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Analysis of anchored retaining walls

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ABSTRACT: The design of anchored retaining walls requires a reliable prediction of anchor capacities. This paper discusses results from a large number of laboratory tests and finite element simulations on pullout behaviour of vertical anchors and multi-anchored retaining walls with sand as the backfill soil. The pullout behaviour was examined at both shallow and deep embedment depths. The effect of the shape of anchors was studied by testing square, rectangular, and circular anchors. The tests were repeated for three different friction angles of backfill soil. The model retaining walls were loaded with a uniform surcharge until collapse. The measured anchor forces at collapse indicated that the lateral pressures in the backfill soil corresponds to Rankine active earth pressure state. The behaviour of these walls was studied for different sizes and configurations of anchors. Based on the results from this work, a method is proposed for the design of these walls.

1. INTRODUCTION

Anchored retaining walls provide an attractive alternative to the conventional gravity type retaining walls. Unlike the conventional gravity retaining walls, these systems are relatively flexible and can undergo large differential settlements without catastrophic failures. These walls can be built rapidly compared to rigid type structures. The factors that influence the behaviour of anchored retaining walls include the size and shape of anchors, properties of backfill soil, embedment depth and spacing of anchors, facing type, etc.

For the design of anchored retaining walls, the capacity of anchors should be estimated accurately. Based on results from laboratory tests and finite element simulations on pullout behaviour of vertical anchors and multi-anchored retaining walls, this paper discusses a method for the design of anchored retaining walls.

2. LITERATURE REVIEW

A number of papers have been published on the pull-out behaviour of vertical anchors, e.g. Neely et al. (1973), Rowe and Davis (1982), Das (1985). All these papers have considered the behaviour of only the anchors at shallow embedment depths. The behaviour of anchors was expressed in terms of a ratio of depth of soil to the bottom of anchors (h) and the height of anchors (H). This h/H ratio was defined as the embedment depth ratio and was assumed to control the pullout-load carrying capacity of anchors. The major drawback of this method of interpretation is that it can not consider the effect of surcharge pressures on anchors. These limitations were overcome by expressing the anchor capacity in terms of normal pressure acting at the mid-depth of the vertical anchors. Further, the behaviour of vertical anchors was studied at both shallow and deep embedments by both experimental and finite element simulations.

The published literature on anchored retaining walls has considered those walls supported by grouted anchors and soil nails, e.g. Hanna and Matallana (1970), Clough (1974), Hanna (1974), Anderson et al. (1977). There is some literature on retaining walls supported by other forms of anchors such as Z-shaped mild steel anchors,

anchors, Singh (1992). More details on this subject can be found in those references.

3. PULL-OUT BEHAVIOUR OF VERTICAL ANCHORS

The anchors placed in a test tank of height 0.8 m, width 0.6 m, and of length 0.8 m were pulled out by applying loads through a pulley mechanism. The sides of the tank are made of plexiglass and are lined with lubricated plastic sheets. This special arrangement was used to minimise the effects due to sidewall friction.

A beach sand predominantly made up of rounded particles was placed in the test tank by sand raining technique. The effective size (D_{10}) of the particles is 0.15 mm which has coefficient of uniformity and curvature of 2.2 and 0.94 respectively. The sand was placed in the test tank at three different relative densities by sand raining technique in which the sand was dropped through a controlled height using a funnel mechanism. The relative density of the backfill soil was varied by changing the height of fall of the soil. The friction angle of the sand was determined from direct shear tests. Table 1 shows the relative density and shear strength of soil for different heights of fall used in the test.

Table 1. Relative density and shear strength of sand for different heights of fall

Height of fall (mm)	relative density (%)	peak friction angle (°)
200	41.2	33
300	57.37	36
400	62.00	38

Three different shapes of anchors viz. square, circular, and rectangular, have been tested. The effect of size of anchors was studied by varying the size of square plates from 25 to 50 mm. The embedment ratio was defined using a non-dimensional embedment parameter $\sigma_v/\gamma H$ in which σ_v is the normal stress at the mid-depth of anchor, γ is the unit weight of soil, and H is the height of anchor. The range of the above non-dimensional embedment parameter was varied from about 4 to 100 to study the behaviour of both shallow and deep embedments. The pullout tests were performed with a uniform surcharge applied on the soil to obtain high ranges of values of the above non-dimensional embedment parameter.

The experimental pullout test data was supplemented by results from finite element simulation of continuous anchors subjected to different surcharge pressures. A modified hyperbolic constitutive model as discussed by Karpurapu and Bathurst (1995) was used in the analysis.

Figure 1 shows the pullout force vs. displacement behaviour of 35 mm square anchors at both shallow and deep embedment depths. Figure 2 shows a comparison of unit pull-out force for different sizes and shapes of anchors.

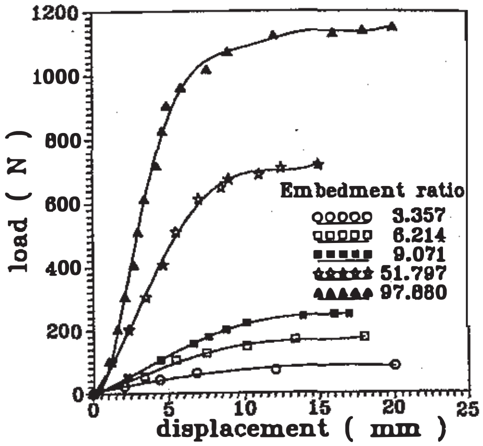

Fig. 1 Pullout behaviour of 35 mm square anchors

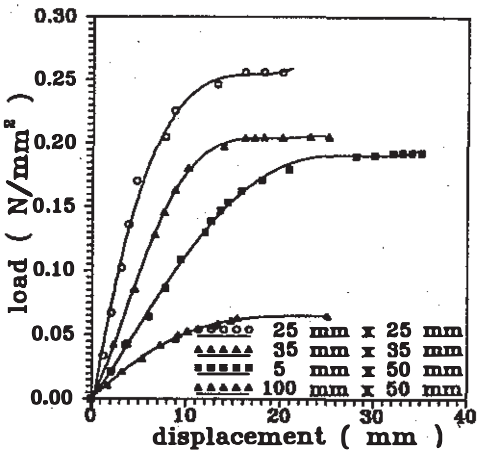

Fig. 2 Pullout behaviour of different shapes of anchors

In general, the capacity of anchors increased with embedment depths. The capacity was observed to increase rapidly at shallow depths and at much slower rates at deep embedments. The unit capacity of square and circular anchors was observed to be more than the rectangular anchors. The efficiency of rectangular anchors decreased as the aspect ratio (B/H) increased.

Continuous anchors were found to be very much less efficient than the other types of anchors. In general, it was observed that as the embedment depth increased, the displacement at which peak load occurred has increased. The deep anchors have developed peak capacities at such large displacements that it is not practically feasible to utilise the full capacity of such anchors.

The peak pull-out load of vertical anchors in sandy soils is related to a number of important parameters such as the size and shape of anchors, friction angle of soil, normal pressure acting at mid-depth of anchors etc. The data generated by laboratory experiments and finite element simulations was used in developing a simple equation to relate all the above parameters, Equation 1. The parameters in the model were determined by minimising the error between the measured and predicted pull-out loads using an optimisation technique. An IMSL (International Mathematical and Statistical Library) subroutine ZXSSQ was used for this purpose.

$$\frac{P}{L} = S_a C\left[1 + \frac{H}{L}\right]^m \gamma H^2 \left(\frac{\sigma_v}{\gamma H}\right)^n K_p^q \quad (1)$$

in which, S_a is the shape factor, C is a non-dimensional constant, n, m, and q are exponents. The circular anchors were found to have a shape factor of 0.8 and the square and rectangular anchors have a shape factor of 1.0. The values of C, m and q are found to be 1.42, 1.36 and 1.09 respectively. For shallow embedment depths for which $\sigma_v/\gamma H$ less than 15, the exponent n was found to be 1.46. For higher embedment depths best-fit was obtained with n values of 1.03.

4. ANCHORED RETAINING WALL TESTS

The same test tank and sand used for the pullout tests were used for the retaining wall tests also. The retaining walls consisted of a 5 mm thick aluminium plate that is laterally supported by a system of vertical anchors. The bottom of the wall facing was left free to move laterally. The walls were subjected to collapse by applying a uniform surcharge on part of the backfill surface as shown in Figure 3.

The forces developed in the anchors have been measured using pre-calibrated proving rings, Figure 3. The lateral movements of the wall and the bending moments developed in the wall facing were also measured.

The variables considered in the laboratory tests are the size of anchor plates, number of anchors, vertical and horizontal spacing of anchors, and the relative density of backfill soil. The performance of the retaining walls for three different sizes and shapes of anchors has been tested. The horizontal location of anchors within the backfill soil behind the wall was also varied in the tests.

All the walls were subjected to small surcharge load increments until the collapse. The anchor forces and lateral displacements of wall facing were recorded at various surcharge increments. Figure 4 shows some of the anchor lay outs considered in the retaining wall tests.

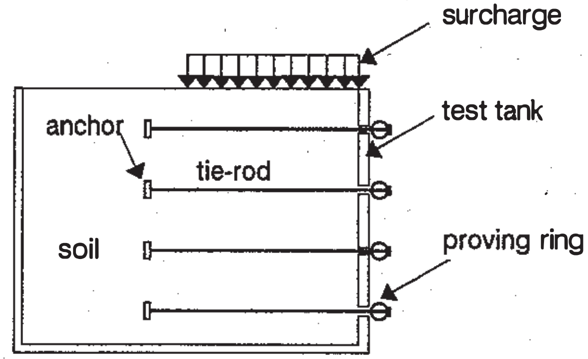

Fig. 3 Setup for retaining wall tests

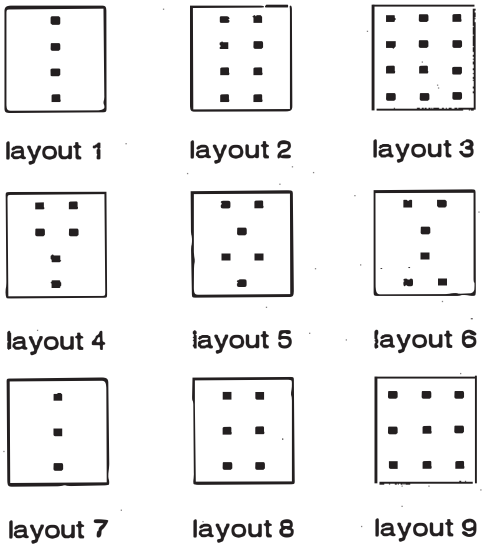

Fig. 4 Anchor layout for retaining wall tests

Figure 5 shows the development of anchor forces and lateral panel displacements as the surcharge pressures were increased. It can be seen that the anchor forces increase rapidly as the surcharge pressure nears the collapse pressure.

The retaining walls collapsed under the self-weight when the wall was constructed with four 25 mm size anchors or three 35 mm size anchors. For all other cases, the collapse happened after some surcharge pressure was applied. The self-weight of retained backfill soil creates an active earth force of approximately 0.90 kN. The total load carrying capacity of 3 Nos. 35 mm and 4 Nos. 25 mm square anchors works out to be approximately 0.65 kN which is much less than the lateral force due to self weight of soil. This clearly explains the reasons for the failure of these two walls under the self-weight of backfill soil.

For other cases of retaining walls, the measured anchor forces and the applied surcharge force were used to estimate the coefficient of lateral earth pressure prevailing in the wall at collapse state using the relation,

$$K = \frac{\sum P_i}{\left[\frac{1}{2}\gamma H^2 + Q\right]} \qquad (2)$$

in which ΣP_i is the sum of anchor forces, Q is the total surcharge force applied on the system, γ is the unit weight of soil and H is the height of the wall. The back-calculated K values were close to the Rankine active earth pressure coefficients calculated using the friction angle of soil.

5. DESIGN OF ANCHORED RETAINING WALLS

At collapse state of these retaining walls, the total pullout capacity of anchors should be equal to the active lateral earth force with some adequate factor of safety. The pullout force of anchors can be reliably estimated using the data presented in this paper for given size and shape of anchors and other relevant parameters. Once the anchor capacities are determined, the horizontal and vertical spacing can be decided based on the total active force.

6. SUMMARY AND CONCLUSIONS

This paper has presented comprehensive laboratory data on vertical anchors and anchored retaining walls. Based on this data, it has proposed a simple design method for these walls.

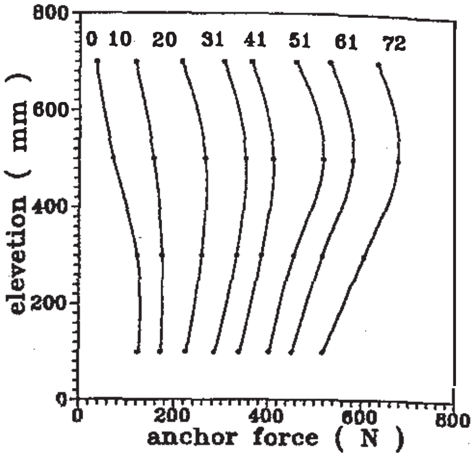

Fig. 5 Anchor forces at different Surcharge pressures (kPa)

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