SCREW ANCHOR TEST PROGRAM (Part II): FIELD TEST RESULTS and DESIGN IMPLICATION

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ABSTRACT: This paper presents the test results obtained from a field experimental study conducted by the University of Alberta on screw anchor piles used in Alberta. A total of 18 pile load tests including compression, tension and lateral pile tests were performed on two sites underlain by soils typically found in Alberta. The axial and lateral loading behavior of the screw pile installed in lacustrine clay (University Farm site) and sand dune (Sand Pit site) were studied.

Key Words: screw anchor, compression, tension, lateral, pile load test

1.0. INTRODUCTION

Screw anchors have been extensively used in foundation applications, such as transmission towers, guyed towers, pipelines and braced excavations. From a brief review of current research and industry practices, design methods for predicting screw anchor capacity can be categorized into "cylindrical shear", "individual plate bearing methods", and "empirical methods". The complexity and variability of Alberta soil, due to glacial history, create uncertainties to adapt these design methods. Thus, the University of Alberta has carried out an experimental study to investigate the load-displacement behavior of multiple screw anchors installed in soils typically found throughout Alberta. The field program consisted of a total of 18 full scale pile load tests including compression, tension and lateral loading, performed at two sites underlain by different material. The soil types at test sites were Lake Edmonton Clay at the University Farm site (cohesive material) and Sand dunes at the Sand Pit site (cohesionless material). The site investigation, instrumentation and installation of screw piles are presented in Zhang et al., (1998). This paper summarizes and discusses the test results obtained during the study including the ultimate pile load capacities achieved, load-settlement relationships, lateral test results and the axial stress distribution along the pile shaft under static load conditions. These full scale field test results will be used to develop a reliable design method for screw anchor piles installed in Alberta.

2.0. RESEARCH BACKGROUND

Research on the analysis and design of individual plate anchors and shallow foundations was initiated with the development of the transmission line industry in the 1950's (e.g. Meyerhof and Adams, 1968, Adams and Hayes, 1967). Because the anchors were mainly used for resisting tensile forces, experimental studies were focused on the ultimate anchor capacity in different soils under static uplift load conditions. It was not until the 1980's that the design of multi-helix screw anchor piles became a research interest. From a brief review of previous work, two design methods, namely the cylindrical shear method and individual plate bearing method, are commonly used to predict the uplift capacity of multi-helix anchors. In addition, an empirical method called the installation torque method is commonly used in the industry. This method was developed based on empirical correlation, but lacks explicit definition related to traditional geotechnical concepts. However, it has been used successfully in the construction of thousands of anchors over the past twenty five years, as outlined by Hoyt and Clemence, (1989).

The cylindrical shear method assumes that the uplift capacity is derived from shear resistance along a cylindrical failure surface and bearing resistance above the top or bottom helix, as shown in Figure 1. The individual plate bearing method assumes that bearing failure occurs above each individual helix (Figure 2). The total uplift resistance is the sum of the individual capacities. The installation torque method predicts the uplift capacity by correlating the installation torque and uplift capacity. This is an approach analogous to the relationship between pile driving effort and pile capacity.

Previous research has shown that factors such as pile geometry, soil disturbance caused by pile installation, soil material properties, and ground water condition, can affect the anchor capacity significantly (Bradka, 1997). However, two major factors, the embedment ratio (H/D) and the inter-helix spacing or the spacing ratio (S/D) are the main contributors to the ultimate capacity. They are, thus, considered in more detail in this study.

Cylindrical Shear Method

Axial Compression *Axial Tension*

Figure 1. Failure Surface Proposed Based on Cylindrical Shear Method (Narasimha Rao et al., 1993)

The multi-helix screw anchors adopted in this field program have 219 mm diameter steel shaft with 356 mm diameter helices, a typical anchor geometry used in Alberta. The embedment ratio (H/D) and the spacing to diameter ratio (S/D) were varied to study the influence of these factors on the ultimate capacity of the helical anchors. A schematic comparing the research anchors with three helices installed to a depth of 3.05 m, 5.18 m, and a typical production anchor with double helices installed to a depth of 5.18 m, is shown in Figure 3.

The embedment ratio (H/D) is defined as the ratio of the depth from the ground surface to the top helix (H), by the diameter (D) of the top helix. Narasimha et al. (1993) showed that the embedment ratio affects the failure surface mobilized in soft marine clay. They also showed that the failure mode can be shallow (H/D<2), transition (2<H/D<4), and deep (H/D>4), and pile capacity depends on the shear resistance developed along the cylindrical failure surface formed. Mooney et al. (1985) proposed a separate design method for screw piles installed in sand. They classified the failure mechanism into shallow (H/D≤4) and deep (H/D>4). Anchor capacity increases with an increase in the embedment ratio.

Spacing ratio (S/D) is defined as the spacing between any two adjacent helical plates divided by their average diameter. In recent studies, researchers discovered that the spacing between helical plates in multi-helix screw anchor piles significantly affect the accuracy of capacity prediction. From a laboratory study on soft clay (Narasimha et al., 1991), a near cylindrical shear surface can be formed for anchors with spacing to diameter ratios of 1.5 or less. With S/D ratio greater than 2, bearing failure

Individual Plate Bearing Method

Axial Tension

Figure 2. Failure Surface Proposed Based on Individual Plate Bearing Method (Hoyt and Clemence, 1989)

occurs above each individual anchor helix and the cylindrical shear does not fully develop. The anchor capacity reduces with higher S/D ratio because less shearing resistance can be developed on a smaller shearing surface area. The study showed that as the spacing ratio (S/D) increases above 1.5 a significant uplift capacity reduction was observed (Narasimha et al., 1991). Therefore, at S/D ratio less than 1.5, the cylindrical failure surface method is valid. For a spacing ratio greater than 1.5, Hoyt and Clemence (1989) and Narasimha Rao et al. (1990) suggested that individual plate bearing method provides a better capacity prediction.

Figure 3. Site Profile for Compression and Tension Tests

3.0. TEST RESULTS

For all piles tested, measurements were taken to obtain the load-settlement, and settlement-logarithm of time for each load increment. Furthermore, the distribution of the stresses along the shaft was established for each load step using strain gages installed at different levels inside the pile shaft. Ten pile load tests including five compression tests (Figure 4), three tension tests (Figure 6) and two lateral tests (Figure 8) were conducted on the University Farm site, central Edmonton. In addition, eight pile load tests, consisting of three compression (Figure 5), three pull out (Figure 7) and two lateral pile load (Figure 9) tests, were conducted on the Sand Pit site located outside of Bruderheim, Northeast of Edmonton. In addition, Figure 10 and Figure 11 show the load distribution along the anchor shaft at various stages during the compression test at the two sites. Table 1 summarizes the geometry of the screw piles used in the study and the capacities achieved in the tests.

For all axial compression and tension tests, the screw anchors were loaded according to the quick test procedure, described in ASTM D 1143-81 and ASTM D 3689-90. All the tests were carried out up to the ultimate load that was defined as the load corresponding to a pile top settlement greater than 10% of the helix diameter (i.e. 35.6 mm). Similar quick loading procedure as described in ASTM D 3966-81, was used for all the lateral tests. The “failure” was assumed to be reached when more than 50 mm of lateral movement was observed (i.e. 23% of the shaft diameter).

3.1. Axial Compression and Tension Test Results

Effect of Embedment Ratio (H/D). As shown in Figure 4 to Figure 7, at the University Farm site, there is a 13 to 31% increase in ultimate compression capacity (Q_c), and 50% increase in ultimate uplift capacity (Q_u) as the embedment ratio increased from 4.69 to 10.7 for anchors installed in cohesive soils. Similarly, for anchors installed in cohesionless material at the Sand Pit site, a 12% increase in compression capacity and 89% increase in tension capacity was found as embedment ratio increases. Therefore, the ultimate capacities in compression and tension increase with the increase of anchor installation depth, although the increase is more significant in tension.

Effect of Inter-Helix-Spacing Ratio (S/D). For the compression tests at the University Farm site (Figure 4), the production anchors, installed to a depth of 5.20 m (S/D=3), yielded higher ultimate capacity than the research pile (S/D=1.5) with a 17% increase in ultimate capacity in compression. However, at the Sand Pit site as shown in Figure 5, different behavior was observed. Research piles with S/D of 1.5 result in higher ultimate capacity in compression than the production pile (S/D=3.0). A 24% increase in capacity was observed for the smaller S/D ratio. Nevertheless, both the research pile and production pile had essentially the same pullout capacity in tension tests at both test sites (Figure 6 and Figure 7).

The reduction in ultimate capacity of the three-helix research pile (S/D=1.5) in compression in cohesive soil may be caused by soil disturbance due to pile installation. If the second and third helixes do not follow the path of the first helix, then, the helical screws create higher degree of soil disturbance along the surface surrounding the anchor. This effect may reduce the soil's shear strength if the soil is sensitive to disturbance (Bradka, 1997). Therefore, in cohesive soil, the closer the helices are to each other, i.e. the lower the S/D ratio, the higher the soil disturbance due to installation. Soil disturbance may not be a factor in cohesionless material, as the research pile (S/D=1.5) reached much higher capacity than the production pile (S/D=3.0). In tension test, the S/D ratio does not have an effect on the ultimate pullout capacity of the anchors. Both piles (S/D=1.5 & S/D=3.0) showed essentially the same uplift capacity at both sites.

Effect of Soil Property. The ultimate capacity in compression and tension are similar in cohesive material. However, the ultimate capacity in compression is higher than in tension in cohesionless material especially for the short piles. As shown in Figure 10 and 11, the resistance of the anchor was mainly developed by friction in cohesive material. Therefore, difference in loading direction does not affect the ultimate capacity significantly because resistance was developed by the same cylindrical shearing surface. However, the contribution to the ultimate capacity from end bearing becomes significant in cohesionless material.

3.2. Lateral Test Results

In lateral tests, the helical anchors used in the lateral tests were designed to have the same geometry, and were installed to a depth of 5.18 m. The shaft wall thickness of the anchor was varied in order to compare the difference in ultimate capacity in lateral loading due to the structural stiffness. Two wall thicknesses (t) were chosen for testing, 6.71 mm and 8.18 mm. Results shown in Figure 8 and 9 demonstrate that there is no significant increase in lateral capacity due to the increase in shaft wall thickness. Hence, the load-displacement response in lateral loading for these screw anchors in these soils is mainly dependent upon the soil characteristics.

Table 1 – Summary of the Test Pile Geometry and Test Results

Test	No. of Helix	Helix Dia. (D, mm)	Helix Spacing (S, mm)	Depth to Top Helix (H, m)	Wall Thickness (t, mm)	Embed. Ratio (H/D)	Space to Dia. Ratio (S/D)	Ultimate Load, Qu		Installation Torque	
								Unv. Farm (kN)	Sand Pit (kN)	Unv. Farm (ft. lbs.)	Sand Pit (ft. lbs.)
Compression Long (CL)	3	356	533	3.79	6.71	10.7	1.50	180	470	15000	33000
Compression Short (CS)	3	356	533	1.67	6.71	4.69	1.50	160	420	11500	30000
Compression Production (Cprod. No. 1)	2	356	533	3.79	6.71	10.7	3.00	210	380	14375	33000
Compression Production (Cprod. No. 2)	2	356	1067	3.79	6.71	10.7	3.00	210	-	15000	32250
Tension Long (TL)	3	356	533	3.79	6.71	10.7	1.50	210	360	16250	37500
Tension Short (TS)	3	356	533	1.67	6.71	4.69	1.50	140	190	15000	31500
Tension Production (Tprod.)	2	356	1067	3.79	6.71	10.7	3.00	210	360	16875	35250
Lateral (L264)	3	356	533	3.79	6.71	10.7	1.50	40	62	17500	36000
Lateral (L322)	3	356	533	3.79	8.18	10.7	1.50	44	65	15000	33000

Note: 1 ft. lbs. = 1.356 N. m.

Figure 4. Compression Test Results from University Farm Site

Figure 5. Compression Test Results from Sand Pit Site

Figure 6. Tension Test Results from University Farm Site

Figure 7. Tension Test Results from Sand Pit Site

Figure 8. Lateral Test Result from University Farm Site

Figure 9. Lateral Test Result from Sand Pit Site

Figure 10. Load Distribution along the Shaft (University Farm Site)

Figure 11. Load Distribution along the Shaft (Sand Pit Site)

4.0. CONCLUSION

A full scale field test program was performed with the purpose of developing a more reliable design method for predicting the capacity of multi-helix screw anchors in Alberta soil. Two major factors, the embedment ratio (H/D) and inter-helix-spacing ratio (S/D), are considered in this study.

Results from a total of 18 pile load tests including compression, tension and lateral are summarized. The results have shown that the ultimate compression and uplift capacity increases with an increase in embedment ratio for both cohesive and cohesionless material although the increase is more significant in tension. In addition, the experimental results have indicated that the inter-helix-spacing ratio (S/D) does not affect significantly the ultimate compression and uplift capacities in cohesive material. However, the S/D ratio does contribute to the increase in the compression capacity in cohesionless material. The effect of soil disturbance in cohesive material on the capacity of the screw piles should be studied in more detail in the future. Lateral pile test results have shown that an increase in pile stiffness does not increase its lateral capacity. Therefore, the lateral response is controlled primarily by the soil properties for these screw anchors.

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