TIEBACKS EXECUTIVE SUMMARY

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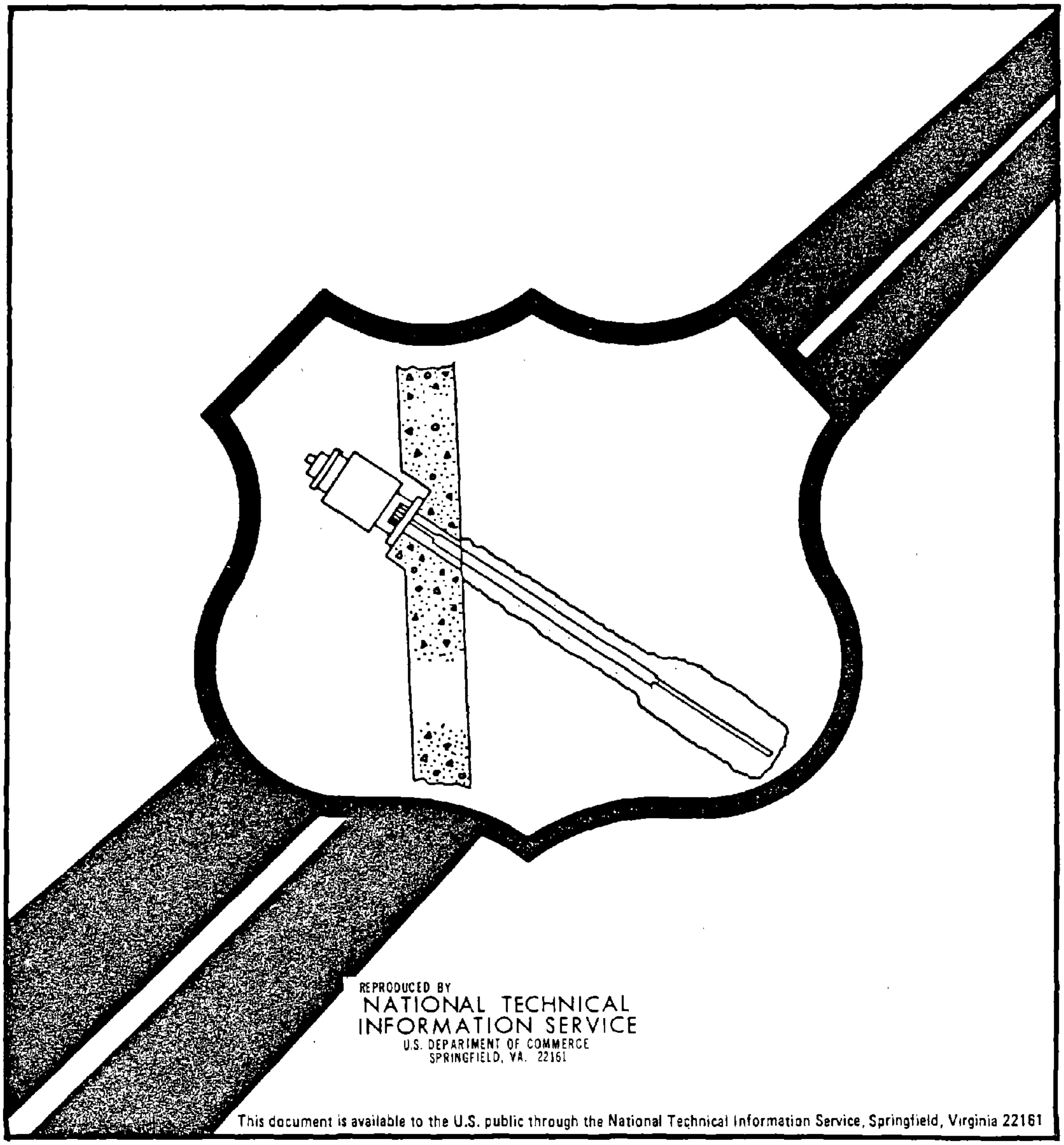
**Final Report
July 1982**



FOREWORD

Highway engineers in the United States have been reluctant to specify permanent tiebacks as the primary support for highway structures. They are concerned about the lack of data on life expectancy of corrosion-protected tiebacks and the ability of foundation soils to sustain long-term loads without excessive movement.

This report describes tiebacks and their applications to highway work, reviews the uses of tiebacks, investigates the causes of the few reported failures, mainly in Europe, looks deeply into the problem of corrosion and creep and develops recommended procedures to assure long life to permanent tiebacks. This report consists of two volumes: the Executive Summary, FHWA/RD-82/046 and the full report "Tiebacks," FHWA/RD-82/047.

Sufficient copies of the report are being distributed to provide a minimum of two copies to each regional office, one copy to each division office and two copies to each State highway agency. Direct distribution is being made to the division offices.

Richard E. Hay, Director
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16. Abstract

This report contains a summary of recommendations for the design, specification, corrosion protection, and testing of permanent and temporary tiebacks.

The main report "TIEBACKS" is FHWA/RD-82/047.

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TIEBACKS - EXECUTIVE SUMMARY

A. INTRODUCTION

A tieback is a structural element which uses a grouted anchor in the ground to secure a tendon which applies a force to a structure. Figure 1 shows the components of a tieback. The anchor length is the length of the tieback which is bonded to the soil, and it is where the tieback force is transmitted to the ground. Each tieback has an unbonded length between the anchor and the structure. There the tieback tendon is not bonded to the soil, and it is free to elongate elastically. Force is applied to the tieback by post-tensioning.

Tiebacks are relatively new construction elements. They have been developed, in a large part, by speciality contractors who design and build temporary excavation support systems. Each contractor has evolved his own method of performing the work, and many of the techniques are proprietary.

Permanent tiebacks have been used to support structures in Europe since the mid-1960's, and since the early 1970's in the United States. They can be protected from corrosive attack, and they are tested to evaluate both their short-term performance and their long-term load holding capacity.

B. DESIGN

An initial evaluation must be made to determine if tiebacks can be used at a particular site, and whether or not they will be able to develop the necessary capacity without excessive movement or loss of load. The capacity of soil tiebacks are estimated using empirical relationships developed for the particular tieback type. Generally all rock materials can be considered as suitable ground in which to found anchors.

Permanent tiebacks are routinely installed in noncohesive soils with a standard penetration resistance greater than ten blows per foot. They should not be anchored in fill. Past experience, including testing and monitoring of many actual installations, indicates that permanent tiebacks installed in sandy soils will have satisfactory long-term performance.

Permanent tiebacks are not routinely installed in soft to medium cohesive soils because their long-term load holding capacity is questionable. These soils can often be avoided by installing the tiebacks at a steeper angle and to a depth where better soil or rock may be found. Soil strength, Atterberg limits, natural water content, and experience in similar soils will provide the best indication of the long-term performance of a permanent tieback installed in a cohesive soil.

Tiebacks installed in soils with a high organic content, in normally consolidated clays, and in cohesive soils with an unconfined compressive strength less than 1.0 ton/ft.^{2} (96 kPa) and remolded strengths less than 0.5 ton/ft.^{2} (48 kPa) may be creep susceptible. Tiebacks installed in

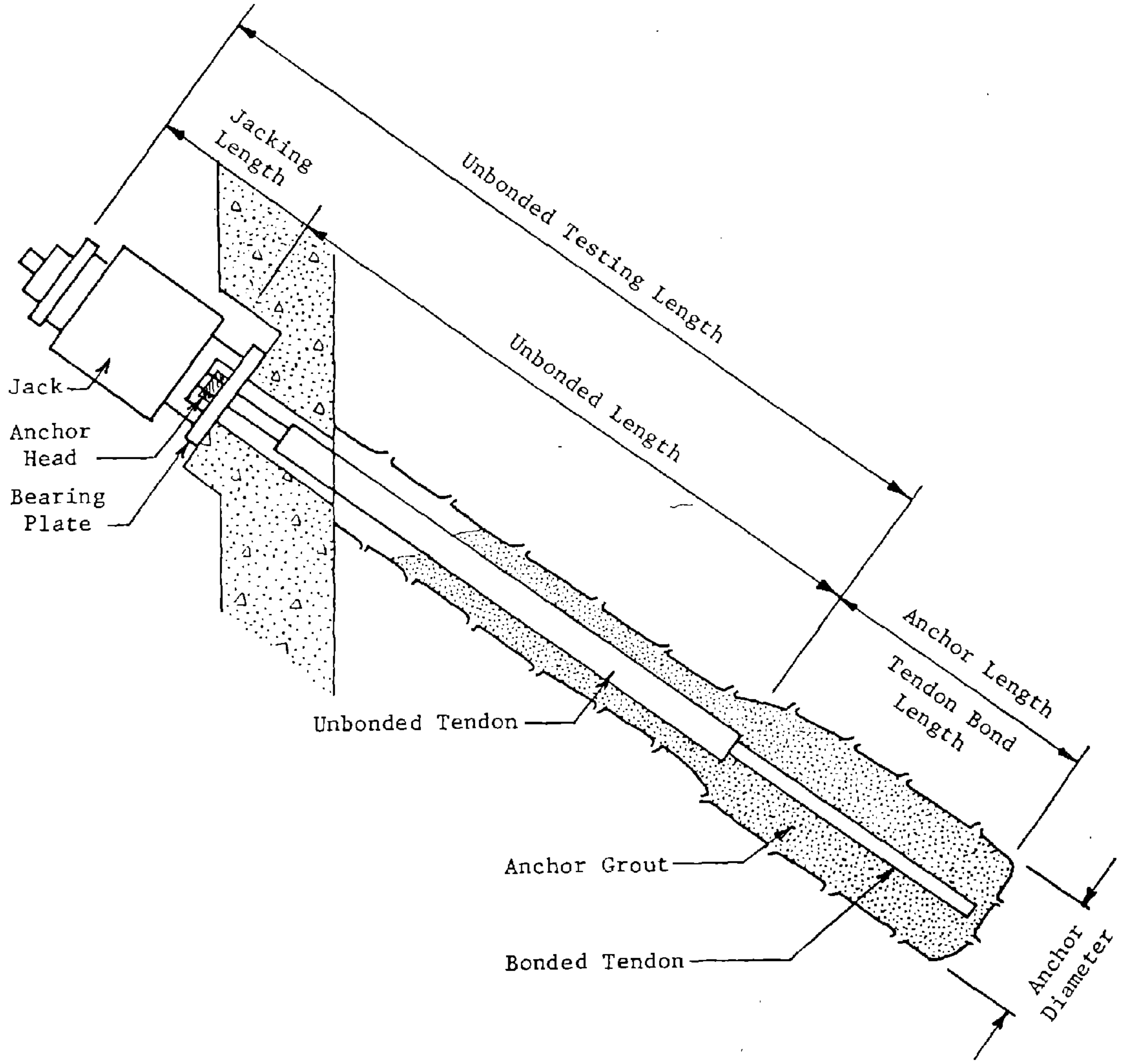


Figure 1. Components of a tieback.

soils that exceed these strengths, and have a consistency index (I_c) [1] greater than 0.8 have not experienced significant loss of load or movement with time. The consistency index is given by the relationship:

$$I_c = \frac{W_L - W}{W_L - W_P}$$

W_L = Liquid limit
W = Natural water content
W_P = Plastic limit

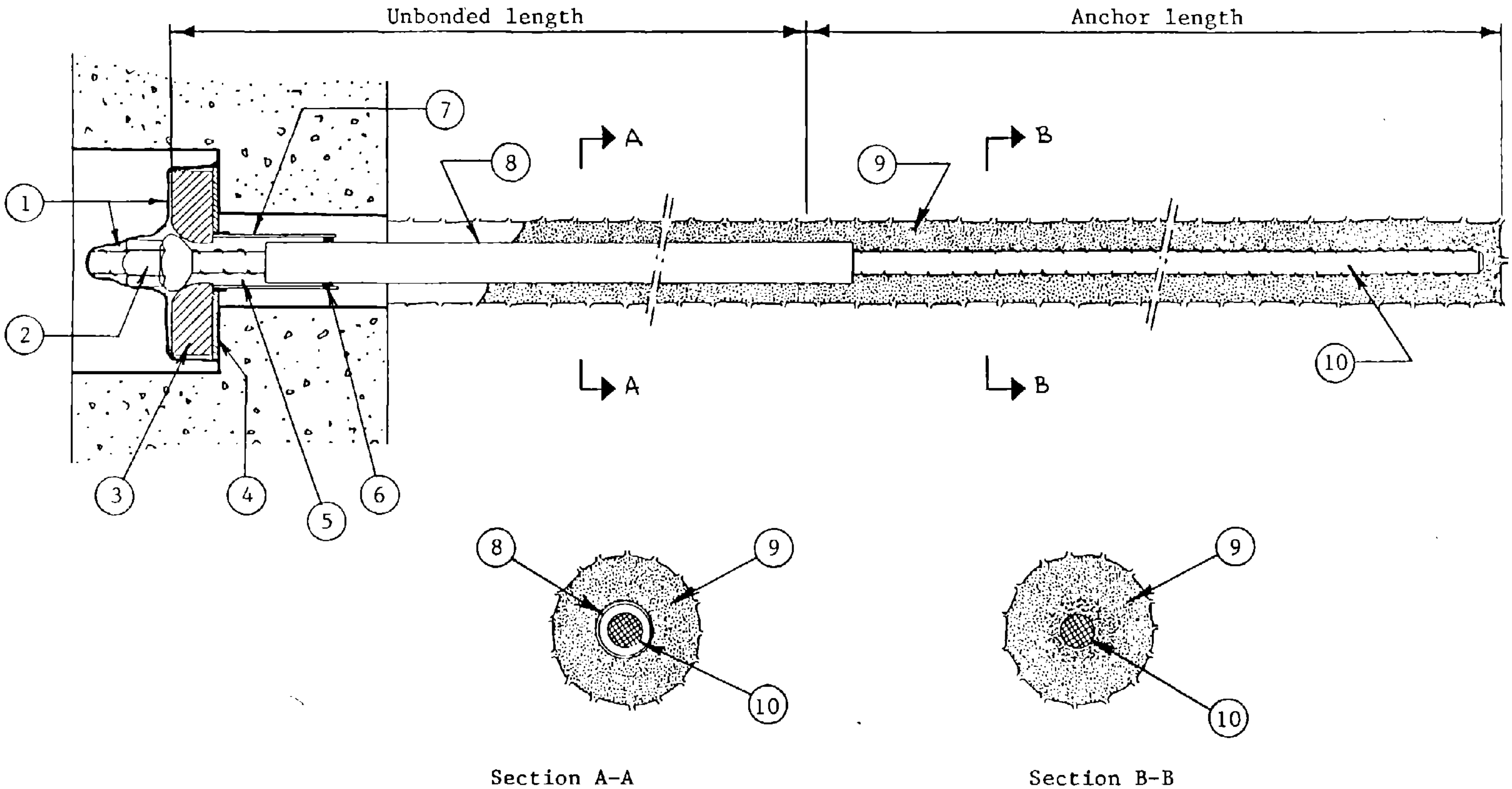
In order to establish load holding characteristics and thus establish confidence in long-term performance, a tieback test program is recommended if permanent tiebacks are to be anchored in a cohesive soil, or in sandy soil with a standard penetration resistance less than ten blows per foot.

The most economical tieback installation will be obtained if the design specifications permit the contractor to select the tieback type, the construction method, and the tieback capacity. The designer should specify the minimum unbonded length, the minimum total tieback length, and the loading diagram for determining the tieback loads. In lieu of specifying a loading diagram, a unit tieback capacity for each tieback level could be specified. Finally, each production tieback should be tested to verify that the anchor will carry the design load.

C. CORROSION PROTECTION

Permanent tiebacks have been installed routinely since the mid-1960's in Europe, and since the early 1970's in the United States. They are performing well in a variety of environments. Most tiebacks use cement grout for protection over their anchor length. Portier [2], and Herbst [3] reported that there is no evidence of a corrosion failure where the tieback tendon was encased in grout. Corrosion failures have occurred along the unbonded length of unprotected tendons, with most of them located within 6.65 feet (2 m) of the anchor head. A significant number of the tieback corrosion failures were in tendons fabricated using quenched and tempered prestressing steels. These steels do not meet ASTM specifications for prestressing wires, strands, or bars.

Most permanent tiebacks can be protected by portland cement grout along the anchor length, and a grease-filled tube or heat shrinkage sleeve over the unbonded length, Figure 2. Grout protected tiebacks should be electrically insulated from the structures they support, and the tendon should have a minimum of 0.5 inches (12.7 mm) of grout protection. Figure 2 shows the anchorage insulation used to insulate the tendon. Electrical insulation interrupts the long-line, differential aeration corrosion cell shown in Figure 3. This cell is potentially dangerous because it does not require oxygen in the soil, and because of the relative size of the cathode and anode. If this cell develops, the tendon at the top of the anchor zone would become the anode, and the entire wall would become the cathode. Electrical insulation would also interrupt the most probable stray-current corrosion system.



Legend:

1) Insulating cover of preformed plastic, heat shrinkable cover, or moldable tape.
2) Nut
3) Bearing plate
4) Bearing plate insulation
5) Anticorrosion grease
6) Seal
7) PVC trumpet
8) Grease-filled PVC or polyethylene sheath
9) Anchor grout
10) Tendon

Figure 2. Insulated simple corrosion protected tieback.

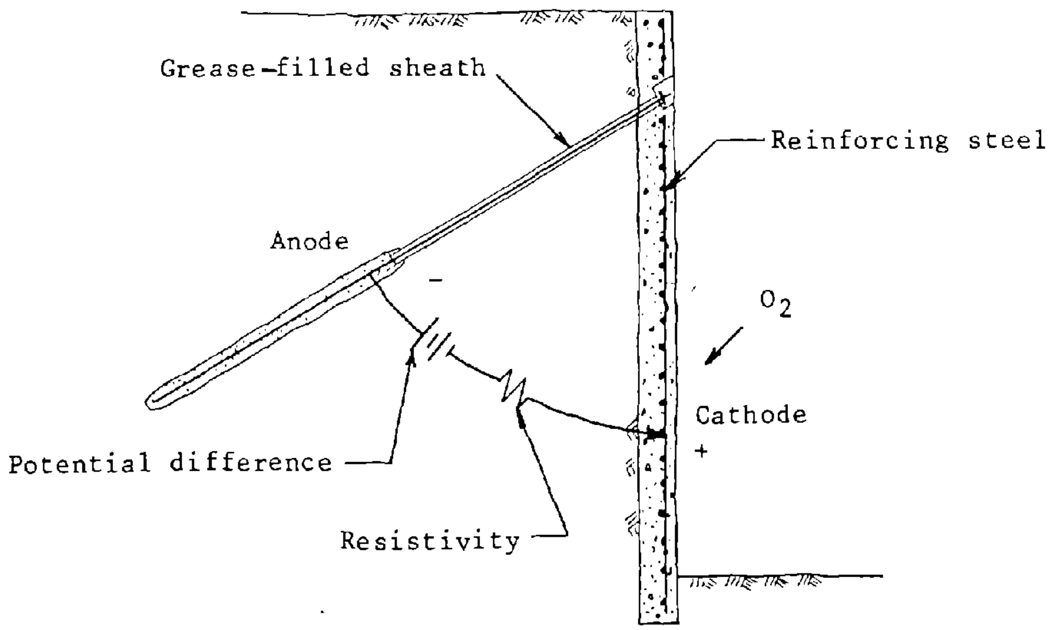


Figure 3. Long-line, differential aeration corrosion system that could affect a simple corrosion protected tieback.

If the soil surrounding the anchor length has a pH less than 4.5, or a resistivity less than 2,000 ohm-cm, or if sulfides are present, then a local corrosion system could develop on the tendon. Figure 4 shows a local corrosion system. When the aggressive environments are encountered, then the tendon should be completely encapsulated in a plastic or steel tube. Figure 5 shows an encapsulated tieback. The encapsulation will interrupt any long-line and stray current corrosion system, and prevent the local corrosion system from developing.

Figures 2 and 5 show two ways to provide corrosion protection for the anchorage and the tendon below the bearing plate. Care must be taken to insure that this area is well protected since most known corrosion failures have occurred near the anchor head. The corrosion protection under the anchorage should be designed to accommodate small movements.

The American Water Works Association (AWWA) [4] describes how the pH, resistivity, and sulfide content can be measured in the field. The soluble sulfate content of the soil is determined in the laboratory. If the soluble sulfate content exceeds 2,000 mg/kg, then ASTM Type V cement should be used. When the pH of the soil is less than 4.5 or when nearby buried concrete structures are suffering from chemical attack, portland cements should not be used for the anchor grout.

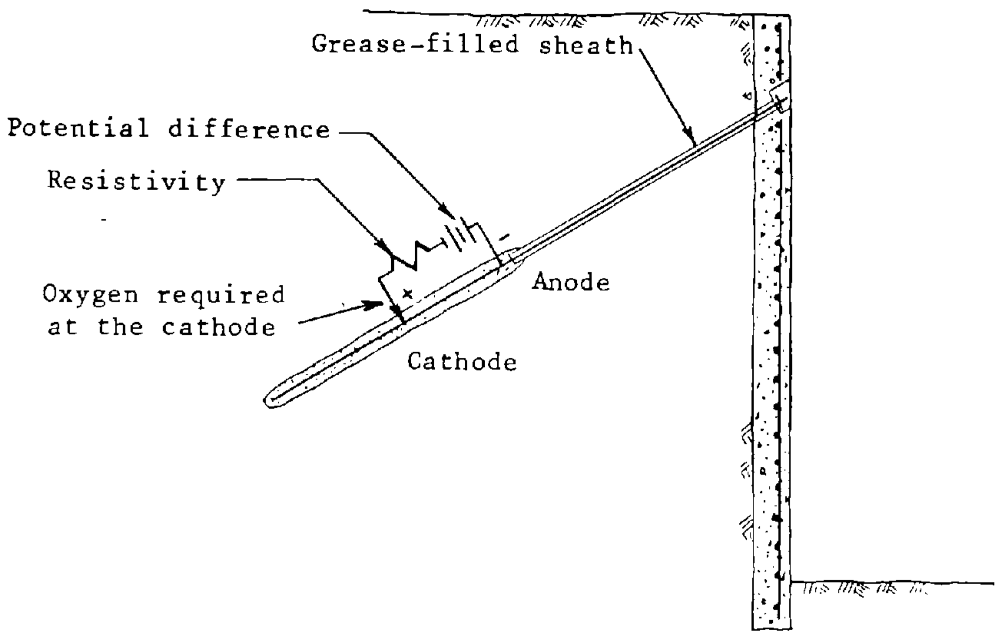


Figure 4. Local corrosion system that could affect a simple corrosion protected tieback.

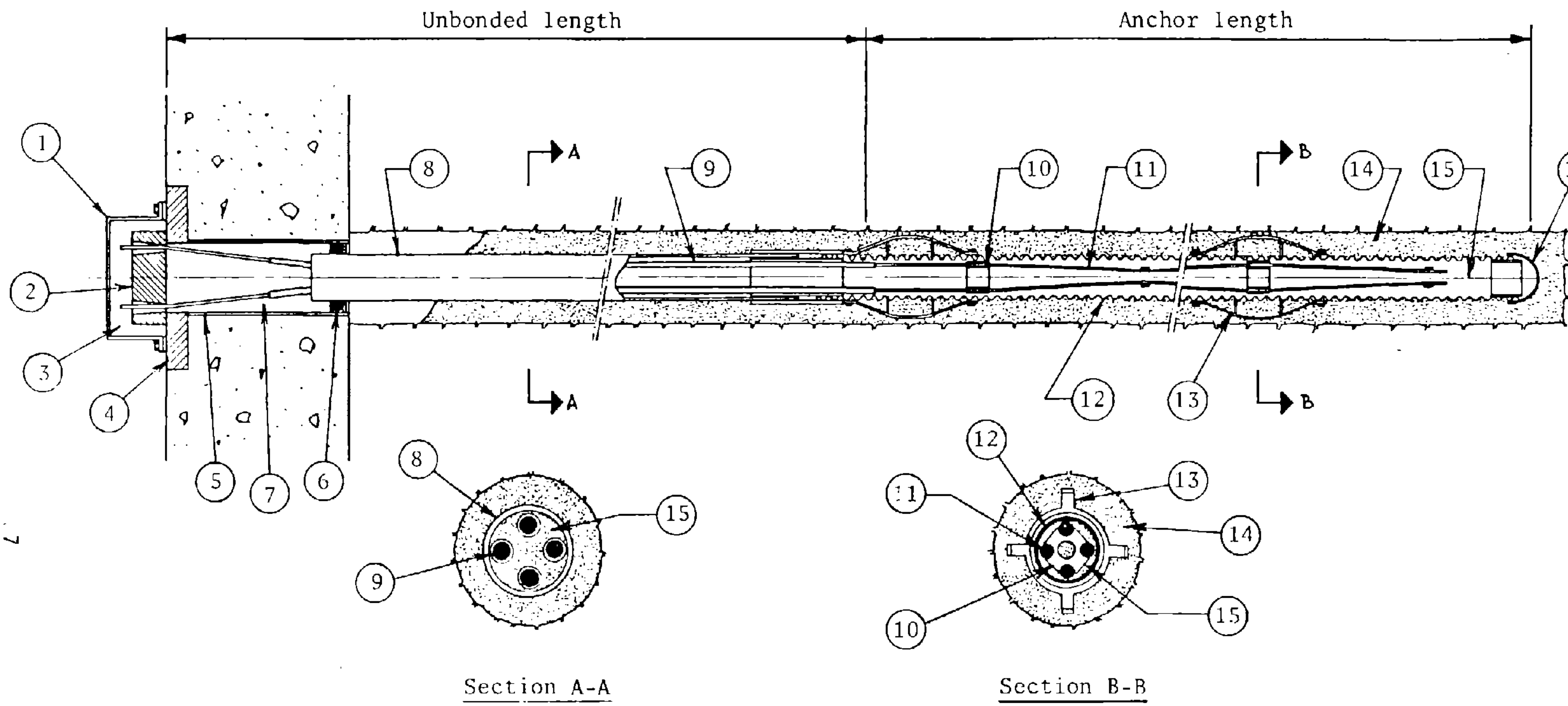
D. SPECIFICATION

The specification should establish a quality level without eliminating suitable proprietary tieback systems or methods. The designer may require the prequalification of the tieback contractor. The prequalification can be based on experience, or a list of acceptable contractors could be included in the specifications.

An alternative type of prequalification warrants evaluation. This method would require the submission and approval of the tieback system, and the corrosion protection prior to bid. The submission must be detailed enough to enable the designer to determine if his design is satisfied. This form of prequalification would also allow the contractor to know if his proprietary techniques would be acceptable, and the owner would be able to take advantage of any cost savings. Preparation and review of the submittal would not require a great deal of time, and this contracting procedure would encourage alternate tieback types, and continued tieback development.

E. TESTING

Every tieback should be tested to verify that it will carry the design load without excessive movement. Tiebacks are one of the few structural systems where every member can normally be tested before placing them into service. Three types of tests are recommended; performance, proof, and creep tests.



Legend:

1. Anchorage cover
2. Anchor head and wedges
3. Anticorrosion grease or grout
4. Bearing plate
5. Trumpet
6. Seal
7. Anticorrosion grease or grout
8. PVC or polyethylene tube
9. Individually greased & sheathed strands
10. Spacer
11. Strand tendon
12. Corrugated polyethylene or PVC
13. Centralizer
14. Anchor grout
15. Grout or polyester resin
16. End cap

Figure 5. Encapsulated strand tieback.

A hydraulic jack and pump are used to apply the load. The entire tieback tendon should be simultaneously loaded during testing. The movement of the tieback is measured with a dial gauge or a vernier scale supported on a reference which is independent of the tiedback structure. Movement cannot be accurately monitored by measuring the jack ram travel.

The first few tiebacks and a selected percentage of the remaining tiebacks should be performance tested. The performance test is used to establish the load-deformation behavior for the tiebacks at a particular site. It is also used to separate and identify the causes of tieback movement, and to check that the unbonded length has been established. The movement patterns developed during the performance test are used to interpret the results of a simpler proof test.

Performance testing is done by measuring the load applied to the tieback and its movement during incremental loading and unloading. Table 1 gives the loading schedule for a performance test and contains the results of a test made on a hollow-stem-augered tieback installed in a stiff clayey silt.

Two types of load movement curves can be plotted for each performance test. Figure 6 (a) shows the total movement curve for the test results contained in Table 1. In order to simplify the presentation of the data and to highlight the behavior of the tieback, only the movement at the maximum load in each increment is plotted. The data to be plotted is identified with an asterisk (*) in the remarks column in Table 1.

When a tieback is loaded, the anchor moves through the soil as it develops capacity. When the load is reduced to zero, a portion of the movement is elastic and recovered, but some of the movement is nonrecoverable. This nonrecoverable movement (residual anchor movement), is also measured during a performance test. Figure 6 (b) shows the residual anchor movement curve for the data in Table 1. The residual movements are plotted as a function of the highest previous load. The movements to be plotted are identified with a double (**) in the remarks column in Table 1.

The total movement of a tieback is made up of elastic movements (recoverable movements) and residual anchor movements (nonrecoverable movements). The elastic movements result from elastic elongation of the tendon and elastic movement of the anchor through the soil, and they are equal to the total movement minus the residual anchor movement. Time-dependent movements (creep movements) make up a portion of the residual anchor movement if the load is held constant for a period of time. The creep movements are a result of time-dependent movement of the anchor through the soil, progressive debonding of the tendon in the grout, and creep movements in the tendon. The components of movement are identified in Figure 6.

The maximum load applied during the performance test is held constant for 10 minutes, and the movements are measured and recorded at the times indicated in Table 1. If the tieback is not creep susceptible, then the elongation between 1 minute and 10 minutes will normally be less than 0.04 inches (1 mm) [5], and [6], and [7]. If this is the case, then the test can be discontinued. If the movements exceed 0.04 inches (1 mm), then the maximum load should be held for 60 minutes. The movements should be

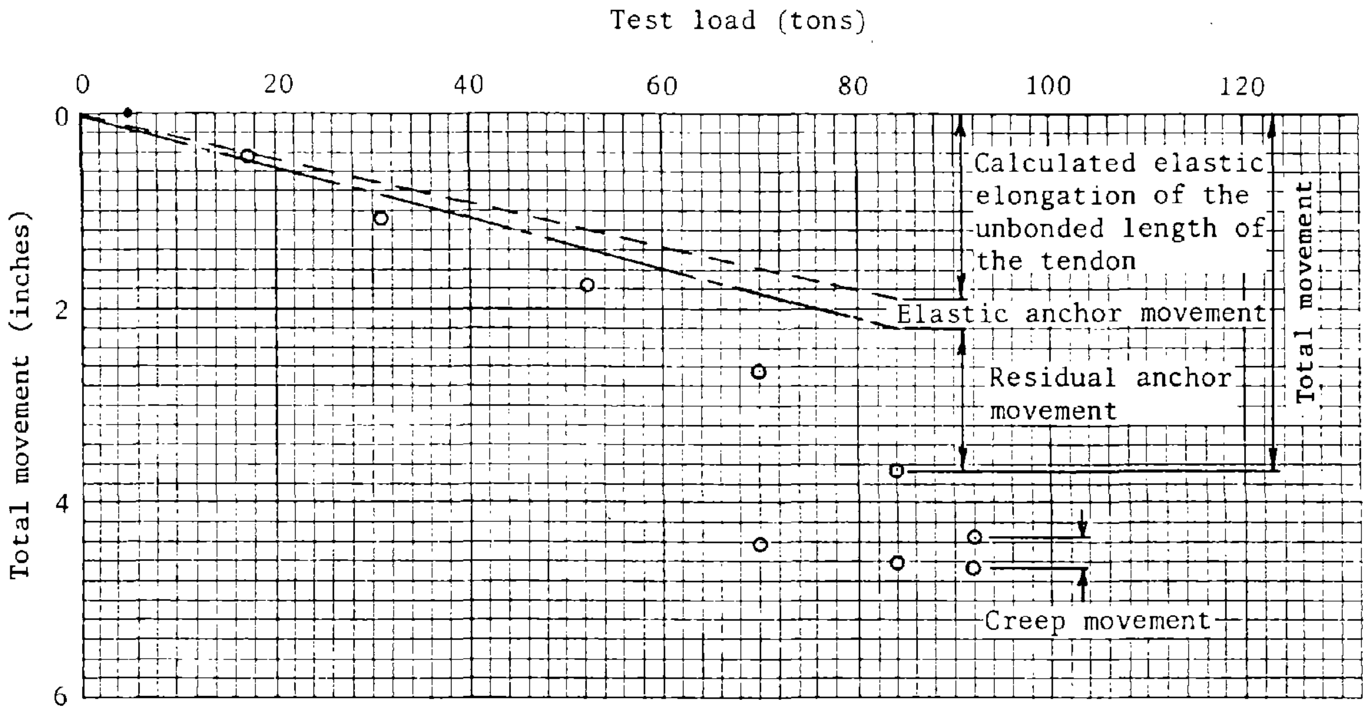
Table 1. Performance test made on a hollow-stem-augered tieback installed in a stiff silty clay.

Load increment	Basis of load (P_{DL}=design load)	Load (tons)	Observation period (min)	Jack pressure (psi)	Movement (inches)	Remarks
0	0	0		0	0	
T_0	(1) See below	5		245	0	
P_1	0.25 P_{DL}	17.5		860	0.449	**
T_0		5		245	0.131	*
P_1	0.25 P_{DL}	17.5		860	0.426	
P_2	0.50 P_{DL}	31		1525	1.102	**
T_0		5		245	0.203	*
P_1	0.25 P_{DL}	17.5		860	0.435	
P_2	0.50 P_{DL}	31		1525	1.097	
P_3	0.75 P_{DL}	52		2555	1.761	**
T_0		5		245	0.298	*
P_1	0.25 P_{DL}	17.5		860	0.446	
P_2	0.50 P_{DL}	31		1525	1.101	
P_3	0.75 P_{DL}	52		2555	1.778	
P_4	1.00 P_{DL}	70		3440	2.622	**
T_0		5		245	0.391	*
P_1	0.25 P_{DL}	17.5		860	0.458	
P_2	0.50 P_{DL}	31		1525	1.123	
P_3	0.75 P_{DL}	52		2555	1.787	
P_4	1.00 P_{DL}	70		3440	2.631	
P_5	1.20 P_{DL}	84		4130	3.679	**
T_0		5		245	0.762	*
P_1	0.25 P_{DL}	17.5		860	0.862	
P_2	0.50 P_{DL}	31		1525	1.523	
P_3	0.75 P_{DL}	52		2555	2.007	
P_4	1.00 P_{DL}	70		3440	2.638	
P_5	1.20 P_{DL}	84		4130	3.689	
P_6	1.33 P_{DL}	92	1	4525	4.367	**
P_6	1.33 P_{DL}		2		4.484	
P_6	1.33 P_{DL}		3		4.529	
P_6	1.33 P_{DL}		4		4.554	
P_6	1.33 P_{DL}		5		4.573	
P_6	1.33 P_{DL}		7		4.593	
P_6	1.33 P_{DL}		10		4.616	
P_6	1.33 P_{DL}		15		4.635	
P_6	1.33 P_{DL}		20		4.646	
P_6	1.33 P_{DL}		25		4.655	
P_6	1.33 P_{DL}		30		4.662	
P_6	1.33 P_{DL}		45		4.680	
P_6	1.33 P_{DL}		60		4.691	**
P_5	1.20 P_{DL}	84		4130	4.632	**
P_4	1.00 P_{DL}	70		3440	4.448	**
Lock-off						

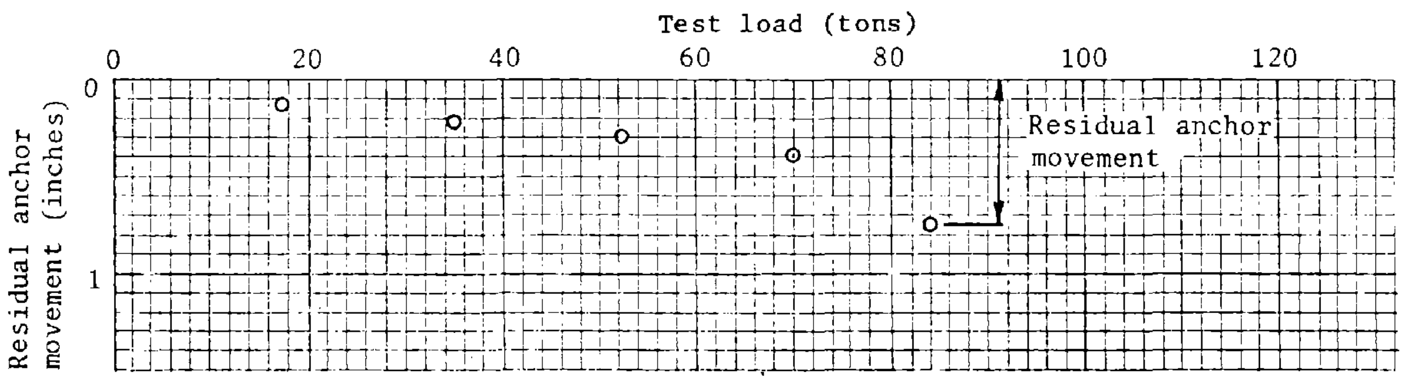
(1) T_0 is the alignment load. It is should be no more than 10 percent of the design load. The actual magnitude of the load depends upon the type of tendon and the weight of the jack.

Note: 1 ton = 8.9 kN, 1 inch = 25.4 mm, 1 psi = 6.9 kPa

*, ** For simplicity, only these movements are plotted. See Page 8.



a) Total movement curve



b) Residual anchor movement curve

Tieback data:

Lengths:

Total = 55 ft. (16.8 m)

Unbonded = 18 ft. (5.5 m)

Anchor = 37 ft. (11.3 m)

Jacking = 5 ft. (1.5 m)

Hollow stem augered tieback

Shaft diameter = 12 inches

Tendon: 6 - 0.5 in. strands

Grouting:

$1\frac{1}{2}$ cu. yds.

100 psi

Note: 1 ton = 8.9 kN
1 psi = 6.9 kPa
1 inch = 25.4 mm
1 cu. yd. = 0.765 m^3

Figure 6. Performance test made on a hollow-stem-augered tieback installed in a stiff silty clay.

recorded at 0, 1, 2, 3, 4, 5, 7, 10, 15, 20, 25, 30, 45, and 60 minutes so a creep curve can be plotted. Tieback creep tests and their interruption is discussed at the end of this section.

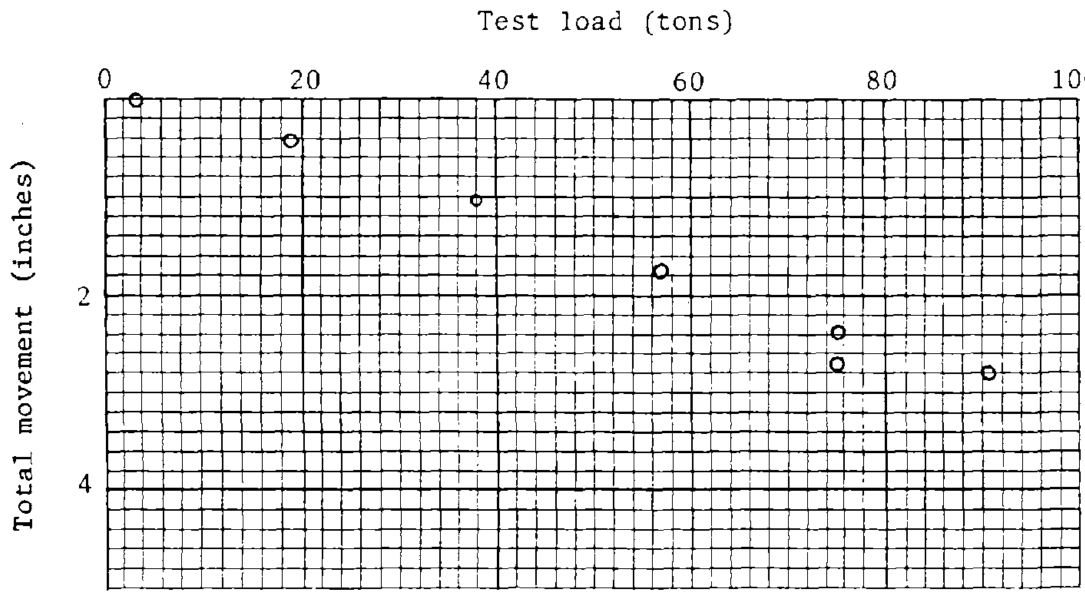
Each production tieback which is not performance tested should be proof tested. A proof test is a simple test which is used to measure the total movement of the tieback. Proof testing is done by measuring the load applied to the tieback and its movement during incremental loading. Table 2 gives the loading schedule for a proof test, and contains the results of a test performed on a hollow-stem-augered tieback. The increments of load are the same as those used in the performance test, except the maximum increment is normally equal to 1.20 times the design load. Figure 7 shows a plot of a proof test performed on a hollow-stem-augered tieback. The maximum load applied during a proof test is held constant for 5 minutes and the tieback movement is recorded. If the movement during the 5 minute observation period is less than 0.03 inches (0.76 mm), then the test is discontinued. If the movement exceeds 0.03 inches (0.76 mm), then the load should be maintained until the creep rate can be determined and compared to the creep behavior observed during the performance or creep tests.

Table 2. Proof test performed on a hollow-stem-augered tieback installed in an interbedded stiff silty clay and silty sand.

Load increment	Basic of load (P_{DL}=design load)	Load (tons)	Observation period (min)	Jack pressure (psi)	Movement (inches)	Remarks
0	0	0		0	–	
T_0	(1) See below	3.5		170	0	
P_1	0.25 P_{DL}	19		950	0.419	
P_2	0.50 P_{DL}	38		1850	1.059	
P_3	0.75 P_{DL}	57		2800	1.781	
P_4	1.00 P_{DL}	75.5		3700	2.355	
P_5	1.20 P_{DL}	90.5	1	4450	2.818	
P_5	1.20 P_{DL}	↓	2	↓	2.835	
P_5	1.20 P_{DL}	↓	3	↓	2.838	
P_5	1.20 P_{DL}	↓	4	↓	2.841	
P_5	1.20 P_{DL}	↓	5	↓	2.845	
P_5	1.20 P_{DL}	↓	7	↓	2.847	
P_5	1.20 P_{DL}	↓	10	↓	2.851	
P_5	1.20 P_{DL}	↓	15	↓	2.856	
P_5	1.20 P_{DL}		20			
P_5	1.20 P_{DL}		25			
P_5	1.20 P_{DL}		30			
P_5	1.20 P_{DL}		45			
P_5	1.20 P_{DL}		60			
P_4	1.00 P_{DL}	75.5		3700	2.680	
Lock-Off		57		2800	2.220	

(1) T_O is the alignment load. It is should be no more than 10 percent of the design load. The actual magnitude of the load depends upon the type of tendon and the weight of the jack.

Note: 1 ton = 8.9 kN, 1 inch = 25.4 mm, 1 psi = 6.9 kPa



Tieback data:

Lengths:

Total = 55 ft. (16.8 m)

Unbonded = 10 ft. (3.1 m)

Anchor = 45 ft. (13.7 m)

Jacking = 5 ft. (1.5 m)

Shaft diameter - 12 inches

Tendon: 7 - 0.5 in. strands

Grouting:

$1\frac{1}{2}$ cu. yds.

100 psi

Note:

1 ton = 8.9 kN
1 psi = 6.9 kPa
1 inch = 25.4 mm
1 cu. yd. = 0.765 m^3

Figure 7. Proof test performed on a hollow-stem-augered tieback installed in an interbedded stiff silty clay and silty sand.

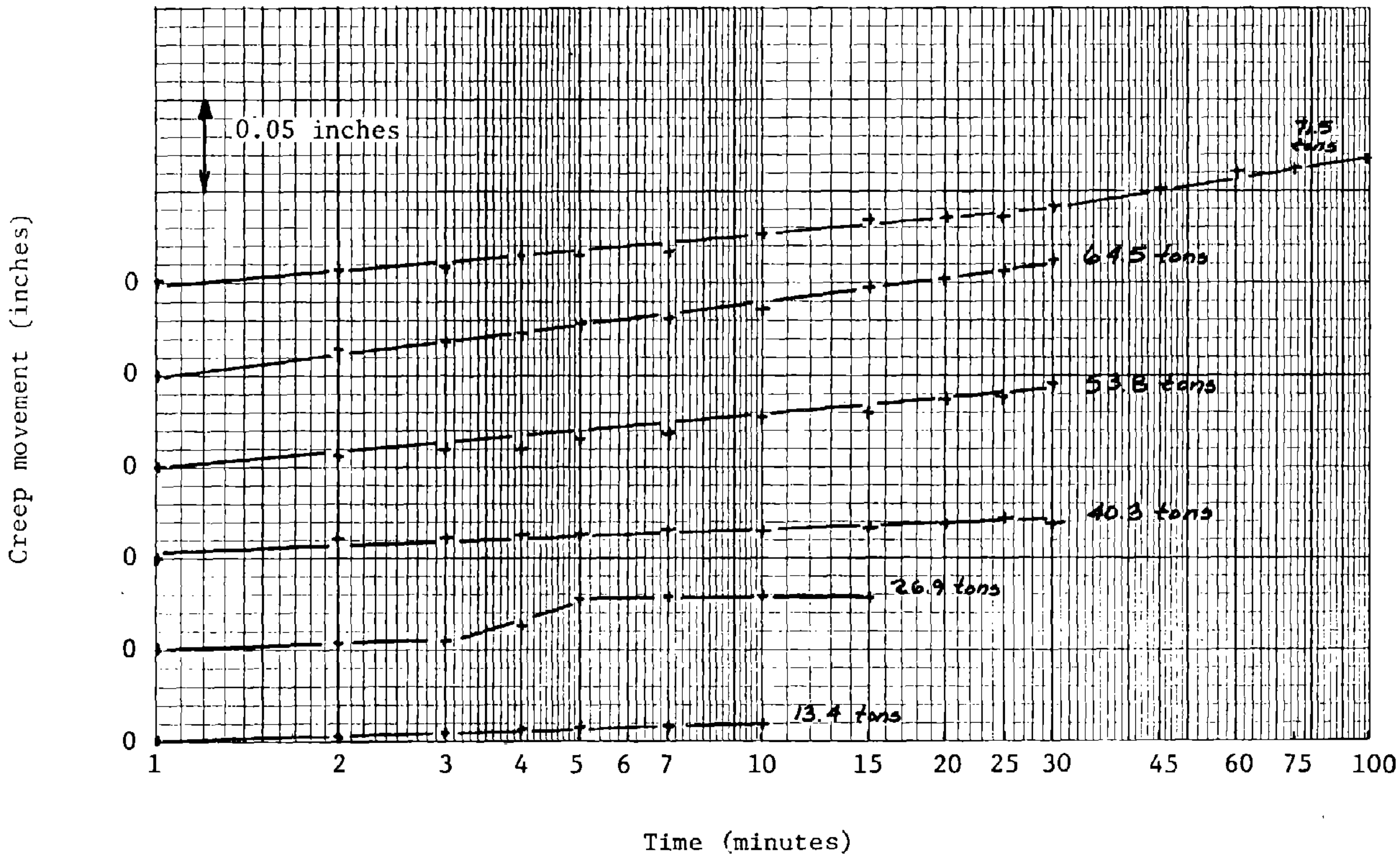
Creep tests are performed on tiebacks installed in cohesive soils. They are normally made on the initial two performance tested tiebacks. During a creep test, each increment of load is held and the elongations are recorded and plotted. Figure 8 shows the results of a creep test performed on a postgrouted tieback installed in a stiff clay with a trace of fine to medium sand. Each curve in Figure 8 represents the creep movement at each load increment.

Figure 9 shows the three characteristic types of creep curves observed during tieback testing. Curves (a) and (b) indicate acceptable behavior as long as the creep movement estimated by projecting the creep rate over the life of the structure is not excessive. A creep rate of 0.08 inches (2.0 mm) per log cycle would produce a creep movement of approximately 0.5 inches (12.7 mm) during 50 years. Curve (c) indicates that the tieback would continue to creep until it failed. In the region between curve (b) and (c), it is possible to have a creep curve which would slope gradually upward at the maximum load. This tieback could be accepted if the creep curve for the design load was similar to curves (a) and (b).

Tieback tests are used to identify the load deformation behavior of each tieback, and provide data that will enable the engineer to make a decision as to their adequacy. The total movement curve is helpful in quickly identifying any unusual behavior. However, the primary purpose of the test is to verify that the tieback will carry the load without excessive movement. The tieback behavior during the load hold or the creep test provides the best indication of the load carrying ability of the tieback.

F. CONCLUSION

Permanent tiebacks can be effective tools to support a variety of different structures. They can be installed in rock and sandy soils without concern about their long-term performance. Permanent tiebacks can also be made in cohesive soils. However, a careful testing program, and a proven tieback system should be used in cohesive soils. The tieback tendon can easily be protected from corrosion. Each tieback should be tested to verify that it will carry the design load for the service life of the structure.



Note: 1 ton = 8.9 kN, 1 inch = 25.4 mm

Figure 8. Creep test performed on a postgrouted tieback installed in a stiff clay with a trace of fine to medium sand.

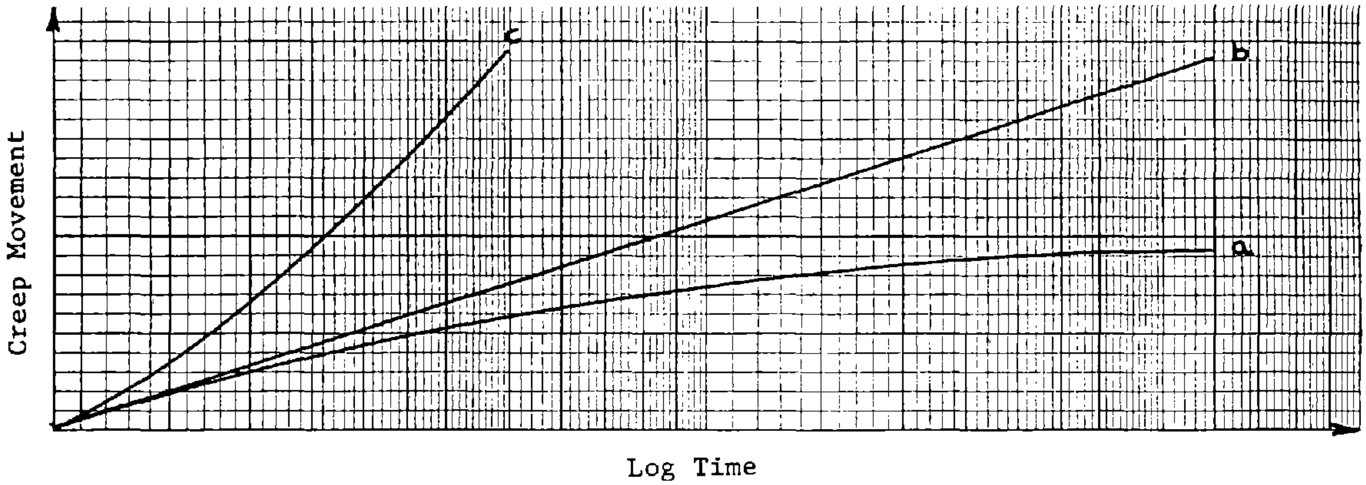


Figure 9. Characteristic creep curves.

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