Interaction of two closely spaced circular ground anchors embedded in homogeneous soil deposit

Priyanka Ghosh i), and V Srinivasan ii)

i) Associate Professor, Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur 208016, India.
ii) Ph.D Student, Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur 208016, India.

ABSTRACT

The present study reveals the effect of interaction of two closely spaced shallow circular plate anchors embedded in a homogeneous medium-dense sand bed subjected to identical loading conditions. The investigation has been carried out in a large scale laboratory testing facility where the size of the anchor plates is deployed in the range analogous to that generally used in the real field situation. It can be deduced that at a closer spacing between the anchor plates the uplift capacity of the anchors decreases as compared to that of an isolated anchor. This phenomenon is due to the intervention and coalescence of the failure plane of an anchor in the presence of the other anchor in its vicinity. The dimensionless uplift capacity factor has been introduced in order to understand the interaction phenomenon of two closely spaced anchor plates and its adverse effect on the design philosophy.

Keywords: circular anchors, interaction, physical modeling, uplift capacity

1 INTRODUCTION

Structures such as transmission towers, harbor and quay walls, suspension structures, anchorage for abutments and guyed structures, mooring system in oceans and submerged platforms are more often subjected to uplift forces and thus, the resistance of the anchorage system of such structures against the uplift is found to be more critical. The uplift capacity of such ground anchors are mainly contributed by the dead weight of the soil mass resting within the failure zone and the shear strength of the soil along the failure planes. In case of shallow ground anchors, the resistance offered due to the mobilization of shear strength is generally predominant compared to that of the deep anchors embedded at a greater depth. More often these anchor systems are laid in a group. In such cases, the theories (Meyerhof and Adams 1968; Rowe and Davis 1982; Murray and Geddes 1987; Kumar 2001; Merifield and Sloan 2006) developed for single isolated anchor without considering the effect of the nearby anchors may land up in misleading design consideration. It has been noted from the literature that some researchers (Meyerhof and Adams 1968; Hanna et al. 1972; Geddes and Murray 1996; Kouzer and Kumar 2009; Kumar and Bhoi 2009, 2010 a, b; Ghosh and Santhoshkumar 2015) have reported the interaction phenomenon of closely spaced ground anchors subjected to the static vertical uplift forces. In the current work, large scale model testing has been performed to investigate the interaction effect of two nearby circular anchor plates embedded in homogeneous cohesionless soil deposit. More often, in case of 1 g experiment, the outcome of the physical modeling of geotechnical structures is under scanner because of the low stress level developed in the experimental set-up. Hence, unlike the recent reported works on the anchor interaction, the present investigation has been carried out on a large scale testing facility where the size of the anchor plates is considered in the range analogous to that generally used in the real practical situation.

2 PROBLEM DEFINITION

Two typical circular plate anchors of 12 mm thickness and 15 cm diameter are placed at a clear spacing, S and embedded at the same depth, D. The anchor plates have been embedded in a homogeneous medium dense sand bed. Fig. 1 depicts the definition of the problem considered in the study. The anchor plates are gradually pulled out until the failure occurs, in order to determine the ultimate uplift capacity (P_u) and the corresponding upward displacement. The objective of the present study is to obtain the complete load-displacement profile of the two interfering circular anchors placed at different spacing and subjected to uniform upward movement.

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3 SOIL PROPERTIES, TEST SET-UP AND METHODOLOGY

In the present study, cohesionless dry Quartzanium sand of grade II collected from Ahmedabad, Gujarat has been used to prepare the foundation bed. The physical properties of the sand are tabulated in Table 1. The sand bed has been prepared and maintained at a uniform relative density of 62.5% and the corresponding peak angle of internal friction has been determined as 28.5° from the direct shear test. The investigation employs the air pluviation technique using the portable travelling pluviator in order to prepare the sand bed of volume in the order of 4-6 m$^3$. For more details about the preparation of the sand bed, the work of Srinivasan et al. (2015) can be referred.

Table 1. Physical properties of Quartzanium sand.

| Physical properties | Values |
|---------------------|--------|
| Coefficient of uniformity, $C_u$ | 2.00 |
| Coefficient of curvature, $C_c$ | 0.83 |
| Effective size, $D_{50}$ (mm) | 0.45 |
| Specific gravity, $G_s$ | 2.57 |
| Maximum density, $\rho_{\text{max}}$ (gm/cm$^3$) | 1.54 |
| Minimum density, $\rho_{\text{min}}$ (gm/cm$^3$) | 1.32 |
| Placing density, $\rho$ (gm/cm$^3$) | 1.45 |

Once the sand bed is prepared up to a certain depth $D$, the two anchor plates fixed at a specific spacing, $S$ are placed on the prepared sand bed and the homogeneous medium dense sand bed is further extended similarly up to the brim. The surface of the anchors has been made perfectly rough using emery sheets, which is in tune with that of the sand used in the present study. During the process of loading, the actuator is set to pull the moveable beam in the upward direction at a rate of 0.1 mm/min. In turn, the anchor plates embedded in the homogeneous sand bed are subjected to a uni-axial (vertical) uplift. The total load carrying capacity of each anchor plate is recorded through the separate load cell mounted between the moveable rigid block and the guiding rods connected to the anchor plates. The upward displacement of each of the anchor plates is measured using the dial gauge fixed over the small rigid plate protruded from the guiding rod above the ground level. It is worth mentioning here that, the considerable thickness of the anchor plate and the rigid connections between the plate and the guiding rod, the guiding rod and the load cell screws, the load cell screws and the moveable rigid block have ensured ‘no tilt’ condition of the anchor plate during the application of the vertical uplift force.

4 RESULTS AND DISCUSSION

In order to ascertain the behavior of closely spaced ground anchors, the load-displacement profile of the isolated circular anchor has been obtained by performing the vertical pullout test of a single isolated anchor. Fig. 3 shows the load-displacement behavior of single isolated circular anchor of diameter (B) 15 cm embedded at 30 cm depth (D) i.e., at $D/B = 2$. The failure load is determined by single or double tangent method as applicable. Further, it is also evident that the displacement of the anchor plate is initiated only after counteracting the entire dead weight of the soil lying of the servo controlled hydraulic jack mounted over the rigid beam.
above the anchor plate beyond which the resistance is generated by the mobilized frictional resistance along the failure envelope. Table 2 provides a comparison of the gross uplift load determined from the current investigation with the available results in the literature in order to ensure the reliability and authenticity of the present experimental observations.

Table 2. Comparison of uplift capacity of isolated circular anchor with B = 15 cm and D/B = 2.0.

| Source                        | Ultimate uplift load (kN) |
|-------------------------------|---------------------------|
| Balla (1961)                  | 0.431                     |
| Murray and Geddes (1987)      | 0.414                     |
| Present study                 | 0.383                     |

It can be conceived that for the given placing density and peak friction angle, the present work compares reasonably well with the theoretical values available in the literature. Considering satisfactory validation of the developed physical modeling, the interaction phenomenon has been studied, when two anchor plates are placed at a clear spacing, S at a depth, D from the ground level.

Fig. 4 depicts the load-displacement characteristics of two interacting anchors at different spacing ratio (S/B). The plots at each spacing ratio are determined by averaging the behavior of the left and the right anchor subjected to identical loading conditions. It can be observed that at lower spacing between the anchor plates, the ultimate uplift load decreases much lesser than that of the single isolated anchor. As the spacing between the two anchor plates increases, the effect of interaction decreases and approaches the load-displacement profile similar to that of the single isolated anchor. Philosophically, at closer spacing the failure envelope of one anchor intervenes and coalesces with that of the other and thus forms a highly stressed overlapped zone in the sand bed, which causes major interaction.

![Fig. 3. Load-displacement behavior of isolated circular anchor at D/B = 2.0.](image)

![Fig. 4. Load-displacement behavior of two interacting circular anchors with B = 15 cm and D/B = 2.0 at different S/B.](image)

5 CONCLUSIONS

The present study determines the interaction effect of two closely spaced circular plate anchors embedded at shallow depth in a homogeneous medium-dense sand bed by developing a large scale physical model testing facility. It has been observed that with increase in the spacing, the ultimate uplift capacity of the interacting anchors increases and eventually reaches the value equal to that of the single isolated anchor at higher spacing. The effect of interaction is more predominant at a closer spacing between the anchor plates.

![Fig. 5. Variation of uplift capacity factor with S/B ratio for interacting circular anchors at D/B = 2.0.](image)
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