Engineering Research Journal
journal homepage: https://erj.journals.ekb.eg/

Experimental Study of the behavior for footings subjected to tension force using digital photogrammetry technique

Nourhan Mahmoud[1,*], Amr Radwan[2], Dalia Bahaa[3], Heba Elsaid[4]

[1] Assistant lecturer, Faculty of Engineering at Egyptian Russian University, Cairo, Egypt
[2] Professor of Geotechnical Engineering, Faculty of Engineering at Mataria branch, Helwan University, Cairo, Egypt
[3] Professor of Geotechnical Engineering, Faculty of Engineering at Badr University, Cairo, Egypt
[4]lecturer, Faculty of Engineering at Egyptian Russian University University, Cairo, Egypt

[*]Corresponding author E-mail: norhanmahmoud350@gmail.com

Abstract. Thousands of lattice towers of various sizes and forms must be built in Egypt in order to build a high voltage electrical network. These towers' foundations often experience three different kinds of loads: side trust (horizontal shear), pullout (tension), and downward trust (compression). A tower foundation's surrounding soil must withstand a significant amount of lateral and tensile load. The uplift capacity of shallow footings subjected to tension force was examined in the current study in relation to various parameters, including the type of soil and the ratio of foundation embedded depth to the width of footing. A comprehensive set of laboratory experiments was conducted using the relative dentists (100% and 92%) and taking into consider the footing dimensions (3.5*7 cm, 5*10 cm, and 7.5*15 cm). The footing width to foundation depth ratio is 1.5%, 1.5%, and 2.5%. A parametric approach is used to analyze the ultimate pullout load of shallow footings under tension force and expect the failure mechanism. To measure the entire displacement field inside the soil mass, a computerized photogrammetry application was utilized. The findings demonstrated that the ultimate pullout force increases in proportion to the footings' the embedded depth in the soil increases relative to footing width. As the percentage of fines increased the ultimate tension capacity resistance increased dramatically. While adding fines to sandy soil increases the angle of inclination, it has little influence on failure rupture.

Keywords: Pullout force – Failure mechanism –photogrammetry program.

1. Introduction

Determining the load-deformation characteristics and expecting the failure mechanism are necessary for the analysis of the footings of electrical towers subjected to tension force. The depth of embedment, soil density, and footing dimension are the main factors that influence of the failure mechanism.

The weight of the soil trapped above the footing and surrounded by the sliding surface, as well as

DOI: 10.21608/erj.2024.343110.1158
Received 09 December 2024; Received in revised form 09 December 2024; Accepted 26 December 2024
Available online 01 March 2025

the friction forces present on the sliding surface as a result of earth pressure or the soil's shear strength, are the primary determinants of the ultimate pullout resistance and the failure rupture, which can be estimated using a variety of analytical techniques. It is believed that the sliding surface at the footing's meridian section will alternate between a logarithmic spiral curve and a vertical or inclined straight line. Over the past three decades, numerous attempts have been made to analyze how anchors behave in soil. A review of the current analytical research in this field is presented in this study.

The behavior of anchors against uplift force was first studied in the 1960s. The initial prediction of anchor pullout capacity was based on test findings for transmission line tower anchors (Giffels et al. 1960; Ireland 1963; Adams and Hayes 1967). Subsequently, the forecast was based on the findings of studies using the centrifuge and 1g models. Extensive study has been conducted in this field over the past 50 years in an effort to determine the true mechanism of anchor failure against uplift force. The limit equilibrium method was used to generate a number of hypotheses, most of which used actual or assumed failure surfaces. With so much information about anchors' ability to lift objects, researchers have focused mostly on enhancing the uplift capacity of the anchors.

A general solution for the ultimate uplift capacity of anchor plates based on experimental works in sand has been produced by numerous studies (Mors 1959; Giffels et al. 1960; Balla 1961; Turner 1962; Ireland 1963; Sutherland 1965; Mariupolskii 1965; Kananyan 1966; Baker and Konder 1966; Adams and Hayes 1967; Andreadis et al. 1981; Dickin 1988; Frydman and Shamam 1989; Ramesh Babu 1998; Krishna 2000; Fargic and Marovic 2003; Merifield and Sloan 2006; Dickin and Laman 2007; Kumar and Bhoi 2008; and Kouzer and Kumar 2009. The works of Meyerhof and Adams (1968), Kuzar and Kumar (2009), Niroumand and Kassim (2017), and Heba (2018), who studied the behavior of symmetrical anchor plates more recently, have also been examined. As a result, all findings and an analysis of the experimental work conducted on the model footing are presented in this study. As previously stated, the purpose of this study is to examine how footings and surrounding soil behave in electrical towers that are frequently subjected to vertical loads. As a result, the expected uplift capacity and the soil failure mechanism are essential design factors for these kinds of foundations. This study uses photogrammetry techniques to investigate the failure process of footings in various types of sand. The results of the various experiments are shown and discussed in this publication. Lastly, a summary of the main findings is provided, taking from the outcomes of the experiment and previous studies.

2. Experimental work description

2.1 Model description

A durable testing tank measuring 60 cm in length, 40 cm in width, and 40 cm in height makes up the model. **Fig. 1** shows the model's components.

A- Perspex plate   **B-** Steel angle
C- Small wheel   **D-** wire
E- Weights   **F-** Footing
G- Vertical angle

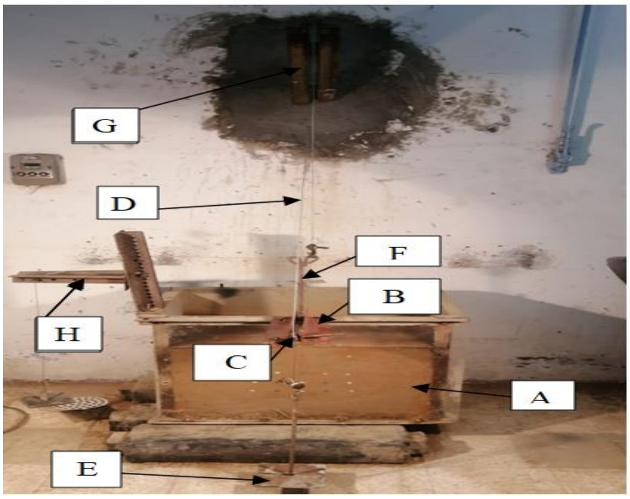


Fig. 1. Photo showing model configuration

2.1.1 Measurements and measuring system

For this study, an exceptionally good digital camera was utilized. The tank's face was 1.2 meters away from where the photos were taken. The camera was set up such that the tank's face and the lens's photographic plane were parallel. Throughout the whole test, the camera was attached and maintained in place. A remote control was used to take pictures in order to prevent camera vibration. As seen in **fig. 2**, two 500 watt Tung strum photographic lamps angled 45º to the tank's face provided the light.

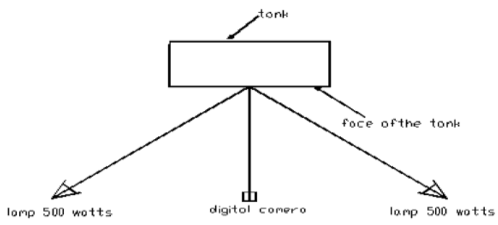


Fig. 2. Set up for photography

Using tracing points in the soil, the test was conducted through the Perspex face to observe the progressive development of soil particle deformation and the failure mechanism of soil and footing based on uplift force. After the test, the digital photogrammetry technique was utilized to measure the photos that were taken.

2.2 Test material

2.2.1 Natural soil characteristics

Two types of soil were used in the current research. The characteristics of the used soil are given in **table 1.**

Table 1. Properties of the utilized soil

The index property	Value
Pure sand	
Specific gravity (Gs)	2.62
D10 (mm)	0.18
Coefficient of uniformity (Cu)	2.4
Coefficient of curvature (Cc)	1.14
Friction angle	36.6º
Maximum dry density	1.80t\m3
Optimum moisture content	6.01%
Sand+8%fines	
Specific gravity (Gs)	2.65
%Coarse	4%
%Silt	26%
%Clay	70%
%Liquid limit	62%-64%
%Plastic limit	36%-38%
Friction angle	43.1º
Cohesion	0.83t\m2
Soil Classification according to (USCS)	CH

2.3 Testing Procedure

Compacted granular soil with a relative compaction of 92% and 100% was placed in a U-shape at the tank's bottom and lateral sides to create a separate tank sample for each test. Two layers of half of the mixture are added to the tank. To meet the necessary maximum unit weight specified by the compaction tests, as indicated in Fig. 3, each layer is compacted using a manual rammer. A straight wooden rod is used to level the soil's surface. After drilling the footing location and compacting the soil above it, the footings were placed there and the ground was leveled. The footing is loaded vertically gradually by applying loads incrementally on the loading system at consistent rates that vary at stages after the footing preparation is finished. The final stage was to position a tripod-mounted digital camera in front of the viewing glass. Using the photos taken during the testing, the footing and foundation soil displacements could be measured, as illustrated in **fig. 4.**

Fig.3. The soil in the model after compaction

Fig.4. Final set up test

3. Results and discussion

3.1 Experimental work results for footing under tension force only.

3.1.1 Pullout loads for footings under tension force only are affected by variations in the embedment footing depth to footing width (D/B).

The ratio of embedded depth of footing to footing width (D\B) (1, 1.5, and 2.5) has been used in cases when soil type, footing dimension, and relative compaction of soil were all constant.

Fig. 5 through 7 show how the ultimate pullout force varies with the ratio of embedded depth to footing width. It is apparent in the numbers that an increase in the soil's D\B causes the ultimate pullout force to rise. This is the cause of the pullout force's increase:

- As the depth increases, the quantity of soil involved in resisting the pull increases. In the case of foundations subject to tension, a large part of the resistance is represented due to the weight of soil above the footing. Therefore, as the depth increases, the resistance increases

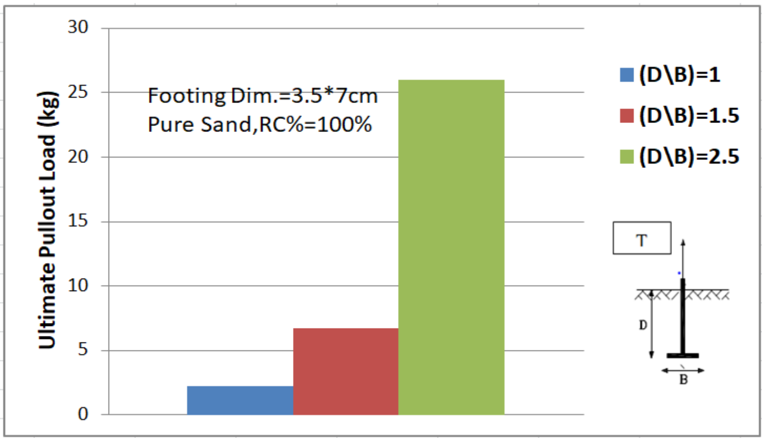


Fig.5. In pure sand with (RC=100%), the ultimate pullout load varies with varying (D\B) of footing dimension (3.5*7) cm.

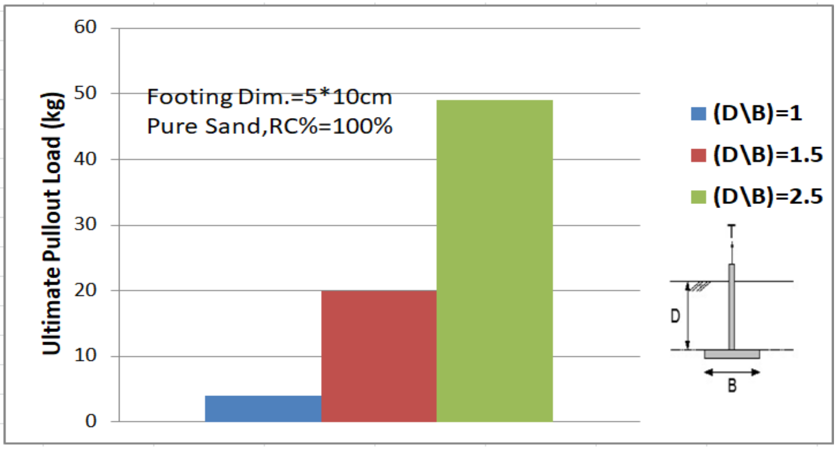


Fig.6. In pure sand with (RC=100%), the ultimate pullout load varies with varying (D\B) of footing dimension (5*10) cm.

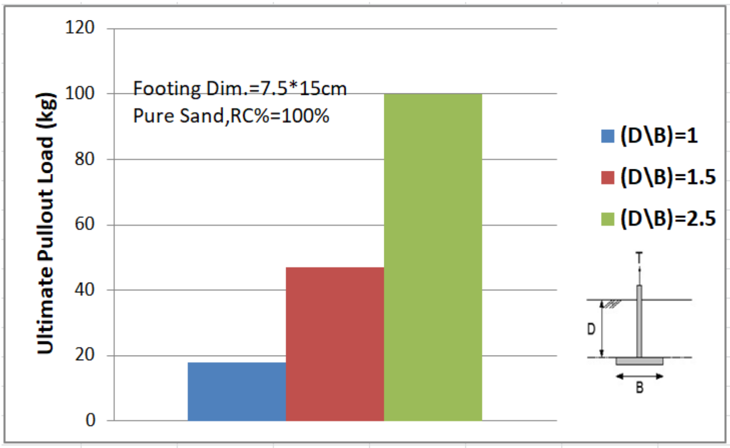


Fig.7. In pure sand with (RC=100%), the ultimate pullout load varies with varying (D\B) of footing dimension (7.5*15) cm.

3.1.2 Effect of footing width to embedment depth variation (D\B) on failure mechanism under tension force only.

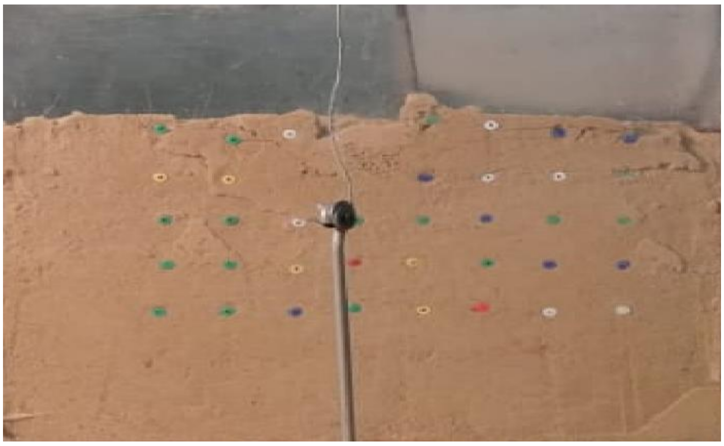
By examining **Fig. 8 to16**, the following was concluded:

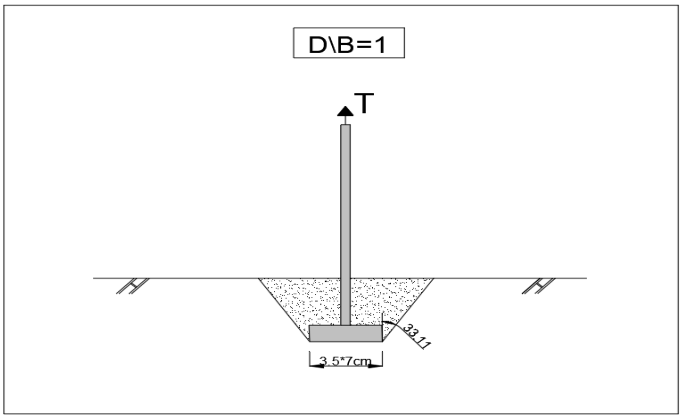
a. In case of embedded depth of footing to footing width (D\B= 1 and 1.5), for all different footing dimensions, the failure shape of soil above footing is the same. It is a symmetric inclination, i/e. the angle of inclination (β) between the vertical line and the failure line are equal. In the case of using pure sand, the magnitude of angle (β) is usually given as a function of the angle of internal friction (φ). It usually ranges between (0.67 to 0.8) of the angle of internal friction (φ), as suggested by Fattah and Macky (1992) and Niroumand &Kassim.

b. In case of embedded depth of footing to footing width (D/B = 2.5), for all different footing dimensions, the rupture surface of soil above footing is the same. In case of using pure sand and footing dimensions (3.5*7 & 5*10) cm, it is vertical then having symmetric inclination. The magnitude of angle (β) usually ranges between (0.67 to 0.8) from angle of internal friction (φ). But for footing dimension (7.5*15) the angle (β) usually does not depend on angle of internal friction It range from 18º to 19º.

c. In the case of using sand +8% fines, with all different embedded depth of footing to footing width (D\B = 1, 1.5 & 2.5) for all different footing dimensions, the failure shape of soil above footing is the same. It is symmetric inclination; the magnitude of angle (β) is does not usually depend on angle of internal friction (φ). It often ranges between 43º and 46º. (β =45º) in this case, but for footing (7.5*15) cm, when (D/B) = 2.5 only the failure mechanism is different being vertical then inclined by angle value ranging between 12º and 13º.

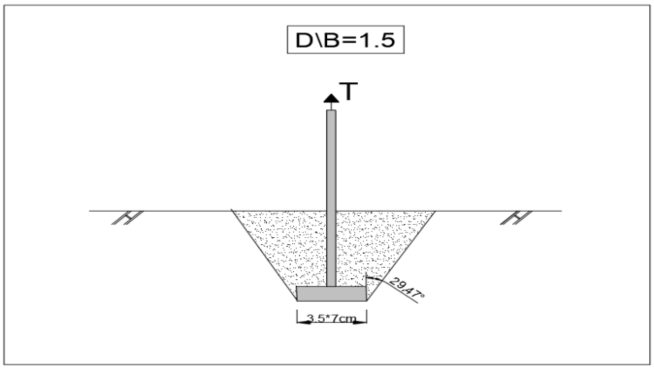
A change in embedded depth of footing-to-footing width up to 1.5 has no effect on the shape failure mechanism or the angle of inclination, but in the case of (D/B) = 2.5, it can be considered as a special case where as the failure mechanism is different, which is vertical then inclined by small angle.





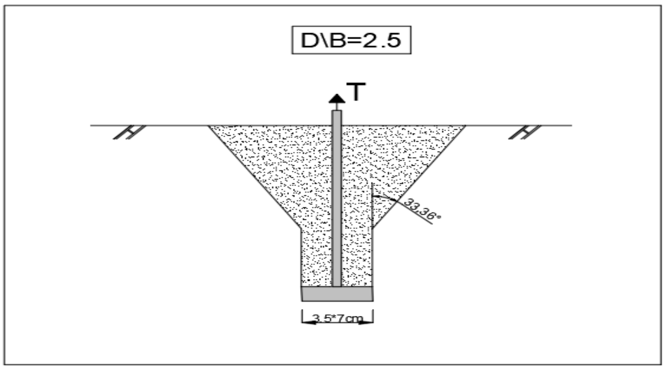
(a) **(b)**

Fig.8. (a),(b): Failure mechanism in pure sand with (RC=100%) for (D/B)=1 of footing dim.(3.5*7) cm.



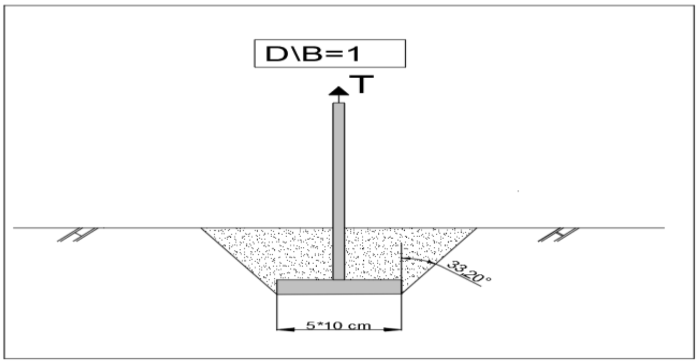
(a) **(b)**

Fig.9. (a),(b): Failure mechanism in pure sand with relative compaction (RC=100%) for embedment depth of footing to footing width (D/B)=1.5 of footing dim. (3.5*7) cm.



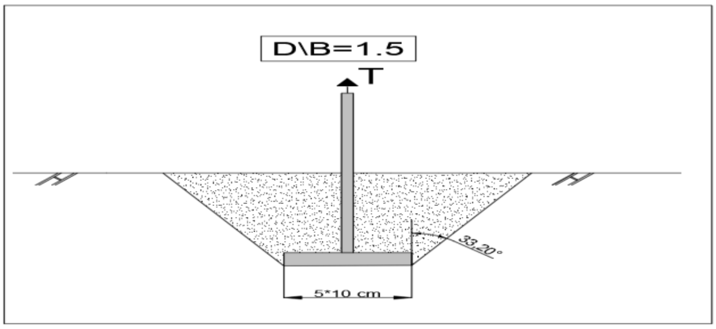
(a) **(b)**

Fig.10. (a),(b): Failure mechanism in pure sand with (RC=100%) for (D/B)=2.5 of footing dim. (3.5*7)cm.

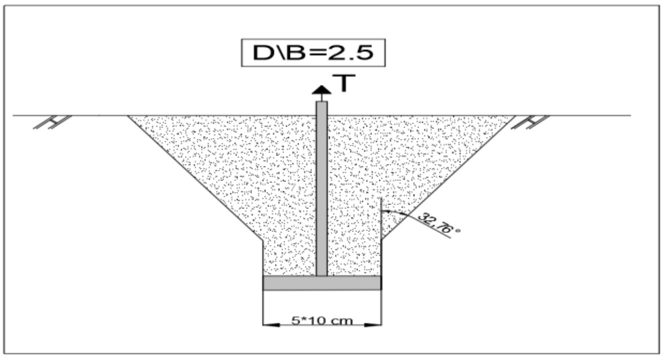
(a) **(b)**

Fig.11. (a),(b): Failure mechanism in pure sand with (RC=100%) for (D/B)=1 of footing dim. (5*10)cm.

(a) **(b)**

Fig.12. (a),(b): Failure mechanism in pure sand with (RC=100%) for (D/B)=1.5 of footing dim. (5*10)cm.

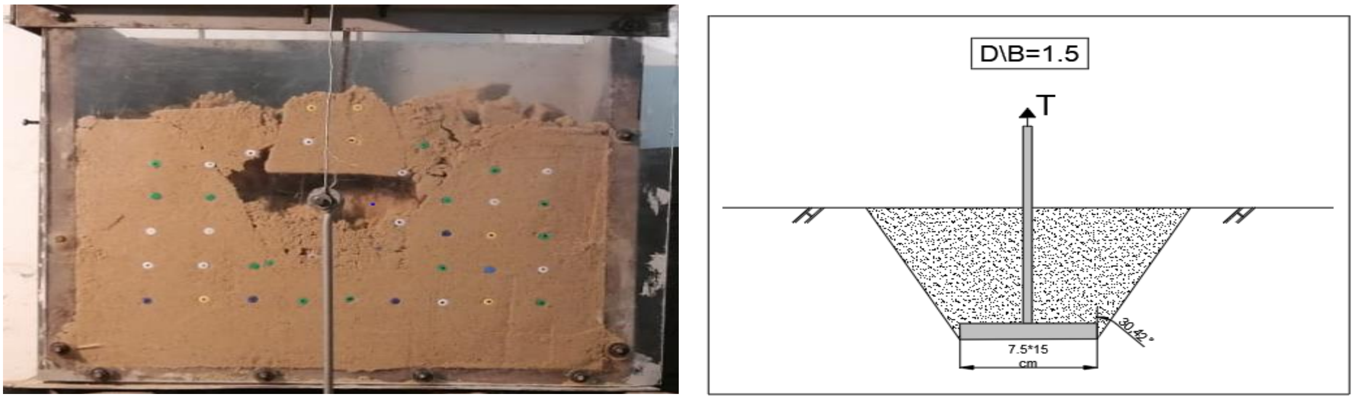



(a) **(b)**

Fig.13. (a),(b): Failure mechanism in pure sand with (RC=100%) for (D/B)=2.5 of footing dim. (5*10)cm.

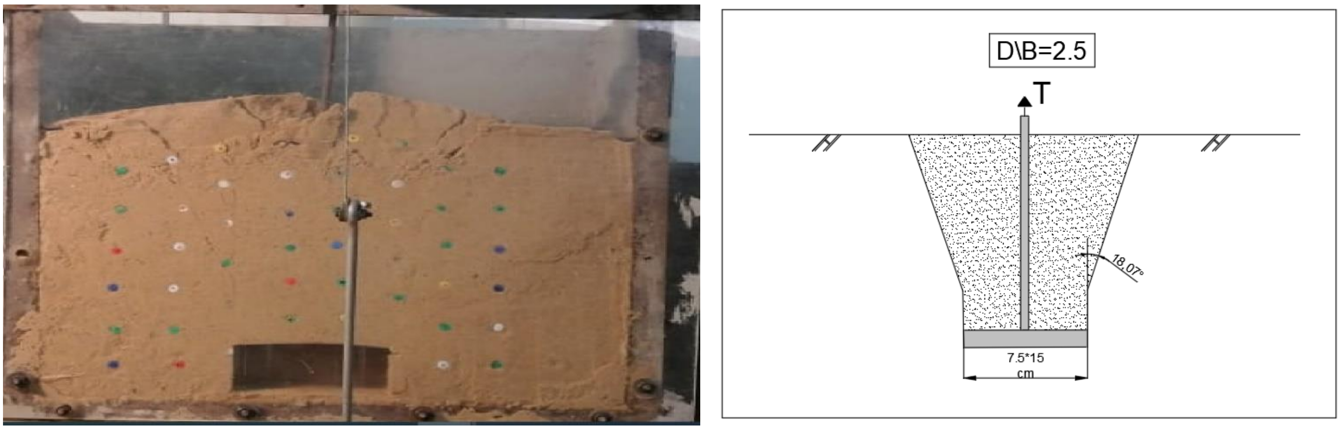
(a)

Fig.14. (a),(b): Failure mechanism in pure sand with (RC=100%) for (D/B)=1 of footing dim. (7.5*15)cm.



(a) **(b)**

Fig.15. (a),(b): Failure mechanism in pure sand with (RC=100%) for (D/B)=1.5 of footing dim. (7.5*15)cm.



(a) **(b)**

Fig.16. (a),(b): Failure mechanism in pure sand with (RC=100%) for (D/B)=2.5 of footing dim. (7.5*15)cm.

3.1.3 The Impact of Different Soil Types on Pullout Loads Under Tension Force Only

Pure sand and sand + 8% particles are the soil types used when the footing dimension, relative compaction, and the ratio of embedded depth of footing to footing width (D\B) are all constant.

Fig. 17 through 19 show how Ultimate Pullout Loads vary depending on the type of soil. It has been found that when the soil type is sand + 8% fines, the ultimate pullout force value is greater than when the soil type is pure sand.

The increase in the value of pullout force is because the presence of a percentage of fines in the soil improves the properties of the soil (shear strength parameters) which leads to friction developed along the failure surface, and also improvement in the cohesion forces between the particles and the footing.

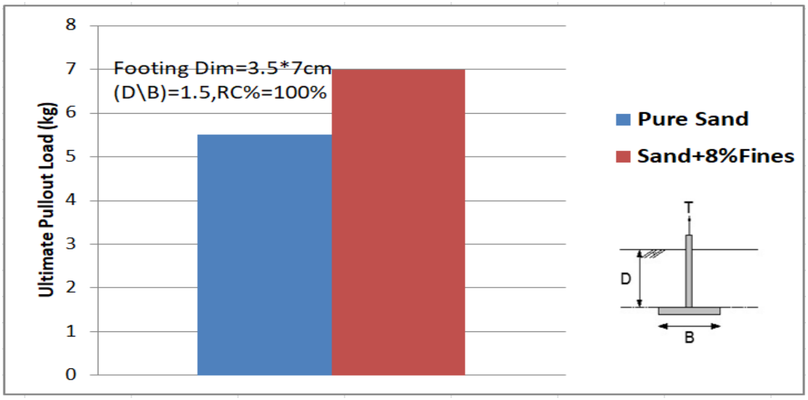


Fig.17. : With varying soil types (pure sand and sand plus 8% fines), the ultimate pullout load varies with footing dimensions (3.5*7) cm in (D/B)=1.5 with (RC=100%).

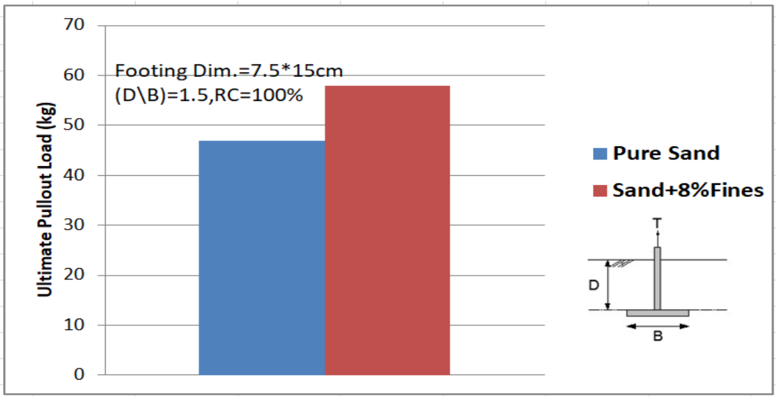


Fig.18. : With varying soil types (pure sand and sand plus 8% fines), the ultimate pullout load varies with footing dimensions (7.5*15) cm in (D/B)=1.5 with (RC=100%).

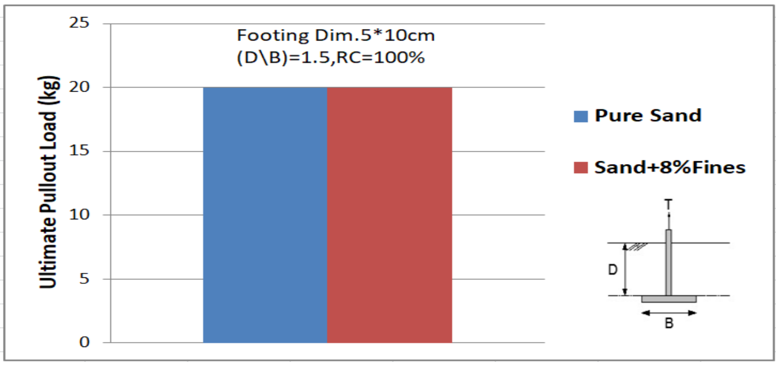


Fig.19. : With varying soil types (pure sand and sand plus 8% fines), the ultimate pullout load varies with footing dimensions (5*10) cm in (D/B)=1.5 with (RC=100%).

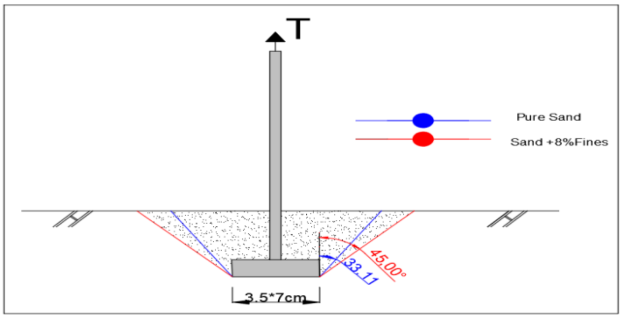
By examining **Fig. 20 to 25** the following was concluded:

- **a.** In case of using pure sand, the embedded depth of footing to footing width (D/B = 1 and 1.5), for all different footing dimensions, the failure shape of soil above footing is the same. It has symmetric inclination. The angles of inclination (β) between the vertical line and the failure line are equal. The magnitude of angle (β) is usually given as a function of the angle of internal friction (φ) which usual ranges between (0.67 to 0.8) from the angle of internal friction (φ). But when the embedded depth of footing to footing width (D/B) = 2.5 the failure mechanism is vertical then inclined. The angle of inclination (β) often ranges between (0.67 and 0.8) from angle of internal friction (φ) for footing dimension (3.5 * 7& 5 * 10). For footing dimension (7.5*15) cm the angle of inclination usually does not depend on angle of internal friction (φ) its range is (18° to 19°).
- **b.** In the case of using sand +8% fines, with all different embedded depths of footing to footing width (D/B = 1, 1.5 & 2.5), for all different footing dimensions, the failure shape of soil above footing is the same. It is inclined, where the angle (β) usually does not depend on angle of internal friction (φ), it usually ranges between (43° and 46°). (β) in this case is considered 45°, but for footing (7.5 * 15) cm, when (D/B) = 2.5, only the failure mechanism is different from being vertical then inclined by angle value ranging between (12° to 13°), it can be considered as a special case.

Using pure sand, the increase of the value of the angle of inclination (β) in the case using (sand + 8%) fines is greater because the strength of sand + 8% fines is more than pure sand, so the soil mass which is resisted increases and thus the angle of inclination (β) increases.

(a) Pure sand

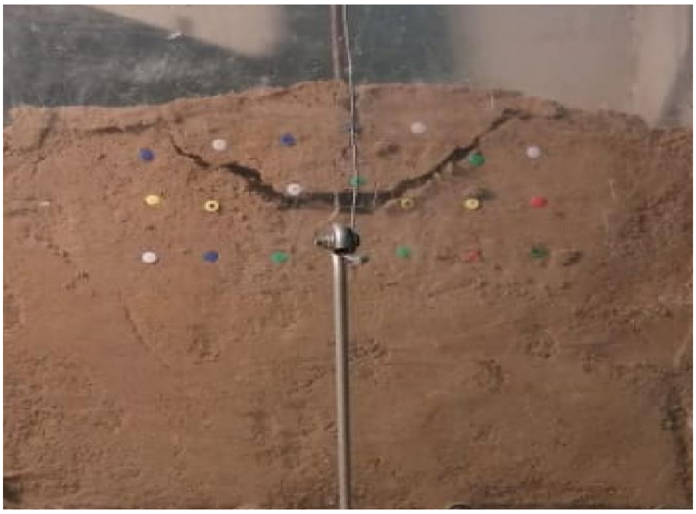
(b) Sand + 8%



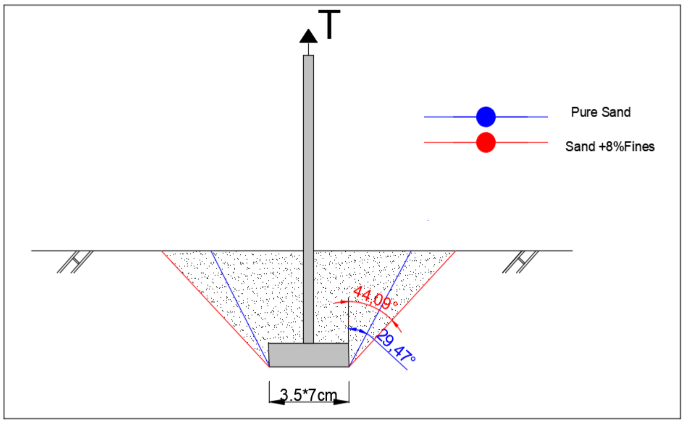
(c)

Fig.20 (a), (b) ,(c) : For various soil types (pure sand and sand+8%fines), the failure mechanism for (D/B) = 1 of footing dim. (3.5*7) cm, with (RC = 100%).

(a) Pure Sand



(b) Sand + 8% fines

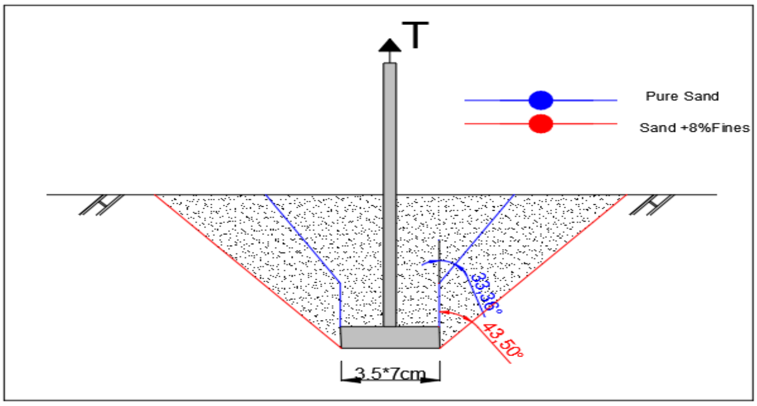


(c)

Fig.21. (a),(b), (c): For various soil types (pure sand and sand+8%fines), the failure mechanism for (D/B) = 1.5 of footing dim. (3.5*7) cm, with (RC = 100%).

(a) Pure Sand

(b) Sand+8% fines

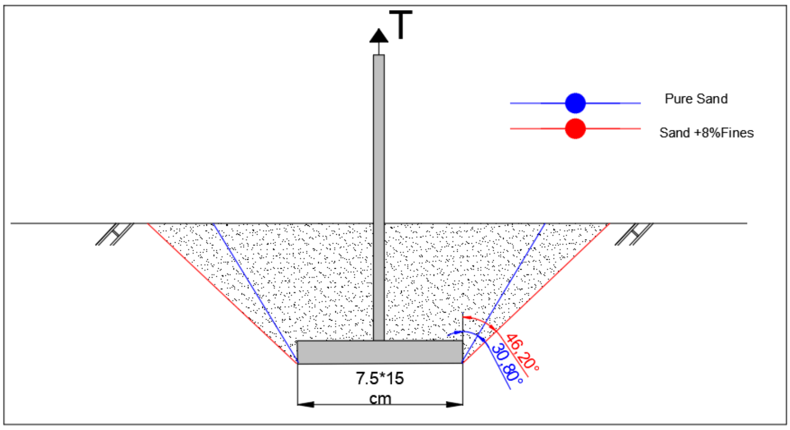


(c)

Fig.22. (a),(b),(c): For various soil types (pure sand and sand+8%fines), the failure mechanism for (D/B) = 2.5 of footing dim. (3.5*7) cm, with (RC = 100%).

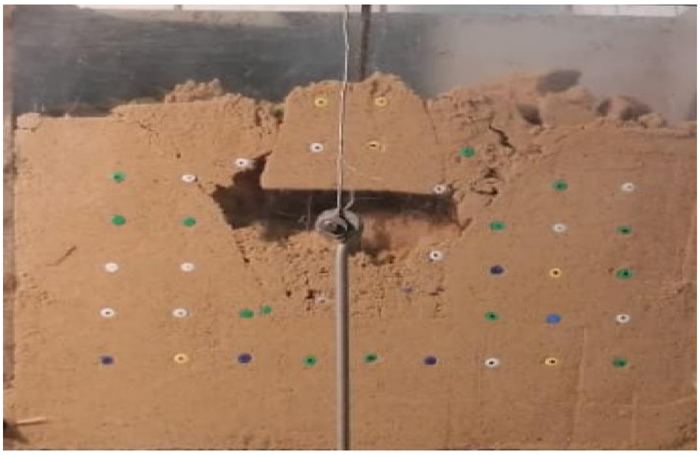
(a) Pure Sand

(b) Sand+8%Fines



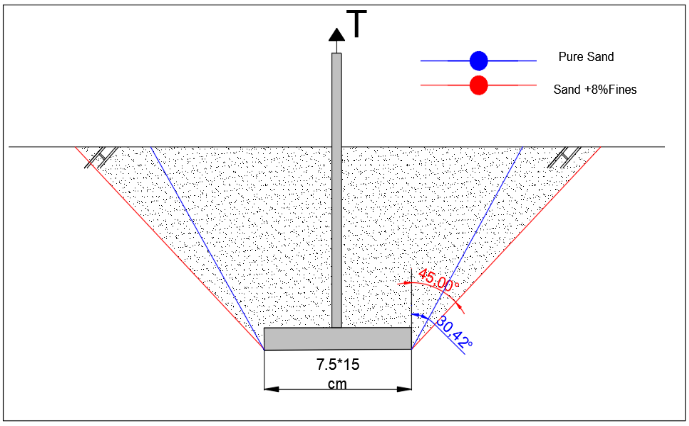
(c)

Fig.23. (a),(b),(c): For various soil types (pure sand and sand+8%fines), the failure mechanism for (D/B) = 1 of footing dim. (7.5*15) cm, with (RC = 100%).



(a) Pure Sand

(b) Sand+8%Fines

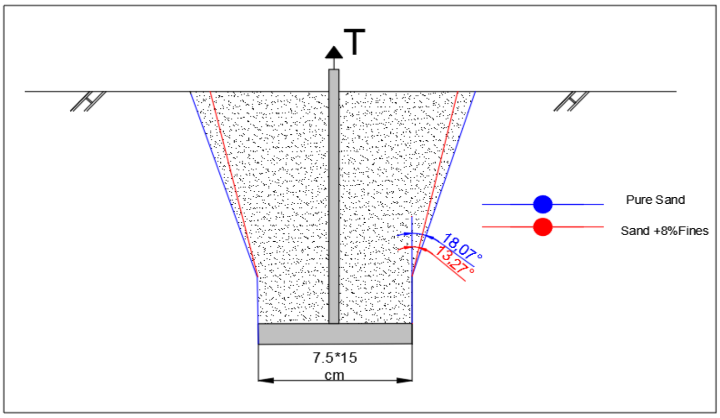


(C)

Fig.24. (a),(b),(c): For various soil types (pure sand and sand+8%fines), the failure mechanism for (D/B) = 1.5 of footing dim. (7.5*15) cm, with (RC = 100%).

(a) Pure Sand

(b) Sand+8%Fines



(c)

Fig.25. (a),(b), (c): For various soil types (pure sand and sand+8%fines), the failure mechanism for (D/B) = 2.5 of footing dim. (7.5*15) cm, with (RC = 100%).

4. Conclusions

The conclusions obtained from this study can be summarized as follows:

- For footings subjected to only vertical force, the ultimate pullout force increases as the footings' embedment depth in the soil increases relative to their footing width.
- A change in embedded depth of footing to footing width up to 1.5 has no effect on the shape failure mechanism or the angle of inclination , but in the case of (D/B) = 2.5, it can be considered as a special case where as the failure mechanism is different, which is vertical then inclined by small angle.
- A rising percent of fines the ultimate uplift resistance of single footings under tension stress was greatly enhanced. Therefore, adding fines to sandy soil at a percentage of at least 6% is recommended.
- Adding fines to sandy soil does not effect on the failure rupture, but the value of the angle of inclination increase.
- The failure rupture for footing under tension force only is symmetric inclination and the value of slope angle is usually given as a function of the angle of internal friction (φ). It usually ranges between (0.67 to 0.8) of the angle of internal friction (φ) in sandy soil, as suggested by Fattah and Macky (1992) and Niroumand &Kassim.
- The failure mechanism for footing under tension force only is symmetric inclination and the value of slope angle on average (43^o:46^o) in sand with fines soil.

5. Reference

1. Adams J.I. and Hayes D.C. (1967), 'The Uplift Capacity of Shallow Foundation', Ontario Hydro Research Quarterly, Vol. 19, No. 1, pp. 1-13.
2. Balla A. (1961), 'The Resistance to Breaking Out of Mushroom Foundations for Pylons', Proc. 5th International Conference on Soil Mechanics and Foundation Engineering, pp. 569-576.
3. Banerjee S .and Mahadevuni N. (2017), 'Pull-Out Behaviour of Square Anchor Plates in Reinforced Soft Clay', Int. J. of Geosynth. and Ground Eng., pp 1-10.
4. 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.
5. Frydman S. and Shaham I. (1989), 'Pullout capacity of slab anchors in sand', Canadian Geotechnical Journal, Vol. 26, pp. 385-400.
6. 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.
7. 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.
8. 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.
9. 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.

10. 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.
11. Meyerhof G.G. and Adams J.I.(1968), 'The Ultimate Uplift Capacity of Foundations', Canadian Geotechnical Journal, Vol. 5, No. 4, pp. 225-244.
12. Meyerhof, G. G. (1973a). 'The Uplift Capacity of Foundations under Oblique Loads', Canadian Geotechnical journal, Vol. 10, pp. 64-70.
13. Mors H. (1959), 'The behaviour of mast foundations subject to tensile forces', Bautechnik, Vol. 10, pp. 367-378 (as reported by Balla 1961).
14. Niroumand, H., Kassim, K.A. (2013a), 'Uplift of Symmetrical Anchor Plates by Using Grid-Fixed Reinforced', China Ocean Eng., Vol. 28, No. 1, pp. 115 – 126.
15. Sutherland H.B. (1965), 'Model studies for shaft raising through cohesionless soils', Proc. 6th Int. Conf. Soil Mechanics and Foundation Engineering, Montreal, Vol. 2, pp. 410-413.
16. Turner E.A. (1962), 'Uplift resistance of transmission tower footings', Journal of Power Division, ASCE, Vol. 88, pp. 17-32.