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Comparison between the Performance of Vertical and Inclined Grouted Soil Anchors in Sandy Soils under Static Axial Load

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Abstract. Grouted soil anchors referenced simply as ground anchors are elements installed in soil or rock. They allow the transmission of the pullout load to soil layers at a greater depth. They can be placed vertically, or in an inclined position according to the orientation of the loads and the type of structures. This paper presents a comparison between the performance of vertical and inclined grouted soil anchors subjected to static axial loading placed in three sandy soils by using the kinematic approach of limit analysis. A parametric study was performed to identify the effect of the bonded length and the diameter of bonded length on the collapse load of vertical and inclined grouted soil anchors. Results obtained from the present theoretical study showed that the highest capacity could be achieved when the grouted soil anchor is in a vertical orientation.
The study also revealed that the pullout load capacity of inclined grouted soil anchor increases with an increase in the bonded length, the diameter of bonded length and the density of sandy soils. In addition, the bonded length significantly affects the ultimate pullout capacity of vertical grouted soil anchor but the diameter of bonded length has no effect on the ultimate load of grouted soil anchor placed vertically and the density of sandy soils has a decreasing effect on the vertical load capacity.

Keywords. Grouted soil anchors, Kinematic approach, Limit analysis, Sandy soils, Static axial load, Ultimate load capacity.

INTRODUCTION

Grouted soil anchors are structural elements including bar or strand, which are mainly tensioned after grout injection. They form an important component of many civil engineering structures. They are used to ensure the stability and control the displacement and deformation of retaining walls, quays, dams, foundations, bridge abutments and underground excavations. However, their performance depends on several aspects, which are the soil properties, the orientation of the grouted soil anchors, the methods of drilling, the dimensions of the perforations and the characteristics and quantity of the grout, the grouting methods and a number of post-grouting cycles. These devices can be used as temporary or permanent structural members and they can be placed vertically, or in an inclined position according to the orientation of the loads and the type of structures.

However, very little research has been done to better understand and predict the collapse load of grouted soil anchors placed in sandy soils. Empirical relationships were suggested to correlate the failure load of a single grouted soil anchor with its geometric properties and with the characteristics of the surrounding soil.

Hawkes and Evans (1951) and Phillips (1970) proposed a formulation to calculate the skin friction along the bonded length of grouted soil anchor.

Littlejohn (1970), Kramer (1978) and Hanna (1982), suggested an expression to determine the collapse load of grouted soil anchor.

Ostermayer (1975) developed an equation for evaluating the skin friction along the bonded length using efficiency factor.

In addition, analytical models were established to determine the ultimate load of grouted soil anchor. Mekki et al. (2009, 2011), Mekki (2015), Mekki and Meksaouine (2020), employed a theoretical approach which is the upper bound of limit analysis to determine the ultimate load of vertical grouted soil anchor subjected to axial static loading and they considered the effects of friction angle of the soil and the length of grouted soil anchor on the pullout capacity.

Mekki and Meksaouine (2019),also adopted a failure mechanism based on kinematic approach of limit analysis theory to evaluate the critical load which is expressed according to the non-dimensionnal uplift factor of an inclined grouted soil anchor under up lift tensile force and they identified the effect of the inclination of the ground anchor. The friction angle of the soil and the angle of the slope on the bearing capacity factor. Zhang et al. (2012) applied the spherical cavity expansion theory and shear displacement method for analyzing the ultimate resistance of grouted soil anchor. Yanget al. (2018) established a mathematical model for the entire pullout process of grouted soil anchor to obtain a complete load-displacement curve using the softening shear model of the ground anchor-soil interface and load transfer model of the anchoring section.

However, it is noticed that most past research had contributed to the study of the stability of vertical and inclined grouted soil anchors subjected to axial static loading in frictional soils separately, no, the theoretical study seems to be available to compare the performance of vertical and inclined grouted soil anchors under static axial forceplaced in sandy soils.

The objectives of this study are to compare the ultimate pullout capacity of vertical and inclined grouted soil anchors under static axial force placed in three sandy soils using the kinematic approach of limit analysis and to examine the variations of the ultimate load with changes in the bonded length and the diameter of bonded length.

LOAD CAPACITY OF VERTICAL GROUTED SOIL ANCHOR

The researchers, Mekki et al. (2009), presented an analytical model which may be approximated as a cone having an apex angle equal to (2β) as shown in figure 1 to predict the ultimate load capacity for a single. Vertical and rough grouted soil anchor placed in homogeneous frictional soil subjected to static load with its point of application coinciding with the axis of the grouted soil anchor. The model was developed based on the kinematic approach of limit analysis.

The soil mass was assumed to obey Mohr-Coulomb's failure criterion and an associated flow rule.

The ultimate load capacity was expressed as:

$$F = \frac{\gamma.H^2.\sin(\beta).\sin(\beta-\varphi)\cos(\beta-\varphi)}{2.\sin(\beta-2\varphi)\sin\left(\frac{\pi}{2}\right)\cos(\beta)} + \frac{\gamma.H^2.\sin(\beta)\sin(\beta-\varphi).\cos(\beta-\varphi)}{2.\cos(\alpha)\cos(\beta)\sin(\beta-2\varphi)} \tag{1}$$

Where:
γ : The unit weight of the soil.
φ: The internalfriction angle of the soil.

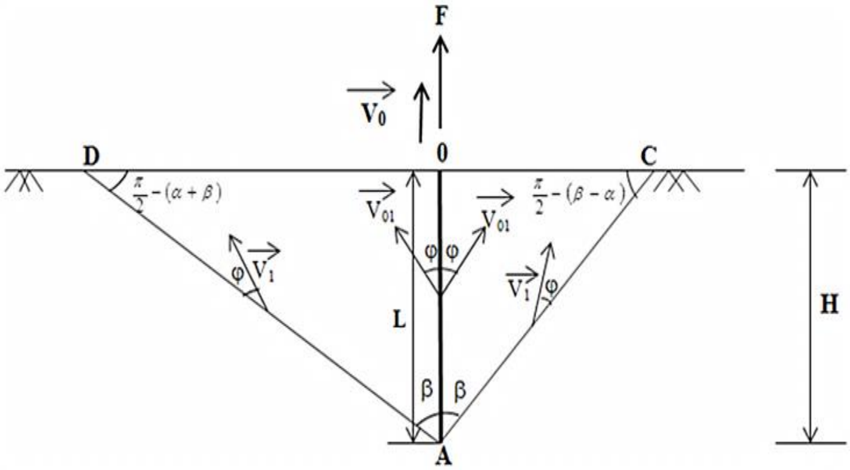

Fig.1. The failure mechanism of vertical grouted soil anchor (Mekki et al., 2009).

LOAD CAPACITY OF INCLINED GROUTED SOIL ANCHOR

A failure mechanism was adopted by, Mekki and Meksaouine (2019), is shownin figure 2. This mechanism is composed of a triangular rigid block (DAB) described: by the parameter (β) limited, the linear rupture surfaces. (AD), (AB) and the tilted free surface to estimate the critical pullout load of a single, inclined and rough grouted soil anchor placed in homogeneousgranular soil under static axial load using a kinematic approach of limit analysis. The methodology is based on the Mohr–Coulomb yield criterion and the associated flow rule. Based on the kinematic approach, Mekki and Meksaouine (2019), proposed the following equation:

$$F=\frac{\pi.\gamma.L^3.tg(\beta).\left[\cos\left[\left(\frac{\pi}{2}+\theta\right)-\left(\frac{\pi}{2}-\eta\right)\right]\right]^2.\left[tg\left[\beta-\left(\frac{\pi}{2}-\eta\right)\right]+tg\left[\beta+\left(\frac{\pi}{2}-\eta\right)\right]\right].\sin(\beta-\varphi).\cos\left(\frac{\pi}{2}-\eta\right)}{6.\sin(\beta-2\varphi)} \tag{2}$$

Where:
γ : The unit weight of the soil
φ: The internal friction angle of the soil
L: The total length of the grouted soil anchor
θ : The angle of inclination of the sloping surface
η : The angle of inclination of the grouted soil anchor

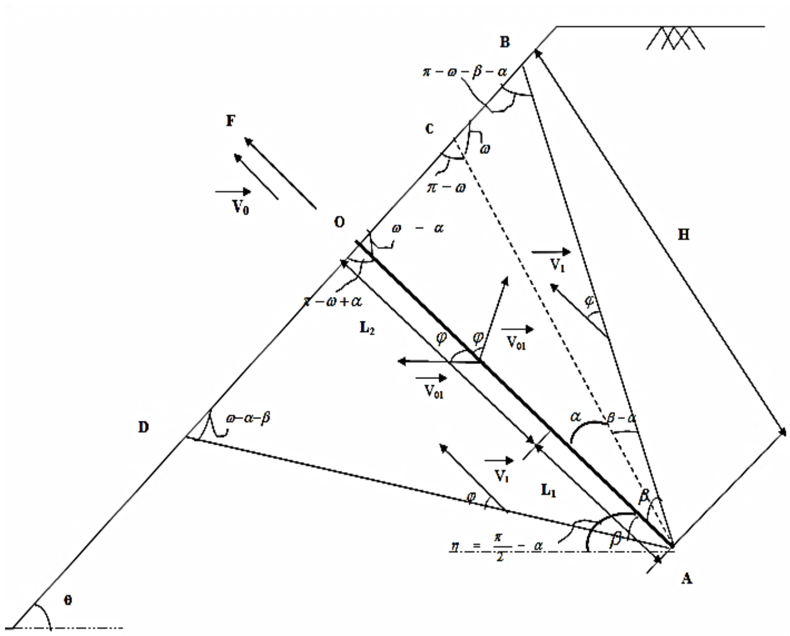

Fig.2. The failure mechanism of inclined grouted soil anchor (Mekki and Meksaouine, 2019).

COMPARISON OF LOAD CAPACITIES

To carry out a comparative study of the ultimate pullout capacity of vertical and inclined grouted soil anchors placed in three sandy soils by using the above theoretical correlations, calculations have been made. We consider two variables which will be studied in the following sections (the bonded length and the diameter of the bonded length), in such a way as to modify the value of the parameter subjected to the study and to fix the other.

Knowing that the unbounded length of vertical and inclined grouted soil anchors is equal to 10 mwas kept constant.

For the inclined grouted soil anchor, the angle of inclination is fixed at 20° and the angle of the sloping surface is fixed at an angle 45° with the horizontal. The properties of sandy soils adopted in the computations are presented in table 1. Numerical optimization calculation was conducted in MATHCAD software.

Table 1. Properties of sandy soils

Properties	Loose sand	Medium dense sand	Dense sand
Unit weight (KN/m^3)	14	17	20
Friction angle (°)	30	35	40

Impact of the bonded length

In this section, the effect of the bonded lengthon ultimate load capacities of vertical and inclined grouted soil anchors was analyzed; three values were considered 4m, 6m and 8 m. The results obtained show that ultimate load capacities of vertical and inclined grouted soil anchors increase continuously with the increase in the bonded length and the density of sandy soils. In addition, the increase in collapse load is more significant for vertical grouted soil anchors as illustrated in figures 3, 4 and 5.

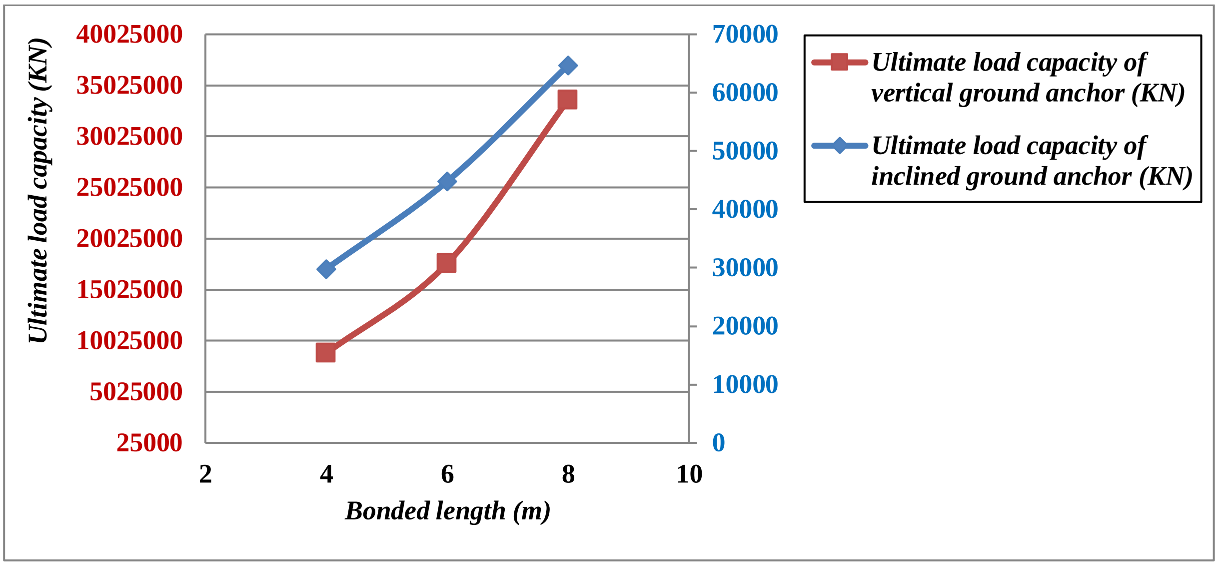

Fig.3. The variation of the ultimate load capacity with the bonded length of vertical and inclined grouted soil anchors in loose sand.

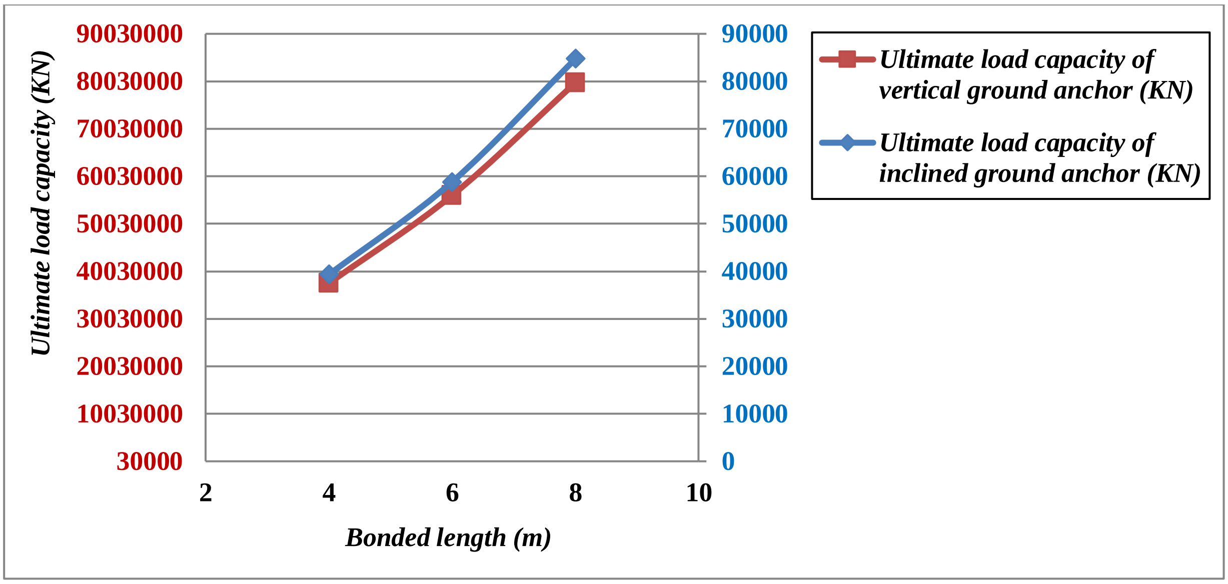

Fig.4. The variation of the ultimate load capacity with the bonded length of vertical and inclined grouted soil anchors in medium dense sand.

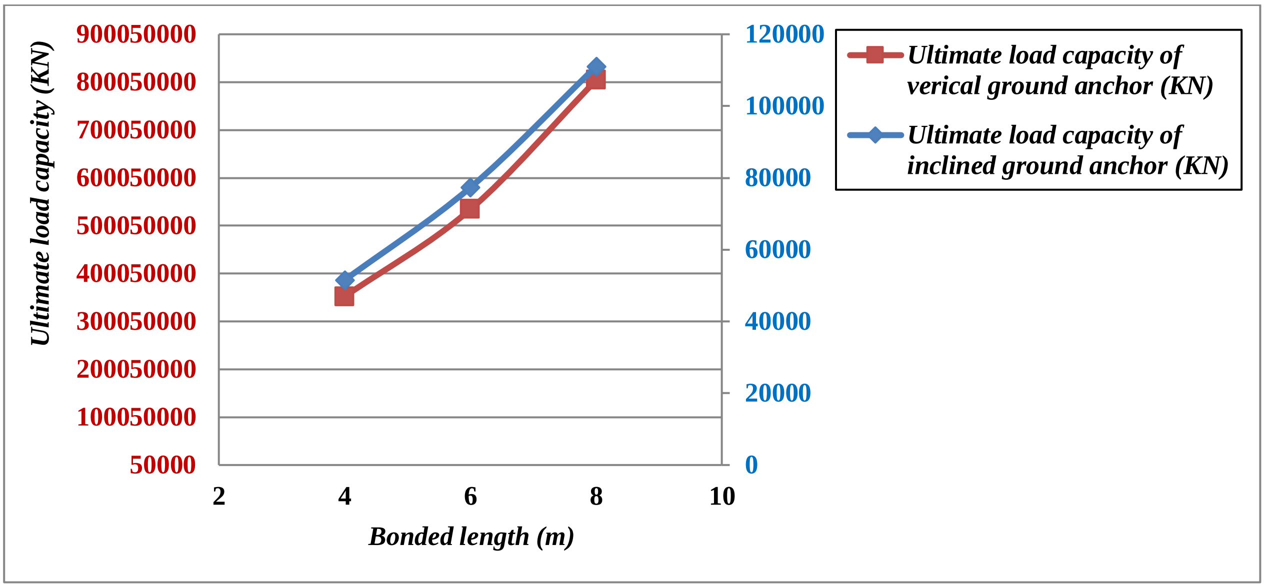

Fig.5. The variation of the ultimate load capacity with the bonded length of vertical and inclined grouted soil anchors in dense sand.

Impact of the diameter of the bonded length

In order to examine the influence of the diameter of the bonded lengthon ultimate load capacities of vertical and inclined grouted soil anchors, this diameter has taken on three different values: 0.12m, 0.14m and 0.16m.

Figures6, 7 and 8,represent the results obtained which show the increase variation of the ultimate load capacity of inclined grouted soil anchor with the increased in the diameter of bonded length and the density of sandy soils. The figures also indicate that the collapse load remains constant for vertical grouted soil anchor and the density of sandy soils has a decreasing effect on the performance of grouted soil anchor placed vertically.

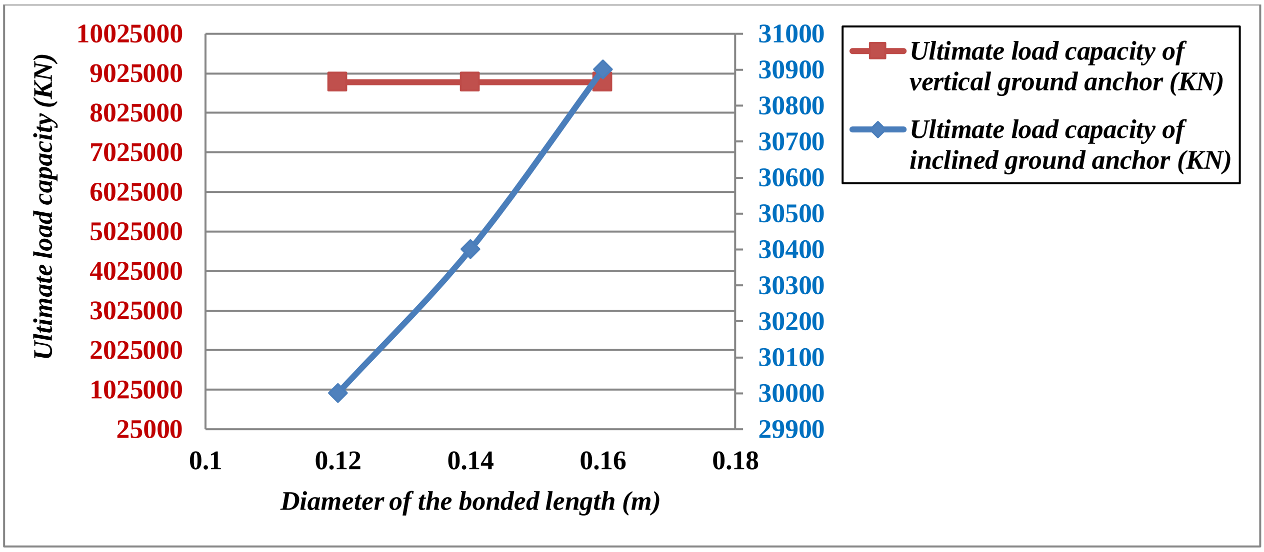

Fig.6.The variation of the ultimate load capacity with the diameter of the bonded length of vertical and inclined grouted soil anchors in loose sand.

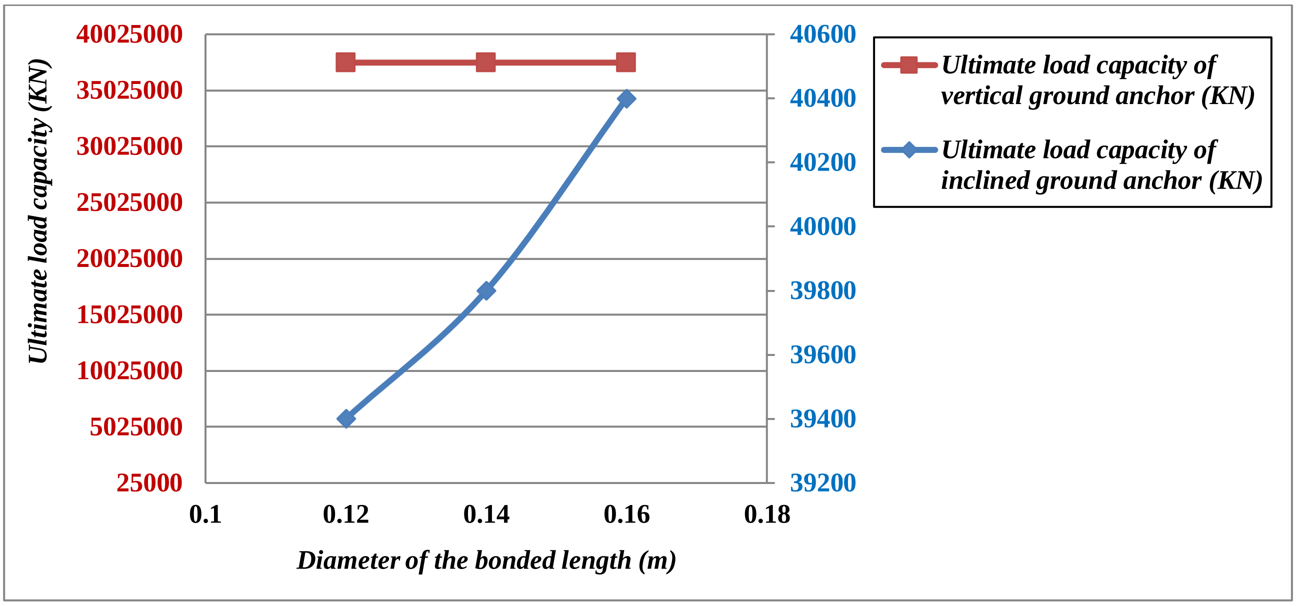

Fig.7. The variation of the ultimate load capacity with the diameter of the bonded length of vertical and inclined grouted soil anchors in medium dense sand.

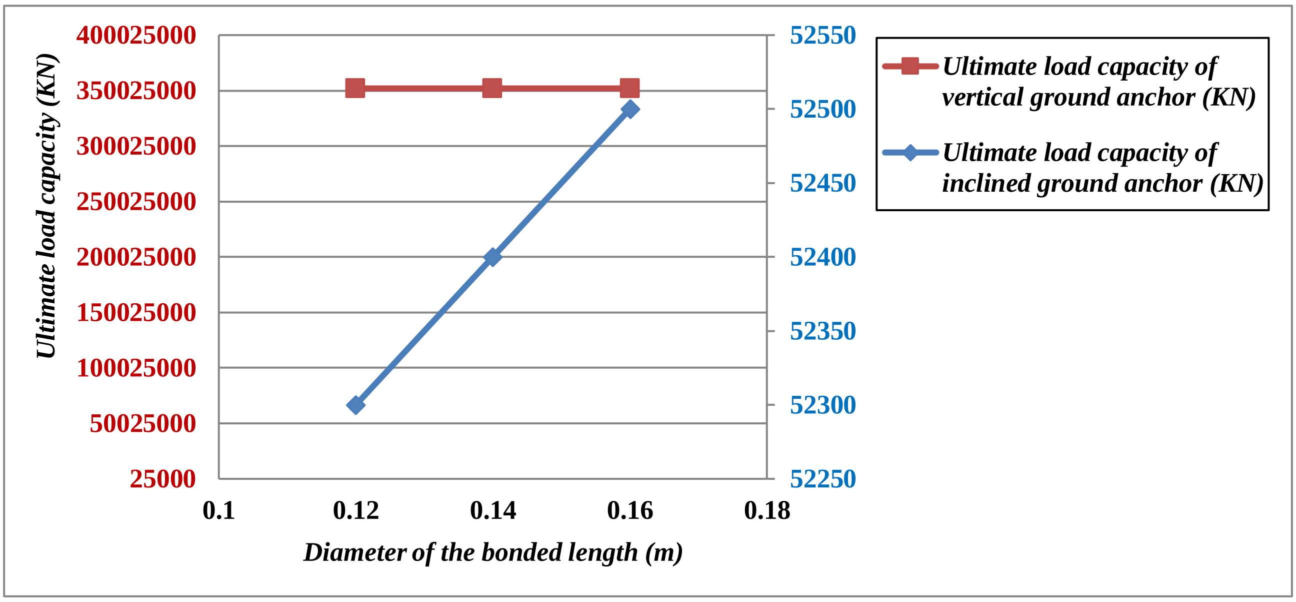

Fig.8. The variation of the ultimate load capacity with the diameter of the bonded length of vertical and inclined grouted soil anchors in dense sand.

CONCLUSION

In this paper, an attempt has been made to compare the performance of grouted soil anchors placed vertically and in inclined orientation under axial static load in sandy soils using an upper bound theorem of limit analysis. The effect of the bonded length and the diameter of the bonded length were considered in this work.

Based on the analysis of the results obtained from the present study, the following main conclusions can be drawn:

- The magnitude of critical loadof vertical and inclined grouted soil anchors was primarily governed by the sand density.

- A comparison of the pullout load capacity indicated that the pullout force of vertical grouted soil anchor is higher than the ultimate load of inclined grouted soil anchor.
- The effect of the bonded length on the collapse load was investigated, it was found that the pullout resistance of vertical and inclined grouted soil anchors increases continuously with the increase in the bonded length.
- In addition, the influence of the diameter of the bonded length was studied, it was found that this parameter has no effect on collapse load of vertical grouted soil anchor but the pullout force of inclined grouted soil anchor increases with the increase in this factor.

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