Journal of Rock Mechanics and Geotechnical Engineering 9 (2017) 726–740

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Full Length Article

Investigations on pullout behavior of geogrid-granular trench using CANAsand constitutive model

Ali Noorzad, Ehsan Badakhshan*

Faculty of Civil, Water and Environmental Engineering, Shahid Beheshti University, Tehran, Iran

ARTICLE INFO

Article history:
Received 16 October 2016
Received in revised form
16 January 2017
Accepted 6 March 2017
Available online 17 July 2017

Keywords:
Anchor
Pullout test
Geogrid
Granular trench
CANAsand constitutive model

ABSTRACT

Experimental and numerical investigations have been carried out on behavior of pullout resistance of embedded circular plate with and without geogrid reinforcement layers in stabilized loose and dense sands using a granular trench. Different parameters have been considered, such as the number of geogrid layers, embedment depth ratio, relative density of soil and height ratio of granular trench. Results showed that, without granular trench, the single layer of geogrid was more effective in enhancing the pullout capacity compared to the multilayer of geogrid reinforcement. Also, increasing the soil density and embedment depth ratio led to an increase in the uplift capacity. When soil was improved with the granular trench, the uplift force significantly increased. The granular trench improved the uplift load in dense sand more, as compared to the same symmetrical plate embedded in loose sand. Although it was observed that, in geogrid-reinforced granular trench condition, the ultimate pullout resistance at failure increased as the number of geogrid layers increased up to the third layer, and the fifth layer had a negligible effect in comparison with the third layer of reinforcement. Finite element analyses with hardening soil model for sand and CANAsand constitutive model for granular trench were conducted to investigate the failure mechanism and the associated rupture surfaces utilized. The response of granular material in the proposed model is an elastoplastic constitutive model derived from the CANAsand model, which uses a non-associated flow rule along with the concept of the state boundary surface possessing a critical and a compact state. It was observed that the granular trench might change the failure mechanism from deep plate to shallow plate as the failure surface can extend to the ground surface. The ultimate uplift capacity of anchor and the variation of surface deformation indicated a close agreement between the experiment and numerical model.

1. Introduction

There are many structures, particularly in industrial application areas, where foundations are subjected to either large uplift forces or overturning moments. Typical instances of such structures are anchor cables of television and transmission towers, leg of elevated water tanks and power transmission towers, tension cables for suspension bridges, tower and floating platforms, all of which are subjected to wind loading and wave forces. In such situations, an economic design is employed for anchor foundations. Plates, belled piles, pedestal and drilled shafts are traditional anchor systems which are capable of resisting uplift forces and are more economical to be installed.

Numerous researchers have carried out experimental and theoretical analyses of the pullout capacity in sand, notably Balla (1961), Meyerhof and Adams (1968), Vesic (1971), Hanna et al. (1972), Das (1978, 1980), Rowe and Davis (1982), Saran et al. (1986), Murray and Geddes (1987), Dickin (1988), Ilamparuthi and Muthukrisnhaiah (1999), El Sawwaf and Nazir (2006), and Merifield and Sloan (2006). The aims of these studies were to investigate the influences of size, embedment depth and density of soil on behaviors of plates. In addition, the influences of two-layered sand (loose and dense sands) and three-layered sand on pullout resistance of plate were studied by Bouazza and Finlay (1990). Also, Patra et al. (2004) examined the influence of anchor piles inclining in the sand and concluded that with the increasing inclined angle of anchor pile with the vertical direction, the ultimate pullout resistance increased.

* Corresponding author. Fax: +98 21 7700 6660.
E-mail addresses: A_Noorzad@sbu.ac.ir (A. Noorzad), E_Badakhshan@sbu.ac.ir (E. Badakhshan).

Peer review under responsibility of Institute of Rock and Soil Mechanics, Chinese Academy of Sciences.

http://dx.doi.org/10.1016/j.jrmge.2017.03.013
1674-7755

Recently, the uplift capacity of multi-plate strip anchors in undrained clay has been explored by Bouazza (1996) for estimating the pullout capacity in plane strain condition. Moreover, El Sawwaf and Nazir (2006) placed steel rods (model piles), with different lengths and diameters, vertically or inclined at different locations relative to the plate for reinforcing the sand in front of both strips and square plates. Their test results indicated that this type of reinforcement significantly increased the stiffness of the soil and the ultimate pullout resistance of shallow plates.

A good and common technique for improving the soil is the application of geosynthetics. Research on the behavior of plates embedded in reinforced soil with geosynthetics is fairly limited. Using geotextile ties to improve the pullout resistance of anchors was studied by Subbarao et al. (1988). Selvadurai (1993) examined the influence of geogrid layers on pullout resistance of buried pipelines in sand bed. He reported that the reinforcement increased soil uplift resistance with increasing in ductility of the system. Additionally, the effect of one layer of geosynthetics inclusion on the uplift behavior of rectangular plates in cohesive and cohesionless soil media with small-scale model tests was considered by Krishnaswamy and Parashar (1994). They reported that the geosynthetics can be employed in both cohesion and cohesionless soils to enhance the pullout resistance. Elsewhere, it was reported by Ilamparuthi and Dickin (2001) that a cylindrical gravel-filled geogrid cell located around the enlarged pile base provided beneficial effects on enhancing resistance. Ravichandran and Ilamparuthi (2004) studied the experimental behavior of plates in submerged sand reinforced with single layer of geogrid in both monotonic and cyclic modes of loading. Furthermore, Ghosh and Bera (2010) attempted to investigate the effect of geotextile reinforcement and tank size on failure surface of belled anchors. Their findings revealed that the failure surface depended on the embedment depth of anchor. Also, the study revealed that the pullout resistance of belled anchors was increased by using geotextile ties and that the optimum number of geotextile layers was found to be 1.

Improving soil with granular trench is one of the recent innovative foundation techniques, which is devised to enhance the uplift capacity of anchors. In a granular anchor, the footing is anchored to an anchor at the bottom of the granular trench. This makes the granular material tension-resistant and enables it to absorb the tensile force imposed on the foundation (Srirama Rao et al., 2007). A field-scale test program conducted to measure the pullout response of granular trench embedded in expansive clay beds was reported by Srirama Rao et al. (2007). They concluded that increases in diameter and length of granular trench increased the uplift capacity. Besides, small-scale laboratory tests were conducted on a loose dry sand to examine the effect of embedded length of granular trench on the uplift capacity of the anchor system by Kranthikumar et al. (2017). They obtained load–displacement response of the granular trench anchor for a constant diameter of plate and showed that its ultimate uplift capacity increased as the H/D ratio increased (H is the embedment depth and D is the diameter of anchor). They also reported that, for H/D ratios greater than 10, further increase in the H/D ratio did not contribute to the load sharing significantly.

Many researchers such as Rowe and Davis (1982), Tagaya et al. (1983, 1988), Vermeer and Sutjiadi (1985), Koutsabeloulis and Griffiths (1989), Sakai and Tanaka (1998), Merifield et al. (2003) and Merifield and Smith (2010) employed finite element analysis for horizontal plates (circular, strip, rectangular, and square shape) in unreinforced sand and used the elastoplastic soil model in their studies. Numerical analysis for plates in reinforced sand is strictly limited. Kassim et al. (2011) studied the behavior of square plates in dense sand using experiments and finite element analysis. They reported that the results from Plaxis were in agreement with the experimental results for particular embedment depth ratios.

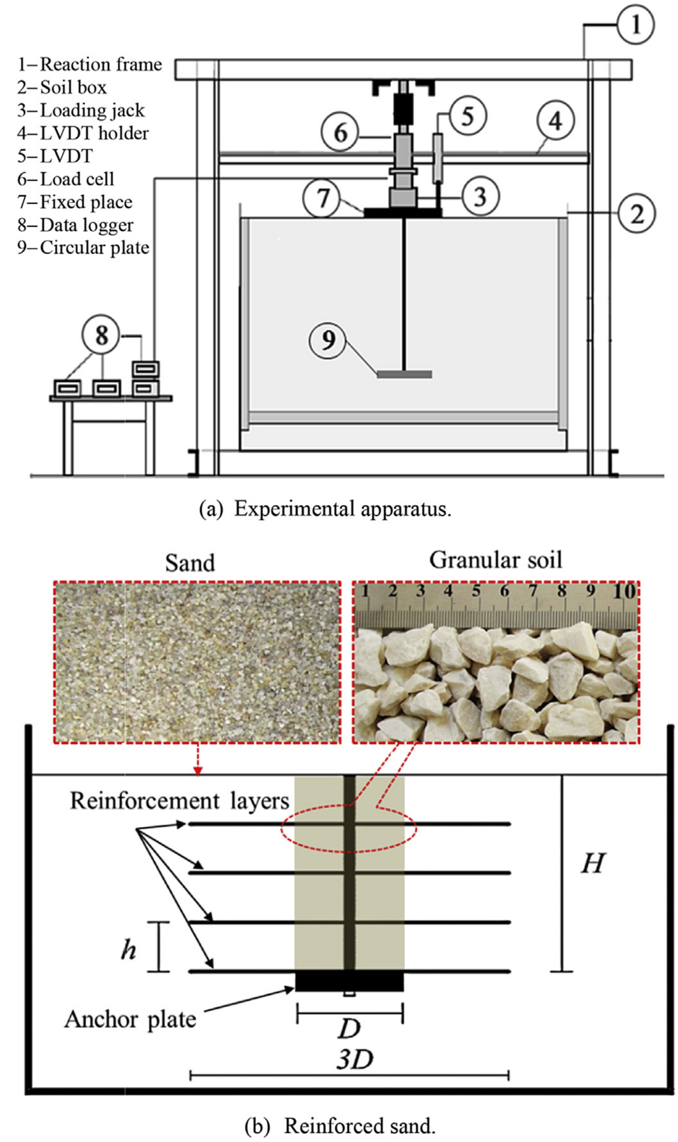

Fig. 1. Schematic view of experimental apparatus and geometry of geogrid-reinforced sand.

In a similar study, Makarchian et al. (2012) investigated the uplift behavior of anchors embedded in geonet-reinforced sand both experimentally and numerically. They reported that the uplift force at failure increased as the number of reinforcement layers increased; but for 3 layers, the increased load was negligible in comparison with that for 2 layers. Also, they revealed two main defects in Mohr-Coulomb finite element method to model the behavior of reinforced anchors. First, the maximum uplift resistance in the finite element model was reached at a lower displacement in comparison with that in the model test. Second, in reinforced sand, the ultimate uplift load obtained from the experiment is lower than that from the finite element method.

In this regard, Kranthikumar et al. (2016) presented the results of numerical study to estimate the ultimate uplift capacity of group granular trench in loose sand. They found that the uplift resistance of the granular trench system in a loose sandy soil increased with the increases in length and diameter of the trench. Surprisingly,