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Behavior of a tieback in cohesive soil

Le comportement d'un ancrage dans un sol cohérent

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SYNOPSIS Large-diameter, straight-shafted tiebacks, anchored in a stiff glacial till in Seattle, Washington, were instrumented to study the load-carrying behavior of both the bonded length and the grout column above the bonded length. The results of the study indicate that high capacities can be developed with relatively short bonded lengths. The grout column above the bonded length is loaded in compression while the grout surrounding the bonded length is loaded in tension.

INTRODUCTION

Large-diameter, straight-shafted tiebacks, anchored in cohesive soils, were instrumented to study the load-carrying behavior of both the bonded length and the grout column above the bonded length (see Figure 1 for terminology used in this paper).

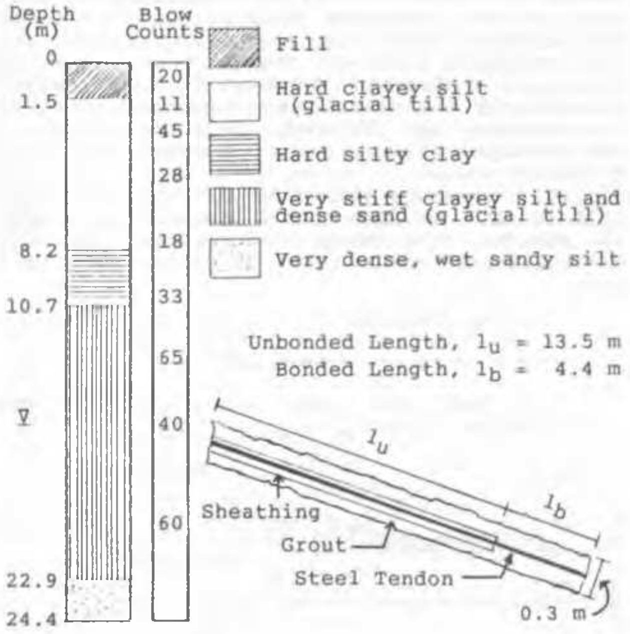

FIGURE 1.
SOIL PROFILE AND TIEBACK TERMINOLOGY

In the past, these tiebacks have had long bonded lengths ranging from 9.2 m to 12.2 m (30 ft. to 40 ft.). The top of the bonded length was designed to fall immediately behind the failure plane. Typically, a mixture of soil and grout was used to backfill the annular space above the bonded length or grout was placed above the bonded length after the tieback was tested in order to prevent the development of capacity within the failure wedge.

In the summer of 1987, ten instrumented, large-diameter, straight-shafted tiebacks were installed in a stiff glacial till in Seattle, Washington. These tiebacks were grouted to the surface and had short bonded lengths ranging from 4.6 m to 6.1 m (15 ft. to 20 ft.) with overall lengths ranging from 13.7 m to 18.3 m (45 ft. to 60 ft.). Vibrating wire strain gauges embedded in the grout in the bonded length and in the grout column above the bonded length were used to measure the compressive and tensile strains within the grout. Although all of the tiebacks exhibited similar behavior, the load-carrying behavior of only one of these tiebacks form the contents of this paper.

PREVIOUS RESEARCH

Previous research on the load-carrying behavior of large-diameter, straight-shafted tiebacks anchored in cohesive soils was largely limited to the bonded length where weldable electrical resistance strain gauges were attached directly to the steel tendon (Ludwig, 1984). The load-carrying behavior of the grout column above the bonded length could only be hypothesized based on some rather crude instrumentation. The previous research did indicate that loading part of the shaft in compression may increase the load-carrying capacity of the tieback (Ludwig, 1984).

Ludwig (1984) developed load transfer-shaft displacement (t-z) curves (see Figure 2 for a typical t-z curve) for large-diameter straight-shafted tiebacks anchored in cohesive soils. His research showed that 1) large-diameter, straight-shafted tiebacks developed their load-carrying capacity through the mobilization of skin friction along the shaft; 2) skin friction was a non-linear function of shaft

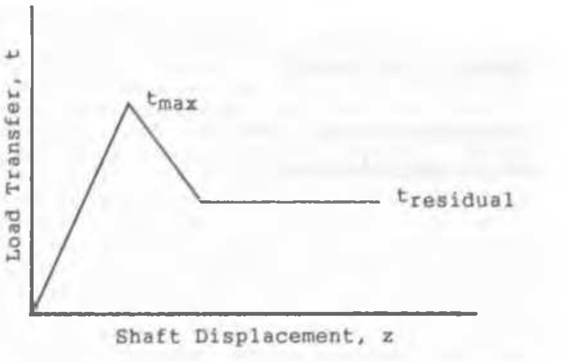

FIGURE 2.
TYPICAL LOAD TRANSFER-SHAFT DISPLACEMENT CURVE FOR LARGE-DIAMETER, STRAIGHT-SHAFTED TIEBACKS ANCHORED IN COHESIVE SOILS

displacement; 3) peak skin friction was mobilized at small shaft displacements [from 1 mm to 4 mm (0.04 in. to 0.16 in.)]; additional shaft displacement led to a reduction in skin friction to its residual value; 4) peak skin friction was not mobilized simultaneously along the shaft; 5) at failure, the entire shaft moved through the soil; and 6) extensometers located in the grout column above the bonded length indicated that a significant amount of load was developed above the bonded length.

TIEBACK DESCRIPTION AND SITE CONDITIONS

Pertinent data for Tieback F and the soil profile are given in Figure 1. Tieback F consisted of six 15-mm (0.6-in.)-diameter strand tendons. The tendon was greased and sheathed over the unbonded length. The 150-mm (6-in.)-long vibrating wire strain gauges were placed in the middle of the strand bundle (see Figure 3). Spacers were placed on either side of each strain gauge to minimize the formation of strains normal to the longitudinal axis of the gauge due to axial elongation of the strand tendon. (The potential for normal strains is greater in the bonded length because waves are usually created in the strands to enhance the bond between the grout and the tendon.) The tiebacks were installed using a 305-mm (12-in.)-diameter, hollow-stemmed auger. The tendon was inserted inside the auger prior to drilling the hole. Once the hole was drilled, grout was pumped under pressure [2 MPa (300 psi)] through the auger as it was extracted.

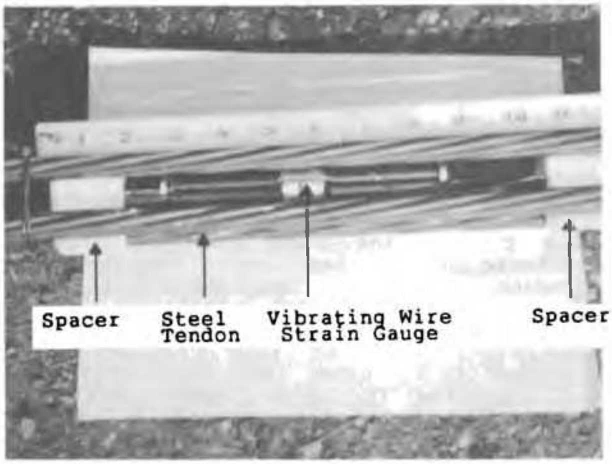

FIGURE 3.
VIBRATING WIRE STRAIN GAUGE USED TO MONITOR STRAIN IN THE GROUT BODY

TEST PROGRAM

Tieback F was subjected to a performance test in general accordance with the procedures described in the PTI manual (1986). The loads were applied to the tieback by means of a center-hole hydraulic jack. The peak load of each successive load cycle was greater than its predecessor. At the end of each load cycle, the load was released to a nominal alignment load. The maximum load was maintained constant for 100 minutes. A load cell was used to monitor load. Displacement of the tendon was measured and recorded to the nearest 0.025 mm (0.001 in.). The strains within the grout column were measured and recorded to the nearest microstrain.

RESULTS AND ANALYSIS

Tieback F did not fail at the maximum test load of 1237 kN (139 tons). The load-total displacement curve and the load-residual anchor movement curve of Tieback F are shown in Figure 4. In the load-total displacement curve, only the displacements corresponding to the maximum load in each cycle are plotted. The maximum residual anchor movement was 13.3 mm (0.524 in.).

Figure 5 presents the creep data for the load hold at 1237 kN (139 tons). Over a period of 100 minutes, the creep rate was less than 0.5 mm/logarithmic cycle (0.02 in./logarithmic cycle).

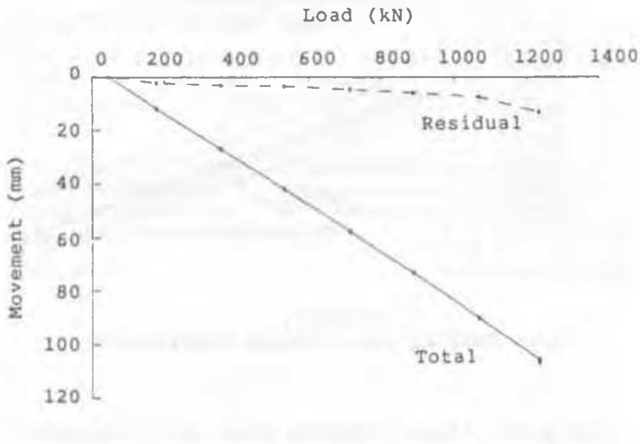

FIGURE 4.
LOAD-DISPLACEMENT CURVES OF TIEBACK F

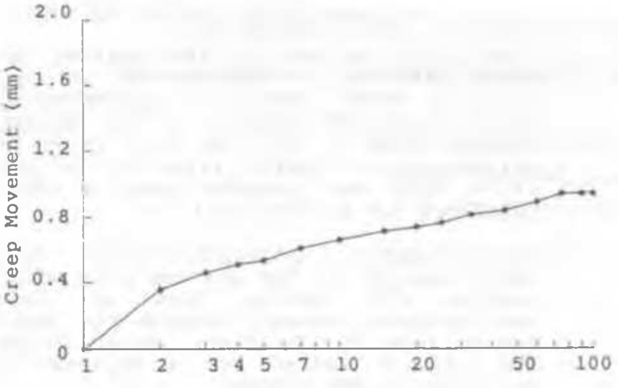

FIGURE 5.
CREEP PERFORMANCE OF TIEBACK F
AT 1237 kN (139 TONS)

Figure 6 shows the distribution of strain in the grout body of Tieback F. The most significant features in Figure 6 are 1) the reversal of strain from tension in the bonded length to compression in the grout column above the bonded length and 2) the concentration of high tensile and compressive strains at the transition between the bonded and unbonded length. At 1237 kN (139 tons), there is also a slight shift of the "neutral axis" (the transition from compression to tension) down the bonded length. This shift is caused by debonding of the tendon from the grout as the load is increased. At a given location in the bonded length, as the tendon debonds from the grout the magnitude of tensile strain transferred from the tendon to the grout decreases. Eventually, the tensile strains in the grout body will change to compressive strains as debonding is complete. Evidence of this behavior is shown in Figure 6 at an applied load of 1237 kN (139 tons). The magnitude of strain at 3.3 m (10.7 ft.) decreased significantly from that of the previous load. Other instrumented tiebacks with more closely spaced strain gauges at the top of the bonded length have shown the complete transition from tensile strain to compressive strain in the grout body as the applied load increases.

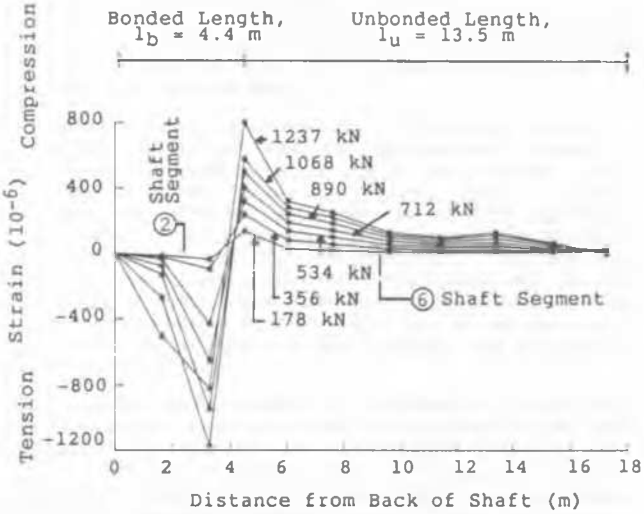

FIGURE 6.
DISTRIBUTION OF STRAIN IN TIEBACK F

In the grout column above the bonded zone, the distribution of compressive strain is similar to that of bored, cast-in-place piles subjected to compressive loads. In the zone of compression, the magnitude of load transfer from the tieback to the adjacent soil is proportional to the slope of the strain distribution curve between any two strain gauge locations and the elastic modulus of the grout. The magnitude of load transfer in the bonded length is assumed to be proportional to the elastic modulus of the steel tendon, because the grout cracks under tensile loading (Ludwig, 1984). That is, load transfer, t, can be described as:

$$t = \frac{(\epsilon_2 - \epsilon_1)\ EA}{\pi\ DL} \qquad \ldots[1]$$

where ϵ_1, ϵ_2 are the strains measured at two strain gauge locations

E = modulus of elasticity (grout in compression, steel in tension)

A = cross-sectional area (grout in compression, steel in tension)

D = shaft diameter

L = shaft length between two strain gauge locations

The higher than expected magnitudes of load transfer in the grout at the top of the bonded length could be due to the complicated state of stress at the tendon-grout interface at this location. Using Equation [1], more representative magnitudes of load transfer were determined in shaft segment Nos. 2 and 6, for example. Shaft segment No. 2 was located in the bonded length, while shaft segment No. 6 was located in the grout column above the bonded length (see Figure 6). At an applied load of 1068 kN (120 tons), load transfer values of 96 kPa (2.01 ksf) and 82 kPa (1.72 ksf) were computed in shaft segment Nos. 2 and 6, respectively. In shaft segment No. 2, it is clear that the value of load transfer (as denoted by the slope of the strain distribution curve) increases up to an applied load of 1068 kN (120 tons). At the maximum load of 1237 kN (139 tons), the load transfer value is less than its peak value. In this case, the decrease in load transfer value may be more a function of the debonding process as described earlier, than additional shaft displacement leading to a reduction in load transfer value as shown in Figure 2. The comparable values of load transfer in the zones of tension and compression show that: 1) the use of vibrating wire strain gauges embedded in the grout appears to be a valid method of measuring both tensile strains and compressive strains; and 2) in the bonded length, it appears valid to assume that the load is carried totally by the tendon once the grout has cracked.

From the back of the shaft of Tieback F to 9.6 m (31.5 ft.), approximately 1041 kN (117 tons), or 84 percent of the maximum applied load of 1237 kN (139 tons), was transferred from the tieback to the soil. This yields a uniform load transfer value of 113 kPa (2.36 ksf) over 9.6 m (31.5 ft.). Relatively little load was transferred to the soil beyond 9.6 m (31.5 ft.). That is, 84 percent of the maximum applied load was transferred to the soil within a shaft length of approximately twice the bonded length. At an applied load of 1068 kN (120 tons), 84 percent of the load was transferred to the soil within the same shaft length. This yields a uniform load transfer value of 98 kPa (2.04 ksf) which compares favorably with the load transfer values of 96 kPa (2.01 ksf) and 82 kPa (1.72 ksf) computed previously for shaft segments Nos. 2 and 6, respectively.

CONCLUSIONS

The results of this study indicate that:

1) Large-diameter, straight-shafted, tiebacks with short bonded lengths ranging from 4.6 m to 6.1 m (15 ft. to 20 ft.) and grouted to the surface can develop high capacities in cohesive soils. Tieback F performed satisfactory at a maximum applied load of 1237 kN (139 tons) with a creep rate of 0.5 mm/logarithmic cycle (0.02 in./logarithmic cycle) and a residual anchor movement of 13.3 mm (0.524 in.). The other instrumented tiebacks installed in a glacial till in Seattle, Washington, developed similar capacities. Loads of 1237 kN (139 tons) are very high in an industry where a design load of 445 kN to 534 kN (50 tons to 60 tons) is considered more typical in a cohesive soil.

2) The use of vibrating wire strain gauges embedded in the grout appears to be a valid method of measuring both tensile strains in the bonded length and compressive strains in the grout column above the bonded length.

3) The grout column above the bonded length is loaded in compression while the grout surrounding the bonded length is loaded in tension. Debonding of the tendon from the grout as shown in the 1237 kN (139 ton) increment caused a shift of the "neutral axis" (the transition from compression to tension) in the direction of the end of the shaft.

4) The higher than expected magnitudes of load transfer in the grout at the top of the bonded length could be due to the complicated state of stress at the tendon-grout interface at this location.

5) Similar load transfer values were computed in the zones of compression and tension if one assumes that the steel tendon carries all the load in the zone of tension because the grout body cracks. In the grout column above the bonded length, the grout body carries the load.

6) Eighty-four percent of the maximum applied load was transferred to the soil within a shaft length of approximately twice the bonded length. At the maximum applied load of 1237 kN (139 tons), a uniform load transfer value of 113 kPa (2.36 ksf) was computed over a shaft length of 9.6 m (31.5 ft.).

7) Large-diameter, straight-shafted tiebacks grouted to the surface with short lengths will develop most of their load-carrying capacity behind the failure surface if the shaft length behind the failure surface is a minimum of twice the bonded length.

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