Ground anchor creep in glacially consolidated clay

Fluage d'ancrage de sol dans l'argile consolidée par des glaciers

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SYNOPSIS: This paper presents the results of a full-scale load testing program to determine the creep characteristics of non-pressure grouted tieback anchors in over-consolidated silts and clays. Anchor creep is examined as a function of the load on the anchor and as a function of the duration of load application. Methods of estimating long-term creep performance from the results of short-term creep tests on tieback anchors are examined and discussed. A method of estimating long-term creep of tieback anchors in over-consolidated silts and clays, based on short-term creep testing, is presented.

INTRODUCTION

The purpose of this study was to establish creep characteristics of non-pressure grouted tieback anchors founded within the Seattle, Washington, overconsolidated silts and clays. Selection of the tieback anchor for this study was based on the standard of practice throughout the Pacific Northwest. The tieback anchors used throughout the area are typically non-pressure grouted anchors with diameters which range from 12 to 18 inches (305 to 460mm). For this study, 12-inch (305mm) nominal diameter, 20-foot (6.1m) long, non-pressure grouted anchors were utilized.

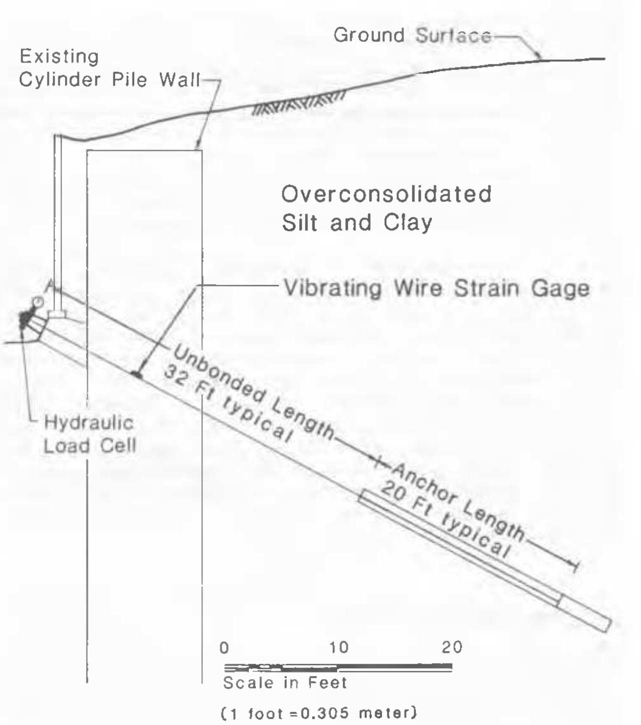


Figure 1 Typical Tieback Instrumentation and Installation

The test site was selected to utilize a massive existing cylinder pile wall as reaction to the tieback anchor loads. The steel reinforced 10-foot (3.1m) diameter cylinder piles which are located on 12-foot (3.7m) centers, provided a very rigid reaction for the testing program. A cross-section of the installation is shown on Figure 1.

The tieback testing for this study was completed in two phases. In the first phase, two anchors were loaded incrementally to pull-out. Each load level was held for up to an hour, while monitoring bar displacement to establish creep versus load characteristics. Based on that data, anchor loads were selected for long-term creep monitoring. During the second phase of the test, seven anchors were loaded to and locked off at various percentages (20 to 60 percent) of the ultimate anchor capacity. The anchors have been monitored for seven months to establish long-term creep relationships as a function of anchor load.

PROJECT DESCRIPTION

A. Geologic Setting and Soil Properties

The site soil deposits generally consist of overconsolidated, very stiff to hard, silt and clay with occasional layers and lenses of sand and scattered gravel, slickensides and fracture zones. The soils were deposited in an interglacial period in a marine environment and subsequently overridden by one or more major glaciations. Because the site soils are overconsolidated, they exhibit relatively low compressibility, and do not tend to increase in strength over the depth of interest.

Two hollow-stem auger borings were advanced at the site and a laboratory testing program was accomplished on the site soils. The range of soil properties, as measured by field and laboratory tests, is summarized in Table I.

Table I Properties of Site Soils

Test	Number of Tests	Mean	Standard Deviation
Water Content in %	14	36	2.4
Atterberg Limits			
w_L in %	14	56	8.8
w_P in %	14	29	3.0
$w_L - w_P$ in %	14	27	6.9
Liquidity Index	14	0.30	0.14
Unconsolidated - Undrained Triaxial Tests			
τ_f in psf	5	3900	1600
ε_f in %	5	3	0.9
γ in pcf	5	117	0.69
Standard Penetration Test N in blows per foot	21	44	12.1

B. Tieback Configuration and Installation

The tieback holes were drilled with a truck-mounted, auger drill rig. The auger's nominal diameter was 12 inches (305mm). Angles of inclination were generally 25 to 30 degrees down from horizontal. The holes were drilled to a depth of about 55 feet (17m). The holes stayed open following removal of the auger, and tieback bars were installed into the open holes. The tieback bars, consisting of 1-3/8 inch (35mm) diameter Dywidag threadbar, were instrumented prior to insertion into the holes to the configuration shown on Figure 1.

The instrumented Dywidag bars were approximately centered in the holes upon insertion. Grouting of each anchor was accomplished on the same day of its drilling. The 20 foot (6.1m) anchor length was grouted with 4000 psi (27,600 kpa) pea-gravel grout. The grout was pumped through a tremie hose inserted into the bottom of the hole and retracted during grouting. The grout was not placed under pressure. The remaining portion of the holes was partially backfilled with a bentonite-sand mixture, and 12-inch (305mm) diameter casing installed.

C. Monitoring Program

Tieback instrumentation utilized for this study consisted of vibrating wire strain gages and hydraulic load cells. Figure 1 shows the typical tieback instrumentation layout.

One vibrating wire strain gage was micro-welded to each Dywidag bar within five to ten feet (1.5 to 3m) of the face of the waler. A strain gage/Dywidag bar section was tested in a load frame with a measured strain vs. applied load relationship of 20 microstrain per 1 kip (4.5 kN) of applied load.

The hydraulic load cells were used primarily for approximation of applied loads during incremental loading and locking off of the tiebacks but not for long-term monitoring. Vibrating wire strain gauges were used for more precise load monitoring, such as evaluation of load drop-off during short-term creep testing and the long-term load drop-off on each anchor.

During short-term testing of the tiebacks, total displacements of the anchor were measured by optical survey equipment sighted on a scale attached to the end of the Dywidag bar. This system has an accuracy of 0.01 inches (0.25 mm).

During long-term monitoring of locked-off tiebacks, the change in vibrating wire strain gage reading, which represents the change in strain of the bar, was interpreted as being due entirely to anchor movement. A 32-foot (9.8m) unbonded bar length was used for the anchor displacement calculations. Displacement (Δ) was calculated by $\Delta = \varepsilon L$. A displacement of 0.01 inches (0.25 mm) would require a change in strain of 26 microstrains.

It was assumed that the rigid nature of the cylinder pile reaction would eliminate the influence of backfill soil pressures, and wall movements, on the testing program. Movements of the wall were not monitored.

ANCHOR PERFORMANCE

A. Performance Criteria

The purpose of the tests was first to establish the ultimate working tension. Once this was established, remaining anchors were loaded to various levels to study differences in creep behavior at different loads. The reliability of extrapolating long-term creep behavior from short-term tests was also evaluated.

The procedures for establishing acceptable creep levels in the test anchors were as follows:

- Load the first anchor incrementally (recording creep at each increment) until the anchor can sustain no additional load (pull out).
- Establish the critical creep tension for this anchor. Two methods of calculating the critical creep tension were utilized, as follows, and as shown on Figure 2:

  T_c: The load level where the slope of the creep coefficient curve deviates from the initial straight line portion of the curve.

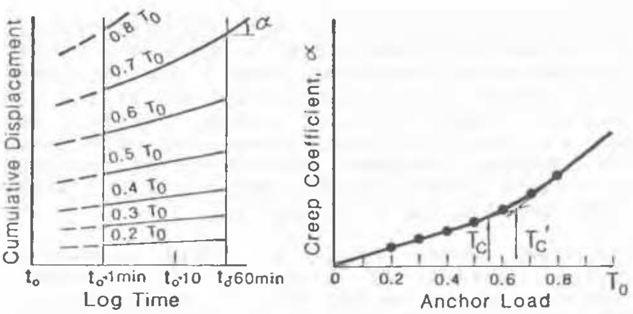
  $T_{c'}$: The load level defined by the intersection of the straight line extended from the initial portion of the curve, with the extension of the straight line extended from the latter portion of the curve.

- Load a second anchor incrementally to the critical creep tension and hold this load for 72 hours followed by loading incrementally to pull-out.
- Based on the results of the two ultimate tests, the ultimate working tension, T_{uw} can be established. The value of T_{uw} is the maximum tension which results in an acceptable level of long-term creep. T_{uw} is determined as the lowest of the following criteria [2]:

  - 80 percent of $T_{c'}$ or 90 percent of T_c

  - load which would result in absolute displacement between the end of the first hour of loading and the end of the 72nd hour of loading of less than or equal to $(0.2 \times 10^{-3}) \times (L_i)$ where L_i is the theoretical free length of the anchor
  - load which would result in a creep coefficient (α) from the creep curves no greater than 0.08 inches (2mm) per log cycle of time

- Load remaining anchors to varying percentages of T_{uw}.



A. Creep Curves

B. Creep Coefficient Plot

Figure 2 Typical Creep Plots

B. Results of Pull-out Tests

The load displacement curves for the ultimate test anchors are presented in Figure 3. The pull-out load (T_o) of 120 kips (534 kN) was observed for both tiebacks. The pull-out load corresponds to an average adhesion of 1.9 ksf (91 kPa) as calculated over the nominal surface area of the 20 foot long (6.1m) 12-inch (305mm) diameter anchor.

C. Results of Short-term Creep Testing

For each load level from the two ultimate tests, a plot of the anchor deflection versus the log of time was made. The slope of each curve, designated the creep coefficient (α), was then plotted versus the corresponding load level. A typical creep curve and creep coefficient plot is presented on Figure 2.

The typical shape of the creep coefficient curve in this study is generally straight for loads lower than approximately 50 kips (223 kN), at values of usually less than 0.03 inches (0.8mm) per log cycle of time. At higher loads the value of increases with each load level. (See Figure 4).

The critical creep tension for each anchor was determined from the creep coefficient plot. The short-term data was utilized to select the maximum working tension of the anchors (T_{uw}) based on the previously discussed performance criteria. The results of our testing indicated that criteria calling for a load no greater than $0.8\ T_c'$ would govern the performance of these anchors. A maximum working tension, T_{uw}, equal to 60 kips (267 kN) was selected.

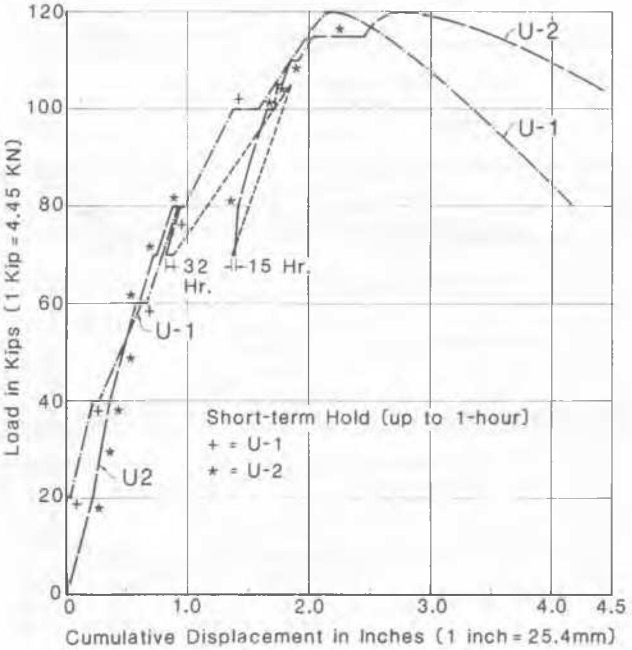


Figure 3 Load Displacement Curves

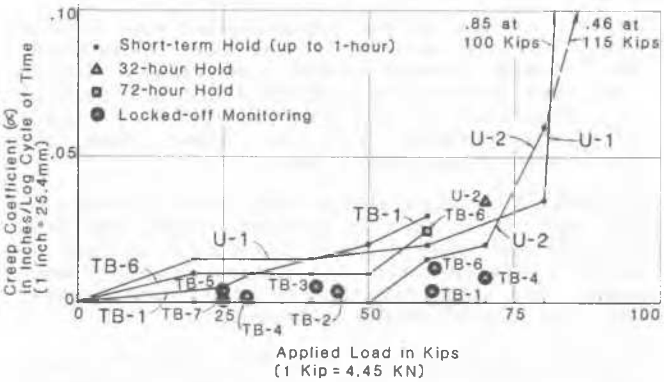


Figure 4 Creep Coefficient vs. Load

D. Results of Long-term Monitoring

The purpose of the long-term monitoring was to establish the creep characteristics of tieback anchors over the long-term (up to 3 years) for comparison to the short term data (1 hour to 72 hours). Seven anchors have been locked off at various percentages of the maximum working tension to collect the desired data. The actual tieback lock-off loads ranged from 42 to 117 percent of the maximum working tension of 60 kips (267 kN). The information presented in this paper represents the first 7 months of creep data. Data will continue to be collected over the next 2 to 3 years by the Washington State Department of Transportation.

The load dissipation observed during long-term monitoring is interpreted to be due to creep of the anchor. Load dissipation occurs in the

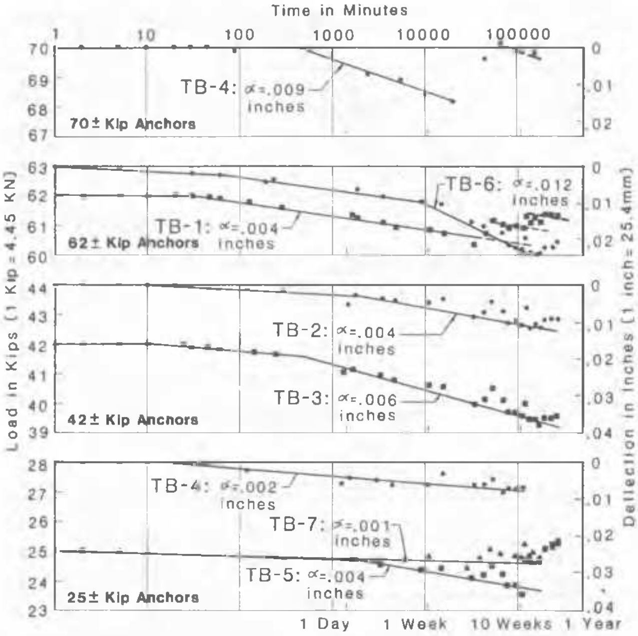


Figure 5 Long Term Creep Data

anchors as the anchor creeps under the applied load, and the strain in the bar is reduced. The creep coefficients measured during long-term monitoring therefore are affected by the reduction in load that occurs as a result of anchor creep, and are lower than the short-term creep coefficients.

To date, load dissipation has been 5 percent or less of the originally applied loads. The drop in load has been 3 kips (13.4 kN) or less on each of the anchors. It is not known at what level of load dissipation the coefficients would be significantly affected.

Figure 5 presents the creep data from the first seven months of monitoring the locked-off tiebacks. The data are presented in terms of both anchor displacement and load drop-off, which are linearly proportional. Adjacent to each curve is the calculated creep coefficient, α , in terms of inches per log cycle of time. The long-term creep coefficients are lower than short-term coefficients, as indicated by the plot of α vs. load on Figure 4.

The conclusions based on long-term monitoring data are presented below, along with conclusions from other phases of the demonstration program.

CONCLUSIONS

The two ultimate anchors each pulled out at a tension of 120 kips (534 kN). The critical creep tension (T_c') is in the range of 70 to 80 kips (312 to 356 kN), which is on the order of two-thirds of the ultimate capacity of the anchor.

The maximum working tension (T_{uw}) was calculated at 0.8 T_c' , or 0.8 x 75 = 60 kips (267 kN). The data collected to date indicate that a 60 kip load does not result in excessive creep.

The long term creep coefficients were generally less than the short-term creep coefficients (see Figure 4). This indicates that the short-term tests give an adequate indication of long-term anchor performance. Continued monitoring is necessary to evaluate the long-term anchor creep coefficients.

Load dissipation has been no greater then 3 kips (13.4 kN) per anchor. Because load dissipation is within 5 percent of the initially applied load, the affect of the load dissipation on the creep coefficients obtained in this program is considered to be relatively small.

The deflection creep coefficient shows a slight increase with increasing load. The long-term displacement creep coefficients are within the range of 0.001 to 0.012 inches (.03 to .3mm) per log cycle of time. These are well below the Federal Highway Administration maximum acceptable creep coefficient of 0.08 inches (2mm) per log cycle of time [2].

The creep curves (Figure 5) tended to show an initial period of virtually no movement, followed by an accumalation of displacements. The break in the curve could be due to a preloading effect from the short-term creep test which was conducted prior to lock-off at the long-term loads, or other yet undescribed factors.

ACKNOWLEDGEMENTS

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