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Application of screw anchor to side shoring of two foundation pits

Zhao Wang & Zude Liu
Wuhan University of Hydraulic and Electrical Engineering, People's Republic of China

ABSTRACT: The steep slopes of two foundation pits varying in depth from 3 m to 6 m were shored by screw anchors in Hubei province of China. Site pull-out tests were conducted to determine the allowed load. The results of tests were compared with those obtained from design formulas. The settlements of buildings by the top side of pits were monitored for 2-3 months until the pits were refilled. The maximum settlement was only 2. 5 mm. The manufacture and installation of screw anchor and method of maintenance of bracing force have been provided. Some proposals are presented for further research.

1 INTRODUCTION

The screw anchor was applied in construction practice as a temporary anchorage before 1950 and developed to become a simple and convenient in situ soil test device which was applied to observation of variation of density of loose sand and to measure of undrained shear strength, c_u and undrained initial modulus, E_{u1} of soft clay during the 1960′s.

The screw anchor may be turned into soil by itself with high speed, simple devices and low expenditure. In the drilling procedure, the soil under the plate is not disturbed, so that the anchor has high capability to bear compression. After a resting phase the strength of disturbed soil will increase, the screw anchor can bear the pull-out load as well. In 1970′ s the screw (or helical) anchor was applied as both compressive foundation plates and tensile anchorage of transmission towers in Canada(Adams and Klym 1972).

This paper introduces the application of screw anchor to side shoring of two foundation pits. One of them was the foundation of Xiaogan supermarket. When it was completed, the expenses were cut down 65% compared with that of original plan of retaining concrete piles. There are not vibration, noise and sludge pollution during installation of screw anchor. In addition, the results of pull-out tests and some proposals about further research works are presented.

2 STRUCTURE OF SIDE SHORING

2.1 *Structure and design of screw anchor*

The structure of a screw anchor, which is composed of screw plates, anchor rod (or tube) and head of rod, is schematically shown in Fig. 1. In order to decrease the disturbance of subsoil, the diameters of plates, d are different, the lower plate has the smaller diameter, however, they have same helical distances, b and distance between two plates, B is equal to integral times of b. In general, taking $B \geqslant 3b$ to decrease the influence of adjacent plates.

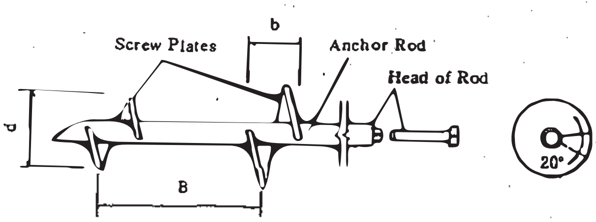

FIG. 1. Structure of screw anchor

2.2 *Structure of facing*

The structures of facing of foundation pit in Xiaogan supermarket are shown in Fig. 2 and that in Diangziqiao building is shown in Fig. 3. Both structures with maximum depth of 6. 0 m were built in urban sites. The distances between new and old buildings were all less than 2. 5 m. Supporting work of temporary braces or large-diameter concrete piles is very time-consuming, money-consuming and the framed braces will prevent later construction of basement. After comparison of different supporting methods screw anchor was finally selected.

Fig. 2 shows that the first and second levels are facings of screw anchors, $\varepsilon = 20°$, third level is structure of steel lagging and piling for better soil condition. Fig. 4 shows that piles are set in predrilled holes, which have distance of 500 mm around the periphery of the excavation. These piles are then grouted in place with weak concrete. In the procedure of excavation the soil is carefully trimmed away from the soldier piles and the screw anchor and horizontal beam are installed at once.

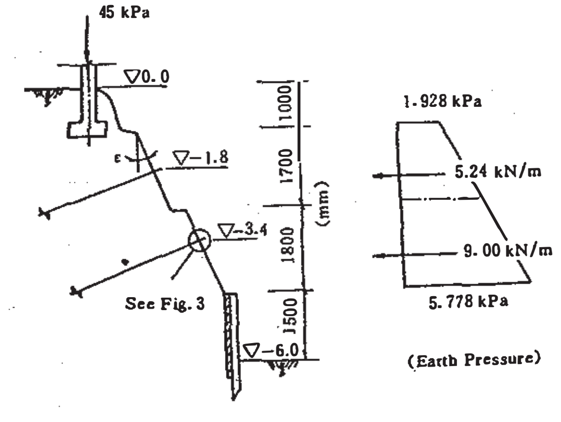

FIG. 2 Facing of foundation pit and earth pressure in Xiaogan supermarket

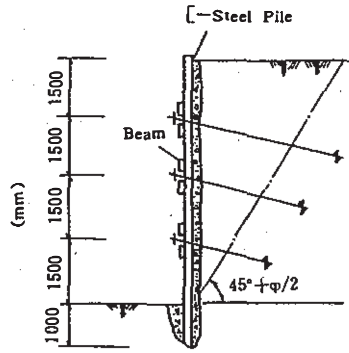

FIG. 3 Facing of foundation pit in Diangziqiao building

3 DESIGN OF SIDE SHORING

Taking Xiaogan supermarket as example, the earth pressure obtained from Coulomb's theory is shown in Fig. 2. Estimation of resistance to pull-out of the anchor can be made by following empirical formulas, but final design is based on pull-out tests. According to pull-out tests in situ, the ultimate pull-out load of first level is $P_{ult1}=23$ kN, that of second level is $P_{ult2}=44$ kN, taking safety factor $F_s = 2.0$, then, the allowable tensile forces are 11.5 kN and 22 kN, respectively. The horizontal distance of poles of both levels are 1.5 m, then, practical load of first level is equal to $1.5 \times 5.24 = 7.86$ (kN), that of second level is $1.5 \times 9.0 = 13.5$ (kN), compared with allowable tensile forces, the safety factor is satisfied.

All screw plates have to be installed behind Rankine's failure surface(See Fig. 3).

4 PULL OUT TESTS

The purposes of pull-out tests are determination of allowable tensile force and examination of accuracy of empirical formulas, furthermore, determination of diameter of screw plate. For example, in the first test the diameter was 15 cm, ultimate pull-out load was only 10 kN, then, the diameters of 20 and 25 cm were determined. The results of tests are given in the relations between pull-out load, P and displacements of head of rods, S. The curves of four tests are shown in Fig. 4. Number I is the first level, II is the second level. The ultimate pull-out load is determined by crosspoint of two direct lines in a curve. The results of some tests are given in Table 1 and compared with following formulas.

Table 1 Comparison of ultimate pull-out load

Rods No.	Level of Rod Head. (m)	Length of Rods (m)	Diameter of Plate (m)	Ultimate Pull—out Load(kN)			
				Test	For. (5.1)	For. (5.2)	For. (5.3)
I—2	−1.80	4.30	0.25	23.0	30.2	23.7	105.2
I—4	−1.80	5.10	0.25	28.5	33.9	24.0	135.4
II—3	−3.40	3.40	0.20	44.0	51.7	37.0	113.1

In order to examine the property of displacement under long-term load, three pull-out tests, in which the pull-out loads were kept in 30 kN, were completed at level of -2.50 m. The results are shown in Fig. 5.

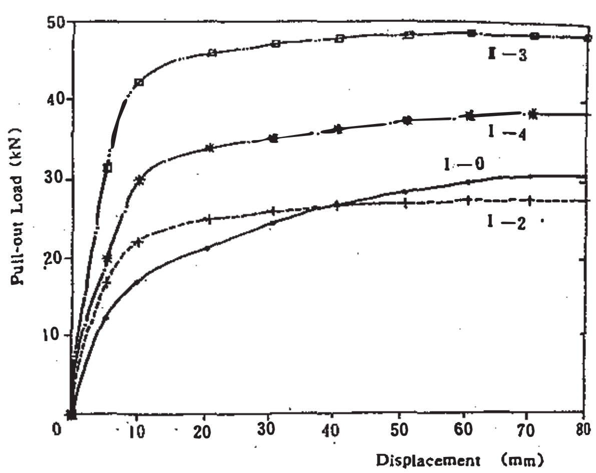

FIG. 4 Pull-out tests

5 ESTIMATION OF PULL-OUT LOADS

There are many theories about failure mechanism and formulas of ultimate pull--out load. They mainly are following:

5.1 *Formula of loading plate*

When the screw anchor is pulled-out, the interaction between screw anchor and soil is same as it is compressed, so that the results of loading plate may be used. Neglecting the helical figure of plate, the ultimate pull-out load, which is equal to the sum of bearing capacity of plate and friction between rod and soil

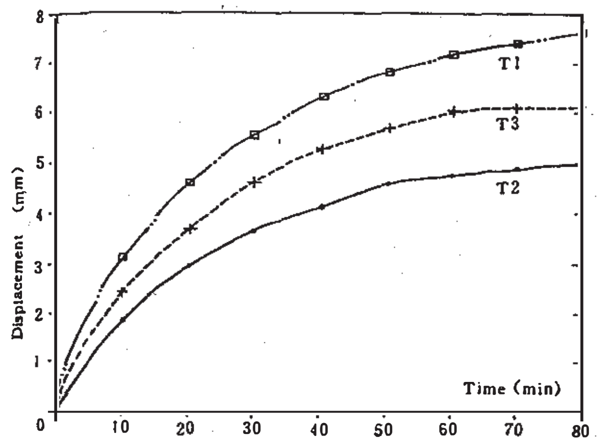

FIG. 5 Creep tests

(Klym et al. 1986), can be estimated as:

$$P_{ult}=A(cN_c+\bar{\gamma}DN_q)+A_sf_s \quad (5.1)$$

in which P_{ult} = ultimate pull-out load; A = net area of plate; c = cohesion; $\bar{\gamma}$ = average unit weight of soil above plate; D = depth of soil above plate; N_c, N_q = factors that are functions of soil's internal friction angle, φ (Kulhawy 1984); A_s = area of rod's surface; f_s = average specific friction of rod's surface that is equal to normal pressure multiplied by friction factor between rod and soil, which is depended on properties of soil, generally, from 0.3 to 0.4, the lower is the plasticity index or water content, the greater is the friction facter.

5.2 *Empirical formula*

When dealing with screw plate tests conducted in cohesive soil media, it is instructive to reassess the performance of the screw plate test by appeal to simplified theories of material behaviour such as linear elasticity and ideal plasticity. They provide useful first approximations for the mechanical behaviour of cohesive soils at ultimate stress levels. The undrained shear strength, c_u can be determined from the ultimate or failure load, P_{ult} observed in a screw plate test via the following relationship (Selvadurai and Nicholas 1981): $c_u=P_{ult}/(\pi R^2)/(9.00 \text{ to } 11.35)$.
in which R = radius of plate.

The P_{ult} may be estimated by the empirical formula:

$$P_{ult}=10\ c_u\,\pi R^2 \quad (5.2)$$

5.3 *Formula of grouted anchor*

For a grouted anchor and considering the cylindrical failure surface, whose radius is equal to R, the ultimate pull-out load can be estimated as:

$$P_{ult}=2\pi RL_ec_u \quad (5.3)$$

in which L_e = length of anchor rod behind the Rankine's failure surface.

A comparison of the ultimate pull-out loads obtained from tests and formulas (5.1), (5.2) and (5.3) is shown in Table 1. Four series of quick direct shear tests were conducted on the subsoils of Xiaogan supermarket. The shear strength envelopes, with slopes of 6.4° to 12.0° and intercepts of 41 to 78 kPa, are not shown in this paper.

The formulas (5.1) and (5.2) are more approximate to results of tests and the formula (5.2) has the highest accuracy and the simplest form. The formula (5.3) overestimated the ultimate pull-out load, because the subsoil was disturbed, when the plate was turned in. At first, the disturbed loose cylindrical soil was compressed and larger displacement was produced, when the plate was pulled, then, the soil was failured along cylindrical surface as that of grouted anchor.

6 MONITORING AND MAINTENANCE

The facing of foundation pit is a temporary structure. In the pit of Xiaogan supermarket the settlements of adjacent buildins had been monitoring and the bolts of rod heads had been tying for two months in 1990.

6.1 *Monitoring of settlements*

Four points of observation were put on the base of two adjacent buildings. The settlements are shown in Table 2. The maximum settlement was 2.5 mm and the steep slope was stable until the pit was refilled in July.

Table 2 Observation of settlements (mm)

Points	May 7	May 14	May 17	May 23	June 13	June 25	July 5	July 21
1	0	0	0.5	1.0	1.0	1.0	1.0	1.5
2	0	0	0	0.5	0.5	0.5	0.5	0.5
3	0	0.5	0.5	1.0	1.5	1.0	1.0	2.0
4	0	0.5	0.5	1.5	1.5	1.0	2.0	2.5

6.2 *Examination of practical tension and displacement*

Relationship between tensile force and displacement of rod head of three anchors (No. I-4, I-6 and II-2) were examined by strain-controlled tests, in which the tensile force was measured by load gauge under giving pull-out displacements, after excavation. The results of the three anchors and another testing anchor installed just before test are shown in Fig. 6. These results show that the practical working states of anchors are better than testing one. It is due to thixotropy of soils, i.e., the rest period of three anchors is longer than that of testing anchor.

6.3 *Relation of pull-out load and tied torque of bolt*

Tied torque, T and the axial tied force, P of an set of

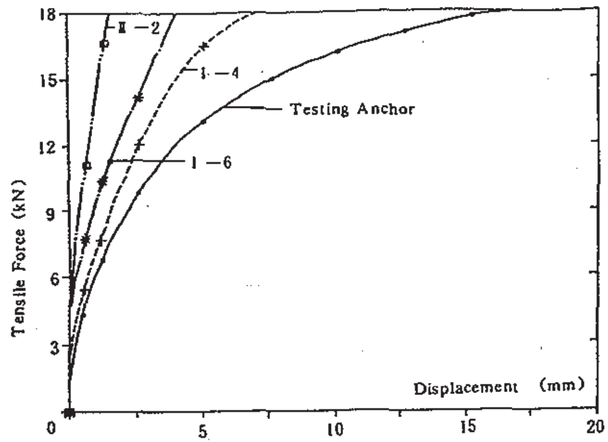

FIG. 6 Tensile force and displacement

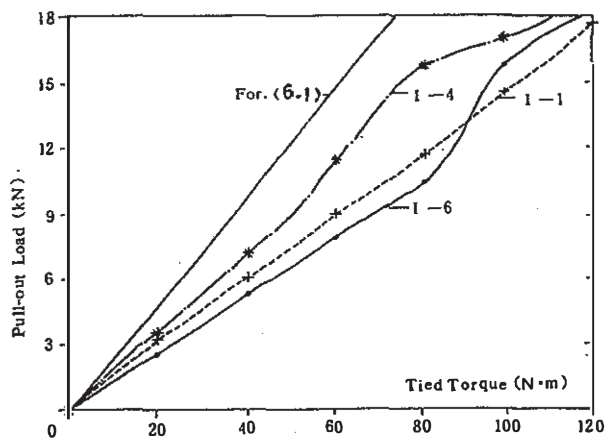

FIG. 7 Pull—out load and tied torque

bolt and nut and the actual values of frictional coefficients for both collar and thread friction, we can obtain a good estimated and very simple relation between T and P(Shigley and Mitchell 1983):

$$T = 0.2Pd \qquad (6.1)$$

in which d = the diameter of bolt.

The relation of formula (6. 1) is shown in Fig. 7 in which the d was equal to 20 mm. The tied torque of the bolt in the anchor rod head was measured by torque spanner (maximum measured torque of 300 N. m) and the pull-out load was measured by load gauge which are shown in Fig. 7 as well. The Fig. 7 shows that the measured pull-out load is less than that from formula (6. 1). In maintenance of tensile force of the anchor the tied torque was depended on the measured relation, for example, the design tensile force was 7. 86 kN for first level of anchor, the tied torque of 55 N. m was taken from the Fig. 7.

6. 4 *Maintenance of bracing force of anchor*

Because the screw anchors have stronger creep properties (See Fig. 5), the tensile force, i. e., bracing force, will gradually decrease. The bolts of rod head should be tied with torque spanner often and at certain period to maintain the bracing force based on the Fig. 7.

7 DISCUSSIONS AND SUGGESTIONS

From successful applications in side shoring of foundation pits and results of pull-out tests in situ of screw anchors the following discussions and suggestions for further research may be given.

1. Because of the better resistance of screw anchor to pull-out load, except for it is applied to temporary prop of excavated slope and tieback anchor of transmission tower, it can be used in other foundation engineering, for example, bearing the back tension of test pile and maintaining stability of slope as a soil nail.

2. In manufacture of screw plates the casting method may be applied so that the figure and helix up-angle are compatible with each other to reduce the disturbance of soil and cost of anchor and increase the resistance to rust.

3. According to comparison of ultimate pull-out load between tests and formula (5. 3) we may predict the screw anchor has large potential resistance to pull-out load. If the disturbed cylindrical soil is stiffened by grout, the ultimate load will be much greater (See Table 1).

4. The section area of anchor tube chosen by resistance to installing torque is much greater than that by design tensile force, it is waste of material. We suggest that the anchor tube is departed from and geared into the screw plate, so that the tube as a tool may be repeatedly used. The anchor rod, which can be made of synthetics, is installed through the plate and tube to bear the pull-out load. When the plate and rod are turned in and reached the design position, the tube with a small screw plate on its tip is gradually turned out, at the same time the grout is proceeded.

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