this research. It presents also the procedures of the experimental work including the loading & measuring systems.

2.1 Model description

The components of the model are shown in figure 1 .The model consist of:



A- Perspex plate
B- Steel beam
C- Small wheel
D- Frictionless wire
E- Weights
F- Footing
G-Vertical angle
H- Horizontal angle

2.2 Soil box

The experiments were conducted in a rigid testing tank of 60 cm in length, 40 cm in width, and 60 cm in height, the sides of the model are made of mild steel plates 8 mm thick which is painted with epoxy. Consequently, during testing, the friction generated between sand particles and the walls of the tank was minimized. The front side of the tank is a Perspex plate. The Perspex is transparent to permit the tracing of the failure planes. The base and the sides of the steel tank are stiffened by additional steel sheets welded on the base and the sides of the tank acting as a strap or tie to prevent buckling of the tank base and tank sides during compacting soil or pulling anchors. The tank was centered under the steel angle, which was exerted a tensile force on the footing. The tank was supported on blocks made of concrete as shown in figure 2.

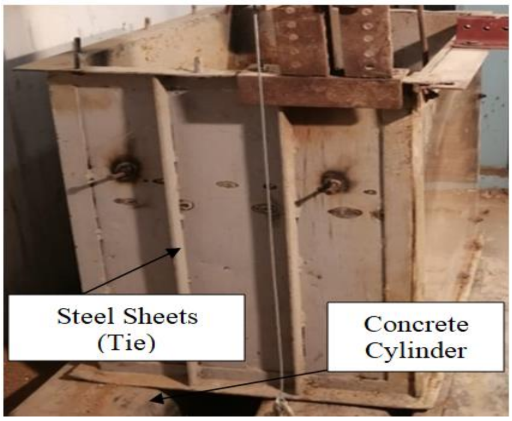


Fig 2: Soil Container

2.3 Footing plates

Tests are performed on half square footing plates, which were used as anchor for structures. Model footings 3mm thick rigid plates are adopted. Experiments used three types of footing plates different in dimensions.

2.4 Loading system

The loading system, as shown in Figure 3 This system was designed to be rigid and capable of sustaining the high stresses involved without suffering from excessive deflections. This system consists of four steel angles. The first steel angle is 55 cm long. It is fixed in the laboratory's wall. The second angle is 20 cm long fixed in the front side on the center of the tank's edge. The first and the second angles used to effect on the footing by uplift force .The third angle is 20cm long fixed in other angle bolted in the left side of the tank's edge these angles used to effect on the footing by lateral force. The angles include four small steel wheels, passing over them a steel wire. The wire connected with the rod of the footing is used, and supported on the five rings to able us putting loads as lateral and vertical.

Fig 3: The loading system

2.5 Test material

TABLE (I): characteristic of the used soil

Index Property	Value
pure sand	
Specific gravity (Gs)	2.64
D10 (mm)	0.18
Coefficient of uniformity (Cu)	2.5
Coefficient of curvature (Cc)	1.15
Friction angle	36.5º
Maximum dry density	1.803t/m3
Optimum moisture content	6.02%
Sand+8%Fines	
Specific gravity (Gs)	2.66
%Coarse	5%
%Silt	25%
%Clay	70%
%Liquid limit	63%-65%
%Plastic limit	37%-39%
Friction angle	43º
Cohesion	0.82t/m2
Soil Classification according to (USCS)	CH

2.6 Testing procedure

The tank sample for each test was prepared separately by placing granular soil compacted to a relative compaction of (100% and 92%) at the bottom and lateral sides of the tank in a U shape. Half amount of the mixture is placed in the tank in two layers. Each layer is compacted by a manual rammer to satisfy the required maximum unit weight determined from the compaction tests. The surface of the soil is leveled using a straight wooden rod. The place of footing was drilled and the soil is well compacted above footing, then the footing is set in their place and the soil is leveled. After the footing preparation is completed, the loading system is fixed; the anchor is loaded vertical gradually by adding loads incrementally on the loading system at constant rates which vary at stages as shown in figure 1. When effect on the footing subjected to vertical and lateral force together we commit by this loading ratio (6:1) vertical to horizontal this ratio we expected from designed tower in horizon consulting engineering as shown in figure 4.

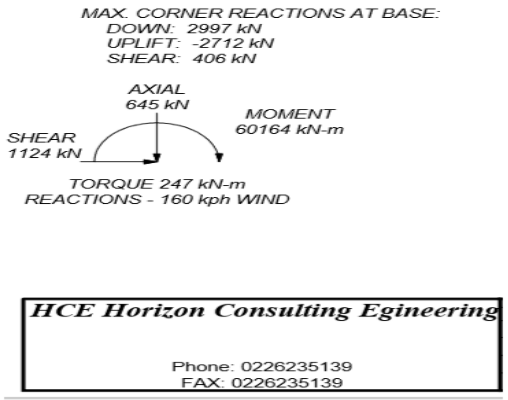


Fig 4: The loading ratio between vertical and horizontal load on tower footing.

3. EXPREMENTAL RESULTS

3.1 Load-vertical displacement relations of shallow footings under tension force and lateral force.

A total of 36 tests were carried out to determine the ultimate pullout capacity of shallow footing under uplift force and lateral force. The soil consists of sand (density 1.8 t/m3) when relative compaction is (RC% = 100%), (density 1.65 t/m3) at (RC%=92%), and sand +8% fines (density 1.92 t/m3) when relative compaction is (RC% = 100%), (density 1.76 t/m3) at (RC% = 92%). Figures 5 to 13 show the load-displacement curves of the tested footings under vertical force and lateral force with different ratios between depth of footing to footing width (D\B) = (1, 1.5 and 2.5) and with different footing dimensions.

From all figures showing test results for different parameters, it is clear that the general shape of these curves has negligible displacement with the initial loading, then the displacement increases with loading, then the pullout resistance decreases with the displacement increasing until the failure occurs.

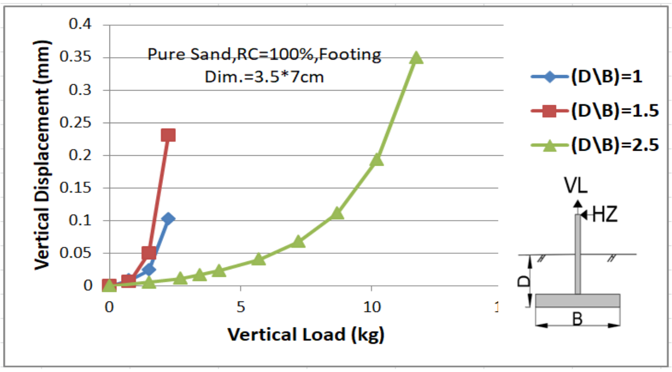


Fig 5: Load- vertical displacement relations of footing dimension (3.5*7) cm in pure sand with relative compaction (RC=100%) for different embedment depths of footing to footing width under tension force and lateral force.

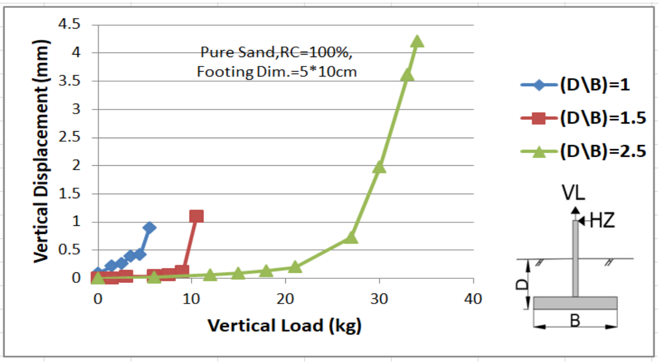


Fig 6: Load- vertical displacement relations of footing dimension (5*10) cm in pure sand with relative compaction (RC=100%) for different embedment depths of footing to footing width under tension force and lateral force.

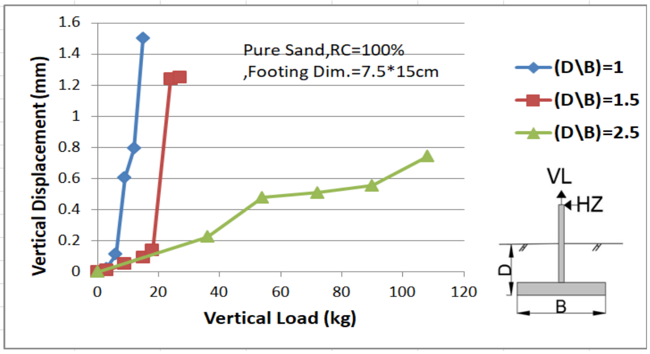


Fig 7: Load- vertical displacement relations of footing dimension (7.5*15) cm in pure sand with relative compaction (RC=100%) for different embedment depths of footing to footing width under tension force and lateral force.

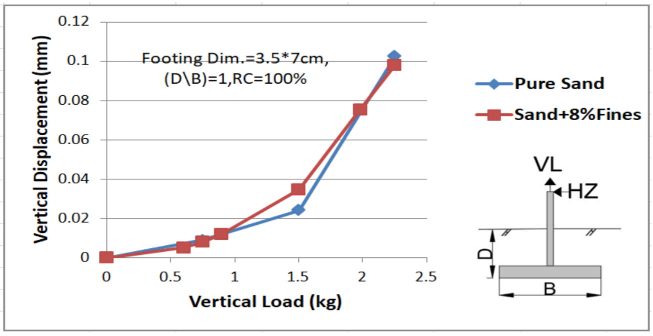


Fig 8: Load- vertical displacement relations of footing dimension (3.5*7)cm in embedment depth of footing to footing width (D\B)=1 with relative compaction (RC=100%) for different types of soil(pure sand and Sand+8%fines) under tension force and lateral force.

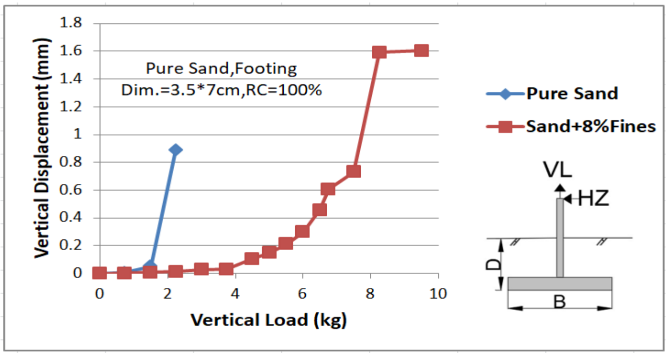


Fig 9: Load- vertical displacement relations of footing dimension (3.5*7) cm in embedment depth of footing to footing width (D\B)=1.5 with relative compaction (RC=100%) for different types of soil under tension force and lateral force.

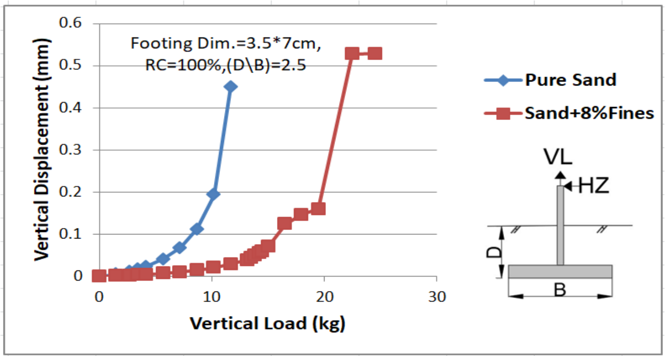


Fig 10: Load- vertical displacement relations of footing dimension (3.5*7)cm in embedment depth of footing to footing width (D\B)=2.5 with relative compaction (RC=100%) for different types of soil(pure sand and Sand+8%fines) under tension force and lateral force.

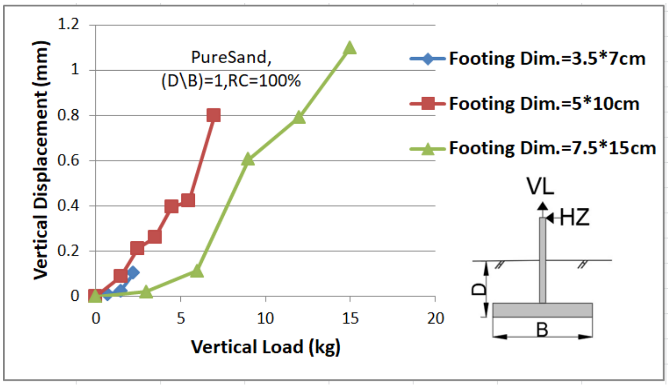


Fig 11: Load- vertical displacement relations for pure sand in embedment depth of footing to footing width (D\B)=1 with relative compaction (RC=100%) for different footing dimensions (3.5*7),(5*10)&(7.5*15)cm under tension force and lateral force.

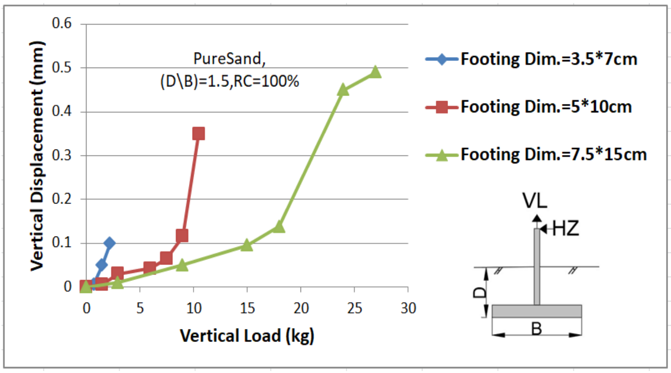


Fig 12: Load- vertical displacement relations for pure sand in embedment depth of footing to footing width (D\B)=1.5 with relative compaction (RC=100%) for different footing dimensions (3.5*7),(5*10)&(7.5*15)cm under tension force and lateral force.

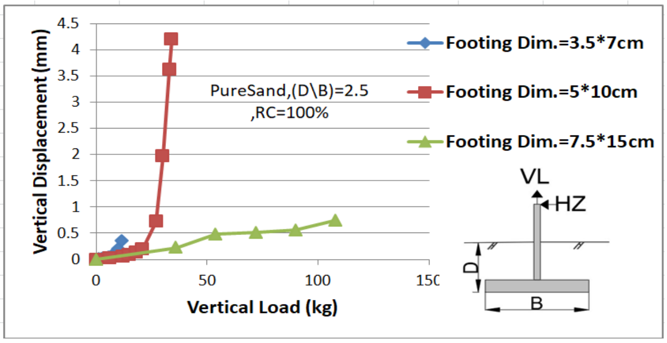


Fig 13: Load- vertical displacement relations for pure sand in embedment depth of footing to footing width (D\B)=2.5 with relative compaction (RC=100%) for different footing dimensions (3.5*7),(5*10)&(7.5*15)Cm under tension force and lateral force.

3.2 Effect of variation of embedment depth of footing to footing width (D/B) on the pullout loads for footings under vertical force and horizontal force.

To study the effect of embedded depth of footing (D) on the ultimate pullout force, tests were conducted with varying embedded depth of footing in relation to widths of footing (D/B). The (D/B) ratio was varied (1, 1.5and 2.5).The thickness of sand layer (D) above foundation level to width of footing (B).

Figures 14 through 16 exhibit the variation of ultimate pullout force and versus the embedded depth to footing width ratio .By examining the figures, it is clear that the increase in the embedment depth of footings to footing width in soil leads to increase in the ultimate pullout force.

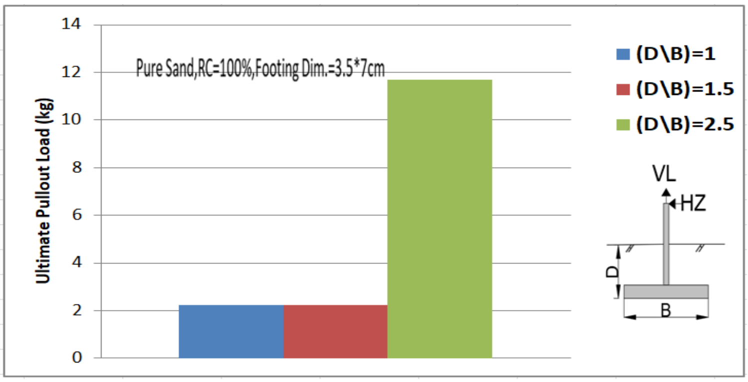


Fig 14 : The variation of the ultimate pullout load with different embedment depths of footing to footing width of footing dimension (3.5*7)cm in pure sand with relative compaction (RC=100%) under tension force and lateral force.

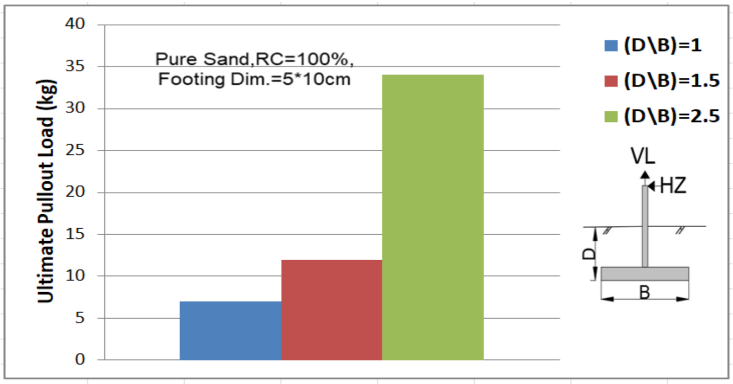


Fig 15 : The variation of the ultimate pullout load with different embedment depths of footing to footing width of footing dimension (5*10)cm in pure sand with relative compaction (RC=100%) under tension force and lateral force.

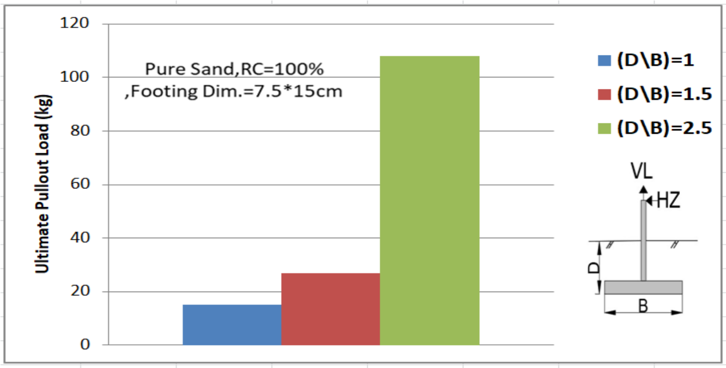


Fig 16: The variation of the ultimate pullout load with different embedment depths of footing to footing width of footing dimension (7.5*15)cm in pure sand with relative compaction (RC=100%) under tension force and lateral force.

3.3 Effect of variation in soil type on pullout loads under tension force and lateral force.

In case footing dimension, relative compaction of soil and the ratio between embedded depth of footing to footing width (D\B) are constant, the soil types used are pure sand and sand + 8% fines.

Figures 17 through 19 exhibits the variation of ultimate pullout loads versus the soil type. It is noticed that the value of ultimate pullout force in case the soil type sand + 8% fines is more than that where the soil type is pure sand.

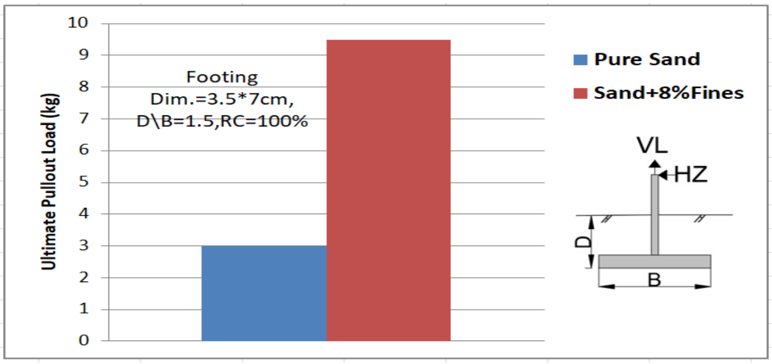


Fig 17 : The variation of the ultimate pullout load with different types of soil (pure sand and Sand+8%fines) of footing dimension (3.5*7)cm in embedment depth of footing to footing width (D/B)=1.5 with relative compaction (RC=100%) under vertical force and horizontal force.

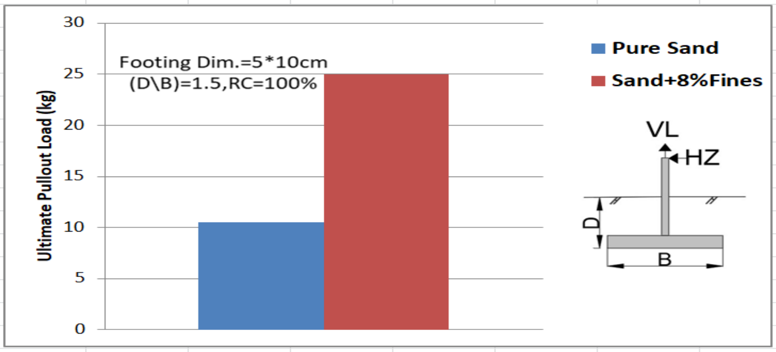


Fig 18 : The variation of the ultimate pullout load with different types of soil (pure sand and Sand+8%fines) of footing dimension (5*10)cm in embedment depth of footing to footing width (D/B)=1.5 with relative compaction (RC=100%) under vertical force and horizontal force.

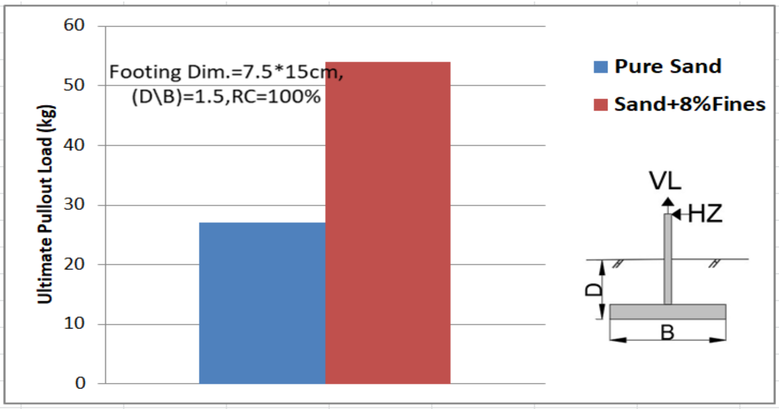


Fig 19 : The variation of the ultimate pullout load with different types of soil (pure sand and Sand+8%fines) of footing dimension (7.5*15)cm in embedment depth of footing to footing width (D/B)=1.5 with relative compaction (RC=100%) under vertical force and horizontal force.

3.4 Effect of variation of footing dimensions on pullout load under tension force and lateral force.

Where relative compaction of soil, with ratio between embedded depth of footing to footing width (D/B) and the soil types are equal, and the footing dimensions are variable (3.5*7, 5*10 & 7.5*15) cm:

The variation of the ultimate pullout loads were drawn as shown in the figures 20 to 22, which show that the variation of pullout load versus the footing dimensions, the increase in the footing dimensions leads to increase in the pullout force.

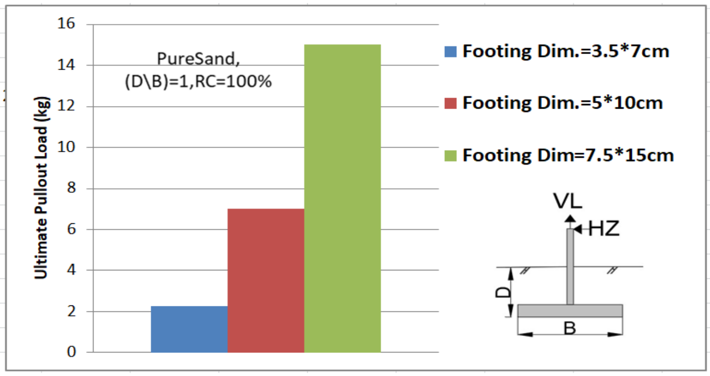


Fig 20 : The variation of the ultimate pullout load with different footing dimensions (3.5*7),(5*10)&(7.5*15)cm for pure sand in embedment depth of footing to footing width (D/B)=1 with relative compaction (RC=100%) under vertical force and horizontal force.

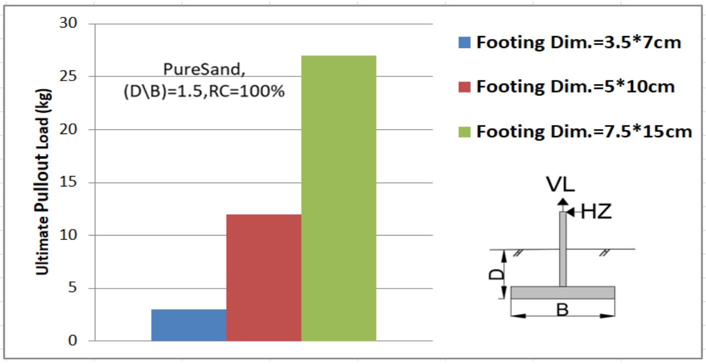


Fig 21 : The variation of the ultimate pullout load with different footing dimensions (3.5*7),(5*10)&(7.5*15)cm for pure sand in embedment depth of footing to footing width (D/B)=1.5 with relative compaction (RC=100%) under vertical force and horizontal force.

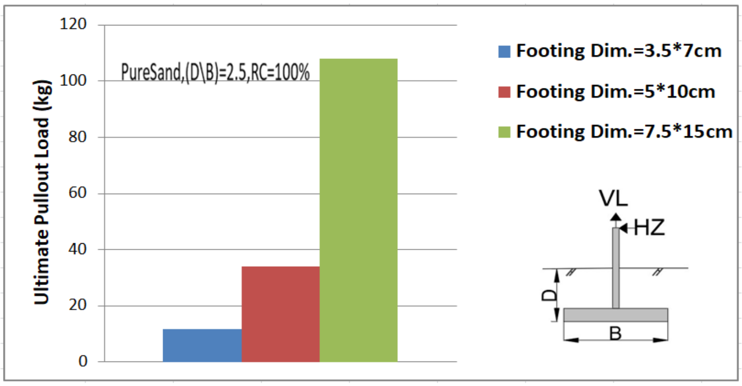


Fig 22: The variation of the ultimate pullout load with different footing dimensions (3.5*7),(5*10)&(7.5*15)cm for pure sand in embedment depth of footing to footing width (D/B)=2.5 with relative compaction (RC=100%) under vertical force and horizontal force.

3.5 Effect of variation in relative compaction (RC%) of soil on pullout load under tension force and lateral force.

When soil type, footing dimension, and the ratio between embedded depth of footing to footing width (D/B) are constant, the relative compaction is variable (RC% = 100% & RC% = 92%). Figures 23 to 25 exhibit the variation of ultimate pullout load versus the relative compaction of soil.

It is noticed that the behavior of footings under the influence of tension force only is the same as that of footings subjected to tension force with horizontal force, which is the increase in the relative compaction of soil leads to increase in the pullout force.

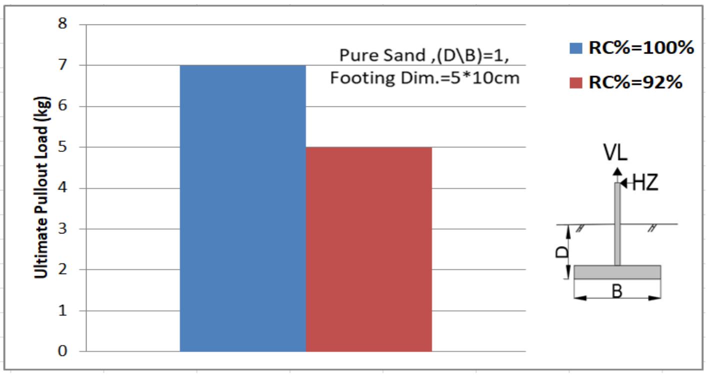


Fig 23: The variation of the ultimate pullout load with different relative compactions (RC=100%)&(RC=92%) for type of soil (Pure Sand) in embedment depth of footing to footing width (D/B)=1 for footing dimension (5*10) cm under vertical force and horizontal force.

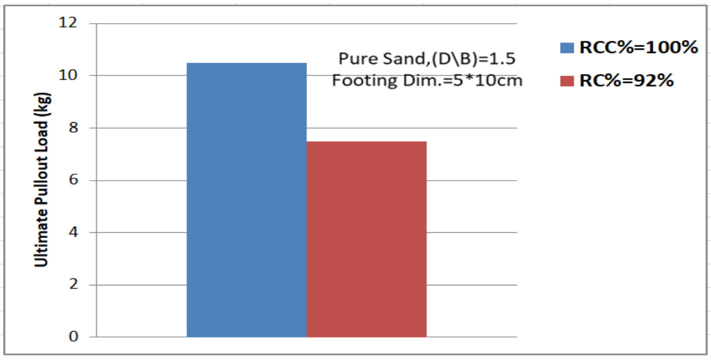


Fig 24: The variation of the ultimate pullout load with different relative compactions (RC=100%)&(RC=92%) for type of soil (Pure Sand) in embedment depth of footing to footing width (D/B)=1.5 for footing dimension (5*10) cm under vertical force and horizontal force.

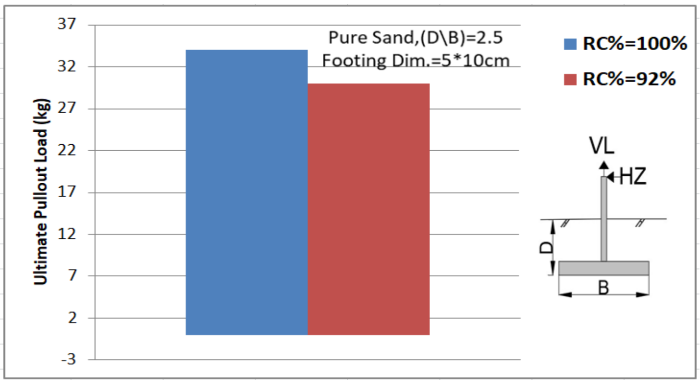


Fig 25: The variation of the ultimate pullout load with different relative compactions (RC=100%)&(RC=92%) for type of soil (Pure Sand) in embedment depth of footing to footing width (D/B)=2.5 for footing dimension (5*10) cm under vertical force and horizontal force.

4. CONCLUSION

1- The shapes of the load-displacement curves for single footings subjected to vertical load and lateral load have negligible displacement with the initial loading, then the displacement increases with loading, then the pullout resistance decreases with the displacement increasing until the failure occurs.

2- The increase in the embedment depth of footings to footing width from (D\B)=1.5 to (D\B)=2.5 in soil leads to increase in the ultimate pullout force by 74 % for single footing subjected to vertical force and horizontal force.

3- Adding percentage of fines by 8% fines significantly increased the ultimate pullout resistance by 58.4% of a symmetrical single footings subjected to uplift load and lateral load. So it is recommended to add fines to sandy soil.

4- The increase in the footing dimension from (5*10) cm to (7.5*15) cm leads to increase in the ultimate pullout force by 58.2% for single footing subjected to vertical force and horizontal force.

5- The ultimate pullout load increased by 22.9% when increasing the relative compaction of soil from (92%) to (100%) for single footing subjected to pullout force and lateral force.

REFERENCES

[1] Dickin E.A. (1988), ‘Uplift Behaviour of Horizontal Anchor Plates in Sand’, Journal of Geotechnical Engineering Division, ASCE, Vol. 114 (GT11), pp. 1300-1317.

[2] Dickin E.A. and Laman (2007), ‘Uplift Response of Strip Anchors in Cohesionless Soil’, Journal of Advances in Engineering Software, Vol. 38, pp. 618-625.

[3] Frydman S. and Shaham I. (1989), ‘Pullout capacity of slab anchors in sand’, Canadian Geotechnical Journal, Vol. 26, pp. 385-400.

[4] Geddes J. D. and Murray E. J. (1996), ‘ Plate Anchor groups pulled vertically in sand’,Journal of Geotechnical Engineering Division, ASCE, vol. 122, No. 7, pp. 509-516.

[5] Giffels W.C., Graham R.E. and Mook J.F. (1960), ‘Concrete cylinder anchors proved for 345-KV tower line’, Electrical World, Vol. 154, pp. 46-49.

[6] Ilamparuthi K. (1991), ‘Experimental investigation on pullout capacity of plate anchors in sand’, Ph.D. thesis submitted to the faculty of Ocean Engineering, IIT Madras.

[7] Ilamparuthi K. and Dickin E.A. (2001a), ‘The influence of soil reinforcement on the uplift behaviour of belled piles embedded in sand bed’, Geotextiles and Geomembranes, Vol. 19, pp. 1-22.

[8] Ilamparuthi K. and Dickin E.A. (2001b), ‘Predictions of the uplift response of model belled piles in geogrid-cell-reinforced sand’, Geotextiles and Geomembranes, Vol. 19, pp. 89-109.

[9] Ilamparuthi K., Dickin E.A. and Muthukrisnaiah K. (2002), ‘Experimental Investigation of the Uplift Behaviour of Circular Plate Anchors Embedded in Sand’, Canadian Geotechnical Journal, Vol. 39, pp. 648-664.

[10] Ireland H.O. (1963), ‘Discussion on Uplift Resistance of Transmission Towers’, by E.A. Turner, Journal of Power Division, ASCE, Vol. 89, No. 1, pp. 115-118.

[11] Jyant Kumar K. (2004), ‘Effect of dilatancy angle on uplift resistance of shallow foundation anchors’, Indian Geotechnical Journal, Vol. 34, No. 2, pp. 203-225.

[12] Korkmaz B. and Keskin M.S. (2017), ‘Numerical Analysis of Uplift Capacity Behaviour of Circular Plate Anchors Under Different Conditions’, Digital Proceeding of ICOCEE – CAPPADOCIA2017, Nevsehir, TURKEY, pp. 1-10.

[13] Kortam El.M. (2008) ‘Uplift Capacity for Footings and Footing Group’. M.Sc. Thesis, Faculty of Engineering, Mataria Civil Engineering Department, Helwan University.

[14] Krishnaswamy N.R. and Parashar S.P. (1991), ‘Effect of Submergence on the uplift resistance of footings with geosynthetic inclusion’, Proceedings of Indian geotechnical conference, Surat, India, pp. 333-336.