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Experimental Study for Determining the Uplift Capacity of Footings Subjected to Tension Force

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Abstract: **The present work is devoted for studying the behavior of shallow footings subjected to vertical pullout force only. This research is applicable particularly in the construction of high voltage electrical network in Egypt, which has required the construction of thousands of lattice towers of different shapes and sizes. The total cost of foundation works in a transmission project may be quite high; therefore, the investigation for the pullout resistance of footings is very important in order to achieve rational and economical design for the footings.**

The ultimate pullout resistance of footing-soil system is calculated as a function of the footing geometrical dimensions and soil properties. The pullout resistance mainly depends on different factors namely, depth of embedment, soil density, footing width and percentage of fine content.

The study was done by performing experimental work comprising footing plate models, fabricated to fit into a tank 60 x 40 x 40 cm.

Keywords: **Pullout force, Uplift resistance, Anchor footing, Footings of lattice towers.**

1. INTRODUCTION

Analysis of the footings of the electrical towers which exposed to uplift force requires the determination of the load-deformation characteristics and expects the ultimate pullout load. The pullout load mainly depend on different factors namely, the depth of embedment, soil density, percentage of fine content and footing dimension [1].

There are many analytical methods to estimate the ultimate uplift resistance and to expect the failure mechanism, which depend mainly on the weight of soil trapped above the anchor plate and surrounded by the sliding surface and the friction forces exist on the sliding surface due to the earth pressure or due to shear strength of soil. The sliding surface at the meridian section of footing is assumed to vary between vertical or inclined straight line or logarithmic spiral curve. Various attempts for analysing the behaviour of anchors in soil had been carried out over the last three decades. In this research, a review is performed to investigate the existing analytical researches in this area **[2]**.

Studies on the behaviour of anchors against uplift force were started way back in the 1960s. Initially, the pullout capacity of anchors was predicted from the test results on anchor for transmission line towers **[3],[4]**. Later on the prediction was based on the results on 1g model and centrifuge model studies. Over a period of the last five decades research work in this area was carried out extensively in order to understand the real mechanism of failure of anchors against uplift force. Numerous theories were developed, mostly based on limit equilibrium method by using assumed or observed failure surfaces. With the vast knowledge on the uplift capacity of anchor, researchers have concentrated mainly on improving the uplift capacity of the anchors.

Varieties of anchors are developed in the field to meet the needs of growing anchorage problems. Scanning through the various types of anchors and the field applications, plate anchors are considered to be one of the most popular varieties of anchors extensively used in various types of onshore and offshore construction and maintenance works. They represent economically better alternative to gravity and other embedded anchors for resisting uplift forces **[5]**. Many researchers have worked with the anchors subjected to uplift of plate anchors buried both in cohesionless and cohesive soils. The works carried out to predict the uplift behaviour of anchors in cohesionless soils under monotonic and cyclic loading conditions are reviewed herein **[6]**.

Uplift theories are generally based on assumed failure surfaces. Developed the first rational approach of loads on buried conduits by assuming a vertical slip surface having a width equal to that of the diameter of the pipe embedded **[7]**. The pullout capacity was computed by considering the frictional resistance along this surface and the weight of soil bounded within the failure surfaces. However, his analysis exhibited the behaviour entirely different from the experimental results as well as from the other investigators **[8]**.

This method developed estimate the uplift capacity of foundation based on experimental and theoretical results. He suggested shearing force acting along a vertical rupture surface. This force expressed in terms of soil cohesion, angle of internal friction and coefficient of earth pressure at rest **[9]**.

The main aim of this research is to investigate experimentally the failure mechanism for shallow footings embedded in soil and affected by uplift force. The force is imposed using loading system. Consequently, this study aims to help researchers to analyse the current state of the research and recognize the future developments in foundation research.

2. EXPERIMENTAL WORK

This research work involves a laboratory testing program carried out to study experimentally the failure mechanism of shallow footings subjected to uplift force only. A digital photogrammetric system is adopted for studying this field of displacement. 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 Fig. 1.The model consist of:

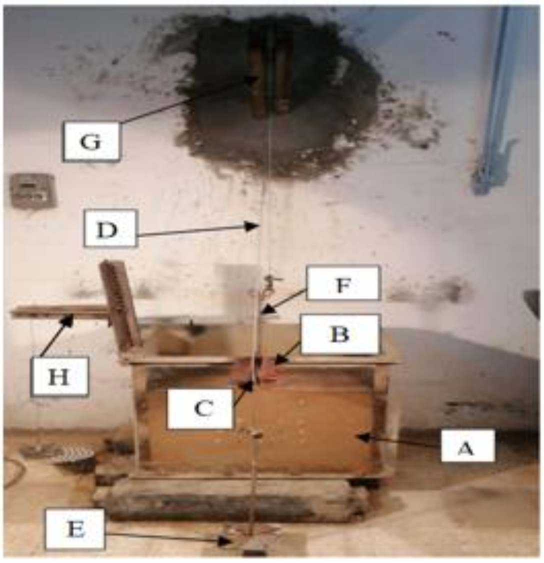

Fig. 1: Photo showing model configuration

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

2.2 LOADING SYSTEM

The loading system, as shown in Fig. 2. This system was designed to be rigid and capable of sustaining the high stresses involved without suffering from excessive deflections. This system consists of two 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 angles used to effect on the footing by uplift force only. The angles include two small steel wheels, passing over them a steel wire. The wire connected with the rod of the footing is used, and supported on rings to able us putting loads.

Fig.2: The loading system

2.3 TEST MATERIAL

Table 1: 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

3. RESULTS AND DISCUSSION

3.1 LOAD-VERTICAL DISPLACEMENT RELATIONS OF SHALLOW FOOTINGS UNDER TENSION FORCE ONLY.

A total of 36 tests were carried out to determine the ultimate pullout capacity of shallow footing under uplift force only. 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%). Fig. 3 to 14 show the load-displacement curves of the tested footings under vertical force only 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 **[10]**.

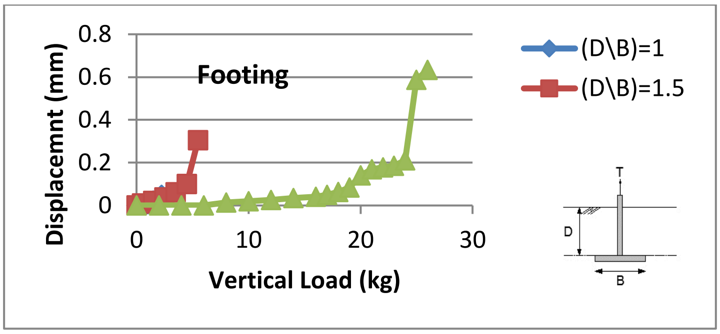

Fig.3: Load- vertical displacement relations of footing dimension (3.5*7) cm in pure sand with relative compaction (RC=100%) for different embedment depths of footing to footing width.

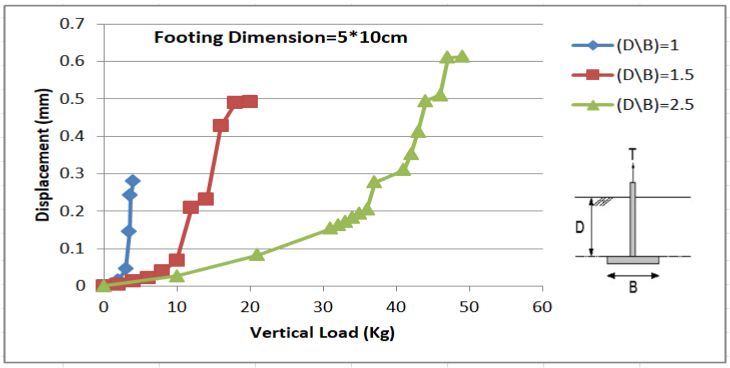

Fig. 4: Load- vertical displacement relations of footing dimension (5*10) cm in pure sand with relative compaction (RC=100%) for different embedment depths of footing to footing width.

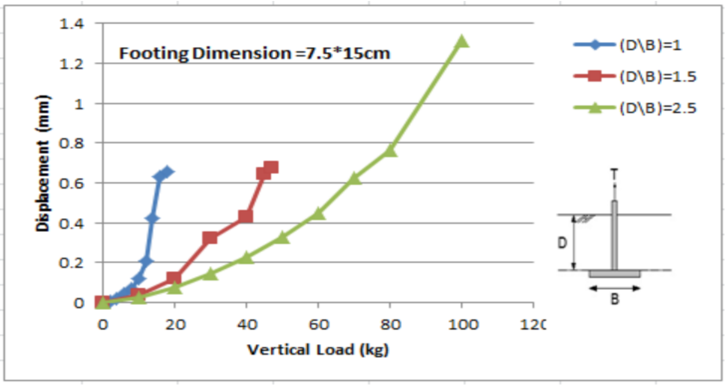

Fig.5: Load- vertical displacement relations of footing dimension (7.5*15) cm in pure sand with relative compaction (RC=100%) for different embedment depths of footing to footing width.

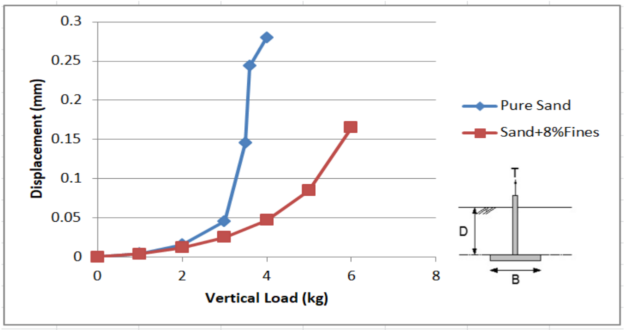

Fig.6: Load- vertical displacement relations of footing dimension (5*10) cm in embedment depth of footing to footing width (D/B)=1 with relative compaction (RC=100%) for different types of soil(pure sand and Sand+8%fines).

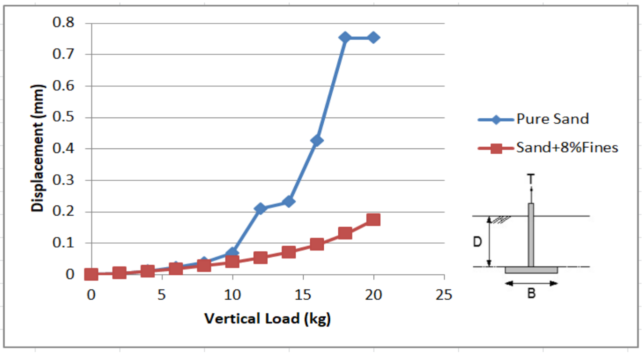

Fig.7: Load- vertical displacement relations of footing dimension (5*10) cm in embedment depth of footing to footing width (D/B)=1.5 with relative compaction (RC=100%) for different types of soil(pure sand and Sand+8%fines).

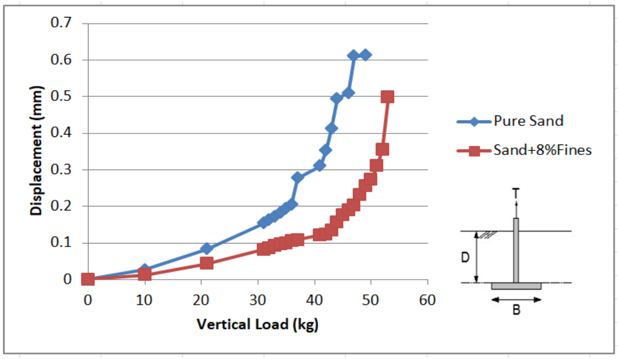

Fig.8: Load- vertical displacement relations of footing dimension (5*10) cm in embedment depth of footing to footing width (D/B) =2.5 with relative compaction (RC=100%) for different types of soil (pure sand and Sand+8%fines).

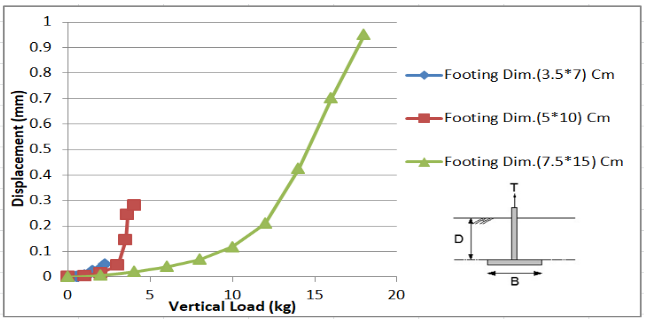

Fig.9: Load- vertical displacement relations for pure sand in embedment depth of footing to footing width (D/B)=1 with relative compaction (RC=100%) for different footing dimensions

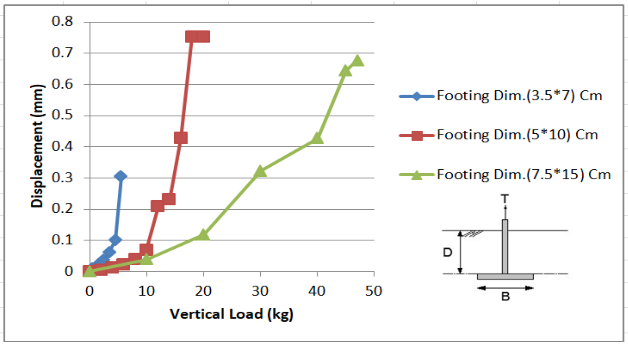

Fig.10: Load- vertical displacement relations for pure sand in embedment depth of footing to footing width (D/B) =1.5 with relative compaction (RC=100%) for different footing dimensions (3.5*7),(5*10)&(7.5*15)cm.

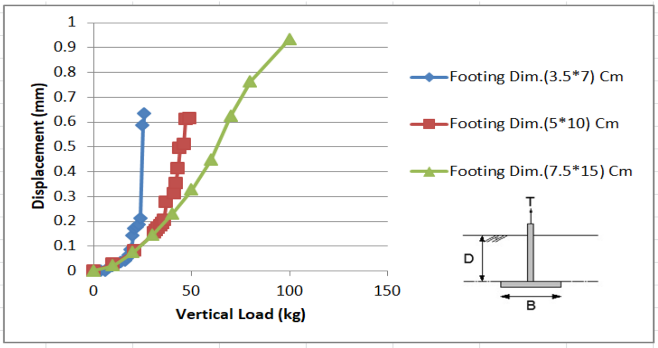

Fig.11: Load- vertical displacement relations for pure sand in embedment depth of footing to footing width (D/B) =2.5 with relative compaction (RC=100%) for different footing dimensions (3.5*7),(5*10)&(7.5*15)cm.

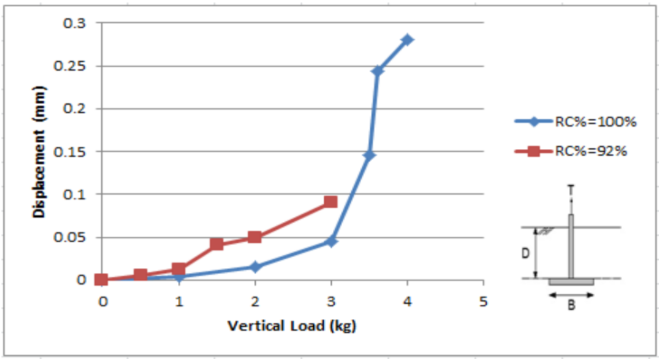

Fig.12: Load- vertical displacement relations for type of soil (Pure Sand) in embedment depth of footing to footing width (D/B) =1 for footing dimension (5*10) cm with different relative compactions (RC=100%) & (RC=92%).

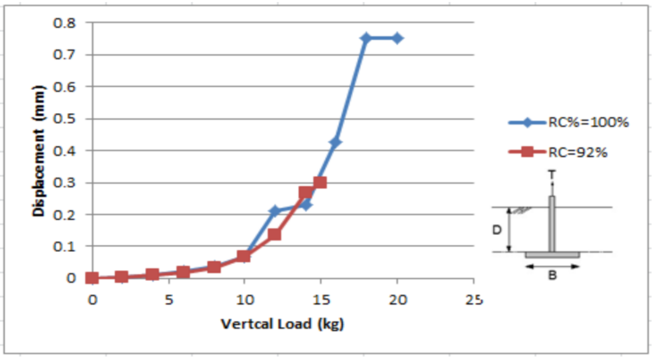

Fig.13: Load- vertical displacement relations for type of soil (Pure Sand) in embedment depth of footing to footing width (D/B) =1.5 for footing dimension (5*10) cm with different relative compactions (RC=100%) & (RC=92%).

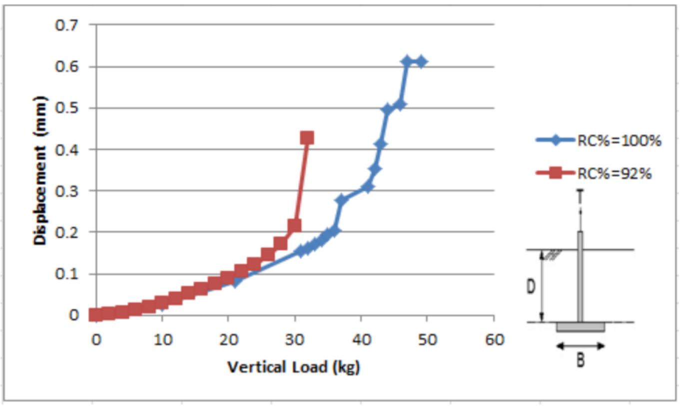

Fig.14: Load- vertical displacement relations for type of soil (Pure Sand) in embedment depth of footing to footing width (D/B) =2.5 for footing dimension (5*10) cm with different relative compactions (RC=100%) & (RC=92%).

3.2 EFFECT OF VARIATION OF DEPTH OF FOOTING TO FOOTING WIDH (D/B) ON THE PULLOUT LOAD FOR FOOTINGS UNDER TENSION FORCE ONLY.

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). Where (D) is the thickness of sand layer above foundation level and (B) is the width of footing.

Fig. 15 through 17 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 **[11]**.

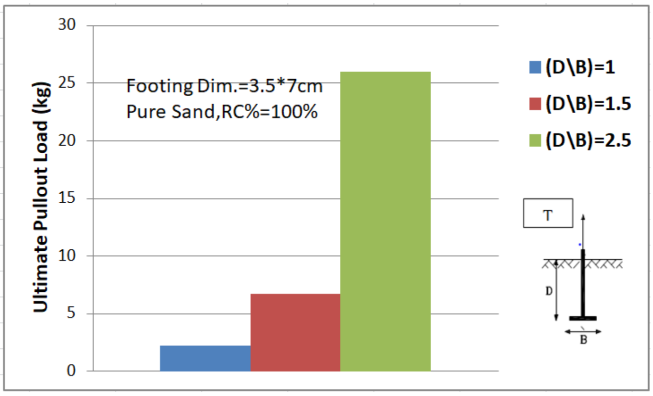

Fig. 15: The variation of the ultimate pullout load with different embedment depths of footing to footing width of footing dimension (3.5*7)cm in pure sand with relative compaction (RC=100%) .

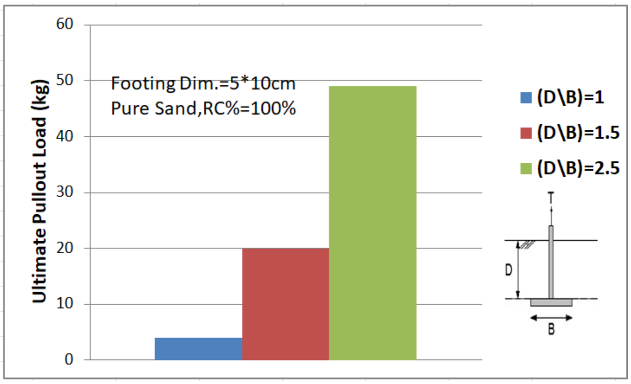

Fig.16: The variation of the ultimate pullout load with different embedment depths of footing dimension (5*10)cm in pure sand with relative compaction (RC=100%).

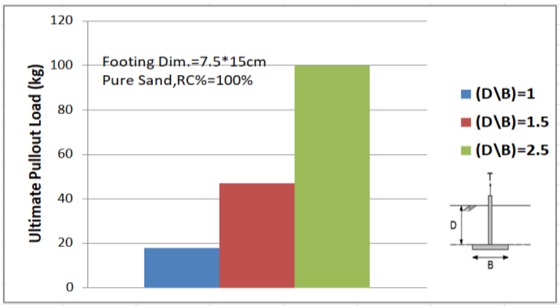

Fig.17: The variation of the ultimate pullout load with different embedment depths of footing dimension (7.5*15)cm in pure sand with relative compaction (RC=100%).

3.3 EFFECT OF VARIATION IN SOIL TYPE ON PULLOUT LOAD UNDER TENSION FORCE ONLY.

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.

Fig. 18 through 20 exhibits the variation of Ultimate Pullout Loads versus the soil type. It is noticed that the value of ultimate pullout force in the case of the soil type sand + 8% fines is more than that where the soil type is pure sand **[12]**.

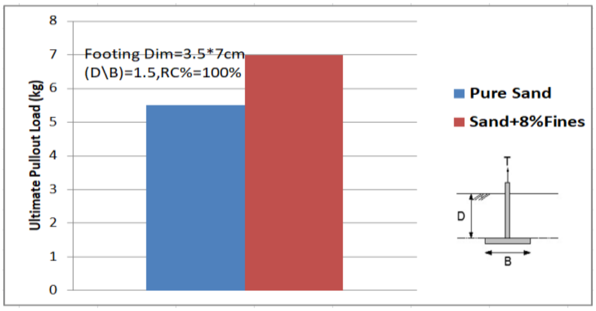

Fig.18: The variation of the ultimate pullout load with different types of soil (pure sand and Sand+8%fines) of footing dimension (3.5*7)cm in embedment depth of footing to footing width (D/B)=1.5 with relative compaction (RC=100%).

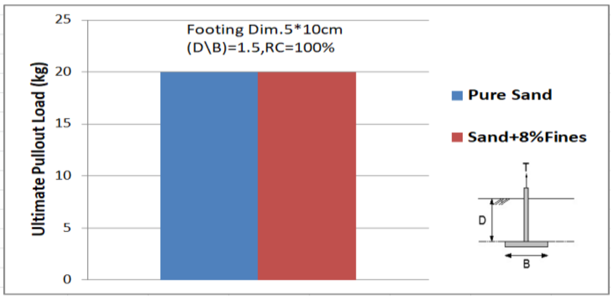

Fig.19: The variation of the ultimate pullout load with different types of soil (pure sand and Sand+8%fines) of footing dimension (5*10)cm in embedment depth of footing to footing width (D/B)=1.5 with relative compaction (RC=100%).

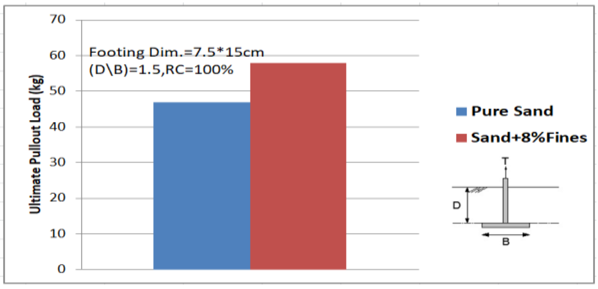

Fig.20: The variation of the ultimate pullout load with different types of soil (pure sand and Sand+8%fines) of footing dimension (7.5*15)cm in embedment depth of footing to footing width (D/B)=1.5 with relative compaction (RC=100%).

3.4 EFFECT OF VARIATION OF FOOTING DIMENSIONS ON PULLOUT LOAD UNDER TENSION FORCE ONLY.

Where relative compaction of soil, with ratio between embedded depth of footing-to-footing width (D/B) and the soil types are constant, 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 fig. 21 to 23, 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 **[13]**.

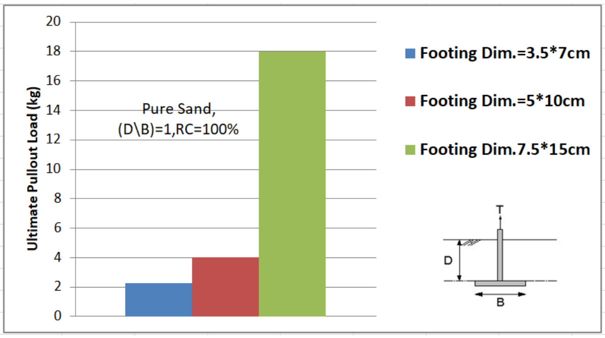

Fig. 21: The variation of the ultimate pullout load with different footing dimensions (3.5*7),(5*10)&(7.5*15)cm for pure sand in embedment depth of footing to footing width (D/B)=1 with relative compaction (RC=100%).

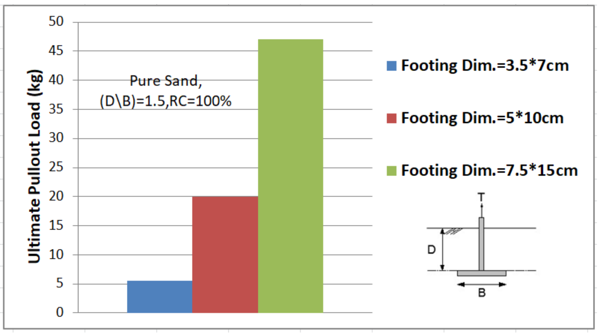

Fig.22: The variation of the ultimate pullout load with different footing dimensions (3.5*7),(5*10)&(7.5*15)cm for pure sand in embedment depth of footing to footing width (D/B)=1.5 with relative compaction (RC=100%).

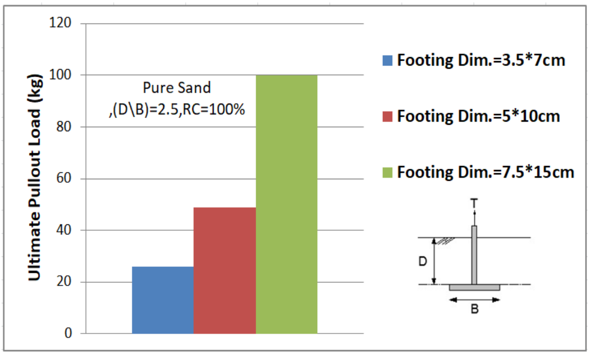

Fig.23: The variation of the ultimate pullout load with different footing dimensions (3.5*7),(5*10)&(7.5*15)cm for pure sand in embedment depth of footing to footing width (D/B)=2.5 with relative compaction (RC=100%).

3.5 EFFECT OF VARIATION IN RELATIVE COMPACTION (RC%) OF SOIL ON PULLOUT LOAD UNDER TENSION FORCE ONLY.

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%). Fig. 24 to 26 exhibit the variation of ultimate pullout load versus the relative compaction of soil.

It is noticed that the increase in the relative compaction of soil leads to increase in the pullout force **[14]**.

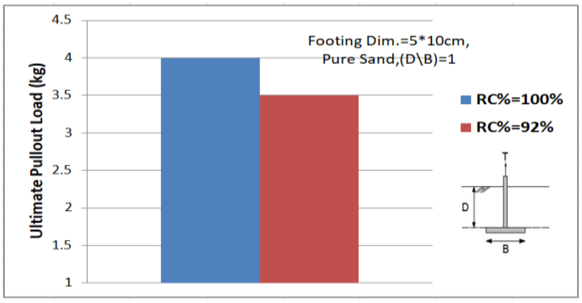

Fig.24: The variation of the ultimate pullout load with different relative compactions (RC=100%)&(RC=92%) for type of soil (Pure Sand) in embedment depth of footing to footing width (D/B)=1 for footing dimension (5*10) cm.

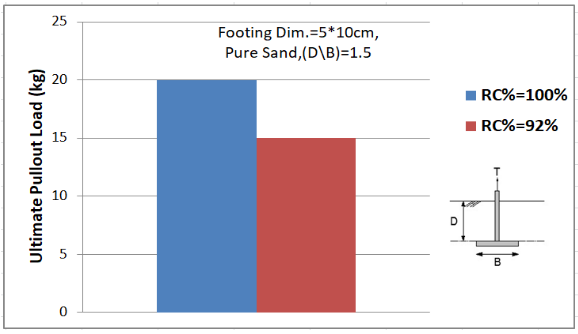

Fig.25: The variation of the ultimate pullout load with different relative compactions (RC=100%)&(RC=92%) for type of soil (Pure Sand) in embedment depth of footing to footing width (D/B)=1.5 for footing dimension (5*10) cm.

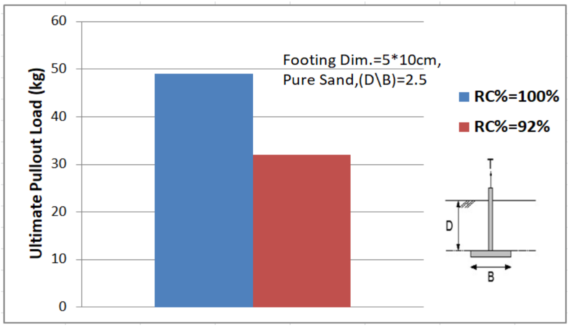

Fig.26: The variation of the ultimate pullout load with different relative compactions (RC=100%)&(RC=92%) for type of soil (Pure Sand) in embedment depth of footing to footing width (D/B)=2.5 for footing dimension (5*10) cm.

4. CONCLUSION

The present study is restricted to shallow single of footings subjected to vertical pullout force. The ultimate uplift resistance of footing-soil system is a function of the footing geometrical dimensions and the soil properties. The uplift resistance mainly depends on different factors such as the depth of embedment to footing width, soil density, percentage of fine content, relative compaction and footing dimension. Experimental work using three footing plate models fabricated to fit in a tank of dimensions 60 x 40 x 40 cm and a loading frame was performed.

The shapes of the load-displacement curves for single footings subjected to vertical load only 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. 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 64.4% for single footing subjected to vertical force only. Adding percentage of fines by 8% fines significantly increased the ultimate pullout resistance by 20% of a symmetrical single footings subjected to uplift load. So it is recommended to add fines to sandy soil. The increase in the footing dimension from (5*10) cm to (7.5*15) cm leads to increase in the ultimate pullout force by 62% for single footing subjected to vertical force only. The ultimate pullout load increased by 23.8% when increasing the relative compaction of soil from (92%) to (100%) for single footing subjected to pullout force only.

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