Evaluation of Tieback Performance

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16. ABSTRACT

The economy and effectiveness of tiebacks for support of temporary excavations has led to their increased use for support of permanent excavations. To better understand the characteristics and performance of tiebacks, a field observation program was undertaken.

Various characteristics of over 900 tiebacks exhumed from an excavation along I-90 in Mercer Island, Washington were observed in the field. The geometric spacing of the tiebacks appeared to be quite uniform. Centering of the anchor tendon in the augered hole was generally good, although some instances of significantly off-center anchor tendons were observed. Significant corrosion was not observed on any of the anchor tendons that could be examined in the field. Evidence of grease leakage at the end of the trumpets was observed at a number of tieback locations. While physical disturbance of the tiebacks during excavation was undoubtedly responsible for much of the observed leakage, leakage was also observed at a number of tiebacks that appeared to be undisturbed.

On the basis of the observations made in the field, no specific changes in the current WSDOT design methods and specifications for tiebacks appear to be necessary.

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Research Project GC 8719, Task 19
Tieback Performance

EVALUATION OF TIEBACK PERFORMANCE

by

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SUMMARY

The use of tiebacks to support temporary excavations has become widespread in recent years. Their economy and effectiveness have been shown on many projects. To fully exploit these characteristics, tiebacks have been increasingly used to support permanent excavations. However, their use for permanent support requires that they meet more stringent standards than those for temporary support, particularly in terms of long-term performance.

The objective of the research described in this report was to evaluate the insitu characteristics of tiebacks that had been in service for an extended period as part of a temporary wall along I-90 in Mercer Island, Washington. Originally, many tieback characteristics were to have been observed; however, construction methods and scheduling limited the number of characteristics that could be accurately observed in the field without impeding the progress of the tieback excavation contractor. The investigators were able to observe anchor tendon corrosion and tieback trumpet effectiveness and, to a lesser extent, tieback spacing and anchor tendon centering.

The geometric spacing of the tiebacks appeared to be generally quite uniform. Wandering of augers during tieback drilling is a commonly observed phenomenon that may be of concern in certain soils. While the absolute magnitude of auger wandering could not be determined in the field, the relative magnitude of wandering appeared to be uniform. Centering of the anchor tendon within the augered hole was generally good, although some instances of significantly off-center anchor tendons were observed.

Significant corrosion was not observed on any of the anchor tendons that could be examined in the field. Though mild corrosion was observed on a very small percentage of anchor tendons, at least part of the corrosion appeared to have resulted from exposure to rainfall after excavation. In general, however, the corrosion protection measures employed along the anchor tendon appeared to have been very effective.

Evidence of grease leakage at the end of the trumpets was observed at a number of tieback locations. While physical disturbance of the tieback during excavation was undoubtedly responsible for much of the observed leakage, leakage was also observed at a number of tiebacks

that appeared to be undisturbed. In general, the amount of leakage at undisturbed tiebacks was small, but was significant at several locations.

WSDOT has been a national leader in the use of tiebacks for excavation support in both temporary and permanent applications. The performance of tieback walls on WSDOT projects has been quite satisfactory and has produced considerable savings on construction costs. The observations made in the field did not suggest that any specific changes were necessary to the current WSDOT design methods and specifications for tiebacks, though some recommendations were made.

INTRODUCTION AND RESEARCH APPROACH

The use of tiebacks to support excavation bracing has increased greatly in recent years. Tiebacks have proved to be effective and economical in comparison to most other types of excavation bracing systems. Though soil nailing has recently become recognized as a viable alternative, the active use of tiebacks is expected to continue.

Tiebacks were originally used almost exclusively to support temporary excavations, and a long history of their successful performance in such applications has developed. As engineers have become more familiar with the design and satisfactory performance of tiebacks, and as their economy has been repeatedly illustrated, their use for permanent support has become increasingly attractive. However, the requirements of tiebacks for temporary and permanent use are different. In temporary bracing situations, the period over which the tieback is under load and subjected to environmental effects is quite small. In permanent installations, the tiebacks may be subjected to unfavorable environmental conditions for a long period, over which they are expected to resist their design loads. The influence of the environmental conditions on the load-carrying capacity of the tiebacks is an important, and often critical, issue in their selection and design for permanent walls.

Of specific concern is corrosion of the tendon that connects the anchor portion of the tieback to the wall. Various corrosion prevention measures have been used, but definitive information on their effectiveness has not been available. One of the most common methods of corrosion protection involves the use of grease-encapsulated tendons. The purpose of the grease encapsulation is to prevent soil or groundwater from coming into contact with the tieback strands and causing corrosion. Leaking and loss of grease at the wall face has been observed with such tiebacks, casting suspicion on the integrity of the corrosion protection behind the wall. Because of the resulting uncertainty about the long-term integrity of the tieback, permanent tieback walls are either not used or are used with very costly corrosion protection systems. In each case, the competitive advantages of tieback wall construction are significantly reduced.

BACKGROUND

According to the International Society for Soil Mechanics and Foundation Engineering, tiebacks belong to a class of systems called ground anchors, which are systems that are capable of transmitting an applied tensile load to a load bearing stratum (1). The system consists of a fixed anchor, an anchor head, and an unbonded zone, generally arranged in the configuration shown in Figure 1.

Tiebacks are constructed by augering a hole through or adjacent to some structural wall element, inserting an anchor tendon into the hole, and grouting the fixed anchor zone with high-strength grout. The space around the anchor tendon in the unbonded zone is filled with a weak material such as sand, bentonite, or very weak grout. A jack is then used to apply tension to the anchor tendon at the anchor head, and a nut or wedge assembly is used to lock the desired tension into the system.

The tensile loads in the anchor tendons are generally quite high, and the successful performance of the entire tieback system depends on the ability of the anchor tendons to resist these tensile loads over the lifetime of the project. Because of the nature of tieback wall construction, tensile failure of an individual anchor tendon can lead to the progressive and catastrophic failure of an entire wall.

CORROSION

In typical tieback wall construction, particularly for permanent applications, the greatest threat to the tensile capacity of the anchor tendon comes from corrosion. Anchor tendons generally fall into one of two categories: solid, threaded rods or bars, and strands. These anchor tendons are fabricated from various types of steel and, consequently, are susceptible to corrosion. The potential for anchor tendon failure due to corrosion depends on the corrosivity of the soil and on the effectiveness of the corrosion protection system used to protect the anchor tendon.

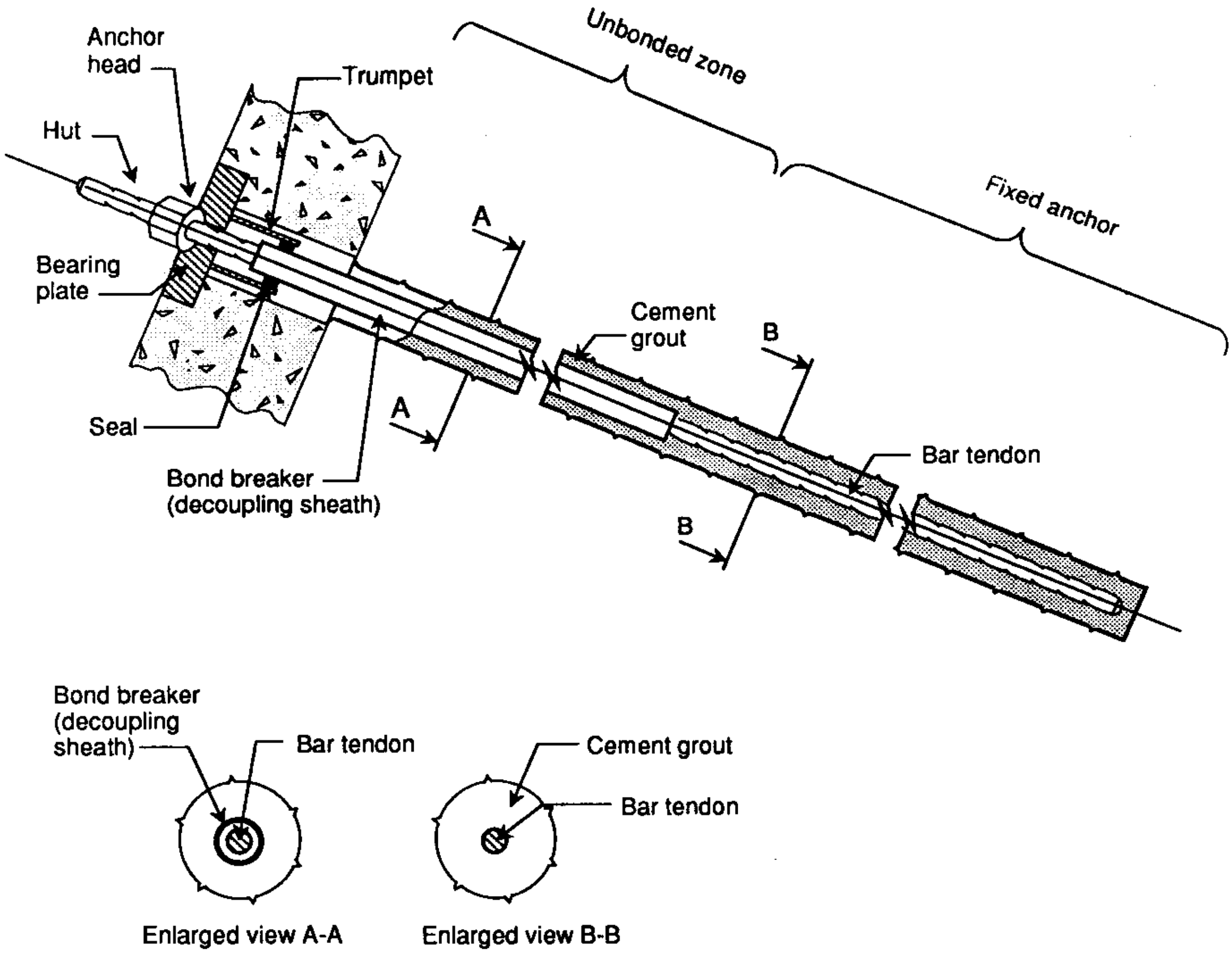


Figure 1. Typical Tieback Configuration and Nomenclature

Soil Corrosivity

Corrosion of metals buried in soils is an electrochemical process in which potential differences due to different materials, salts, oxygen levels, and other factors induce electrical currents. Corrosion is accelerated in a subsurface environment of low resistivity and extreme pH. Bacterial corrosion, which can cause metal pitting, is possible where organic materials or sulphates are present in the soil; this condition can be related to the redox potential of the soils. Guidelines for estimating soil corrosivity are presented in Table 1.

Table 1. Soil Corrosivity Indicators (after King, 1977)

Corrosivity	Resistivity (Ω-cm)	Redox Potential* (mV)
Very corrosive	< 700	< 100
Corrosive	700 - 2000	100-200
Moderately corrosive	2000 - 5000	200 - 400
Mildly or non-corrosive	> 5000	> 430 (clay soil)

* Corrected to pH = 7. Normal hydrogen electrode.

Stray currents from nearby electrical equipment can also accelerate corrosion of buried metals.

Protection Systems

Corrosion protection systems generally cover the anchor tendon with some combination of corrosion-inhibiting grease, sheathing, and grout. Different measures are commonly employed in the fixed anchor, unbonded zone, and anchor head areas. Junctions between these zones and between different protection systems are particularly susceptible to corrosion.

The fixed anchor zone may be protected by grout alone; however, the potential for grout cracking under stress renders reliance on such an approach inadvisable for many cases, particularly when the soil is corrosive or the anchors will be loaded for more than 12 to 18 months. Encapsulation of the anchor tendon within a corrugated plastic or deformed metal tube greatly increases protection. The space between the tendon and the tube is filled with polyester resin or cement grout. Such double protection systems can be used with bar or strand anchor tendons, as illustrated in Figure 2.

The unbonded zone is generally protected by a polypropylene or polyester sheath filled with grease or grout. The outer surface of the sheath is usually smooth in order to facilitate its action as a bond breaker.

Protection of the anchor head area is probably the most important, and most difficult, aspect of corrosion protection. According to the WSDOT Ground Anchor Inspection Manual (2), all known cases of ground anchor corrosion failure in the United States have occurred at or near the anchor head. The inner portion of the anchor head assembly is protected by a steel tube, or trumpet, that extends behind the wall until it overlaps the unbonded zone protection system. A seal may be used at the far end of the trumpet. The trumpet is completely filled with corrosion-inhibiting grease or grout. Complete filling of the trumpet is essential for satisfactory performance. The outer portion of the anchor head is covered by a plastic or metal cap filled with grease (if the anchors need to be restressed), grout, or epoxy.

Corrosion Failures

Littlejohn (1,3) described a study in which 35 published case histories of corrosion-induced failure of anchor tendons were identified. Of these, 24 cases involved permanent systems (with and without corrosion protection) and 11 involved temporary systems with no specific corrosion protection.

Corrosion was localized and was observed in bar, wire, and strand anchor tendons. Of the observed failures, nine occurred within six months of construction, ten between six months and two years, and the remainder more than two years after construction, up to a maximum of 31 years.

Only two failures were observed in the fixed anchor zone; both were attributed to inadequate grouting, which allowed the anchor tendons to be exposed to a corrosive environment. The remainder of the failures were nearly evenly distributed between the unbonded zone and the zone at or within 3 feet of the anchor head.

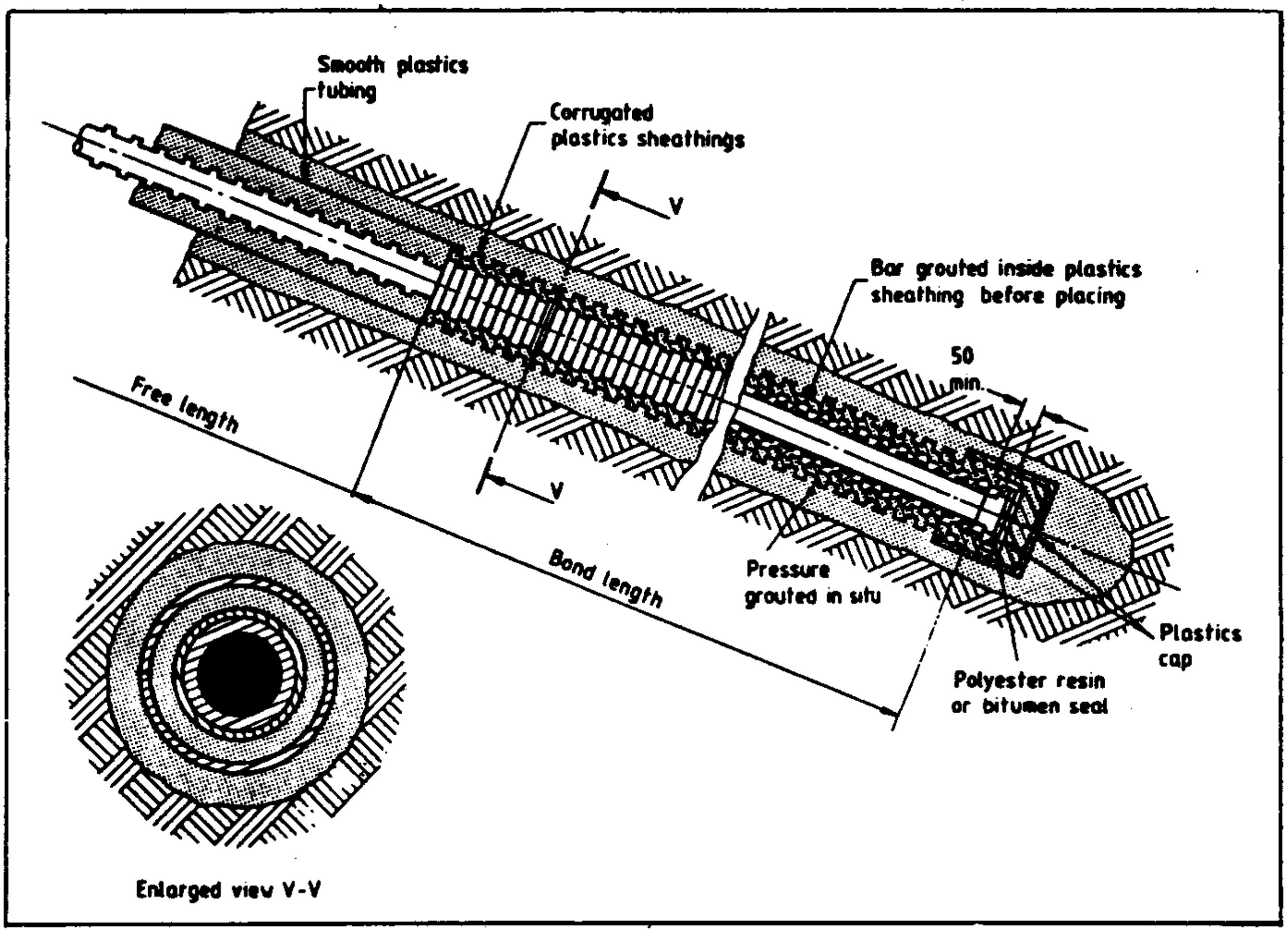


Figure 2(a). Double Corrosion Protection for Bar-Type Anchor Tendons (after Littlejohn 1990a)

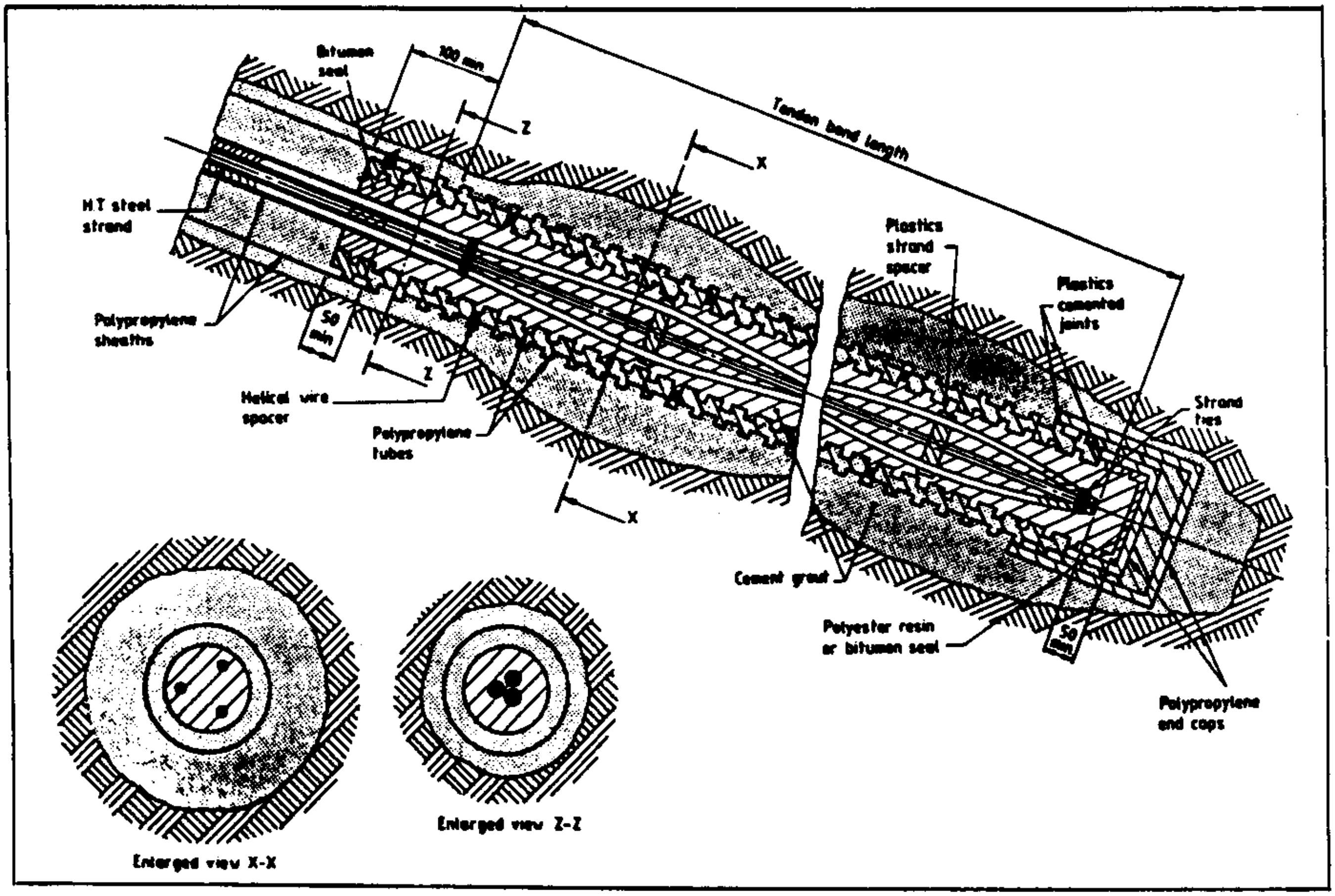


Figure 2(b). Double Corrosion Protection for Strand-Type Anchor Tendons (after Littlejohn 1990a)

Failures in the no-load zone resulted from one or more of the following conditions: (1) tendon cracking by ground movement-induced overstressing, sometimes augmented by corrosion, (2) inadequate tendon cover in the presence of chlorides, (3) breakdown of bitumen tendon coating, (4) inappropriate choice of protective material, and (5) use of anchor tendons that had been unprotected during prolonged on-site storage.

Failures near the anchor head resulted from absence of protection, which led to failure in as little as a few weeks in some corrosive environments, and inadequate performance of corrosion protection measures. Incomplete filling of the trumpet or leakage from the trumpet during service generally led to unsatisfactory performance.

Research Approach

To evaluate the effectiveness of tieback corrosion protection systems after a substantial period of service, a program of field observation of tieback characteristics was undertaken. The observations were made as tiebacks were exhumed during construction of the eastbound lanes of I-90 across Mercer Island, Washington.

The effectiveness of the observation program was dictated by the schedule and actions of the excavation contractor. Three student assistants monitored the site during construction, initially together to develop consistent criteria for field classification, and later on a rotating basis to maximize observation time. The student assistants observed tieback characteristics as closely as possible without impeding the contractors progress or risking their own safety. Numerous photographs were taken throughout the observation program.

FINDINGS

The schedule and nature of excavation construction, along with the weather, limited the scope and effectiveness of the tieback observation program. The contractor elected to excavate limited zones near the wall to cut the anchor tendons before removing the soil and anchors by backhoe and bulldozer, as illustrated in Figures 3 and 4. The anchors were manhandled along with the rest of the soil, and consequently were disturbed and broken before many of their characteristics could be observed. The contractor worked at the excavation process somewhat sporadically. As a result, it was difficult for project personnel to be on-site during some stages of excavation.

The best access available to the observers was near the wall, which allowed observation of at least the upper portion of the unbonded zone and of the trumpet and anchor head assembly. As a result, the findings emphasize tieback characteristics in those areas.

SITE LOCATION

The site was located along I-90 in Mercer Island between MP 4.67 and 5.70 (Stations LR 269 + 76.56 and LR 343 + 21.18), as shown in Figure 5. The area is often referred to as the Shorewood area of Mercer Island. To construct the new westbound lanes of I-90, a tied back soldier pile wall of up to about 40 ft high was constructed. The tieback wall extended from Station LM 269 + 54.74 past the end of the project area at Station LM 315 + 00.00. Each soldier pile was numbered on the construction plans and, with spray paint, in the field.

WALL CONSTRUCTION

The wall was constructed with tiebacks typically installed at four levels. The soldier piles were predominantly W14 sections of A36 steel with pressure-treated timber lagging placed between. Between Station LM 295 + 98.65 and Station LM 306 + 73.24, a composite wall consisted of a permanent slurry wall at depths below the eventual eastbound grade line with a temporary soldier pile wall above. In the composite wall section, welded W24 sections were used

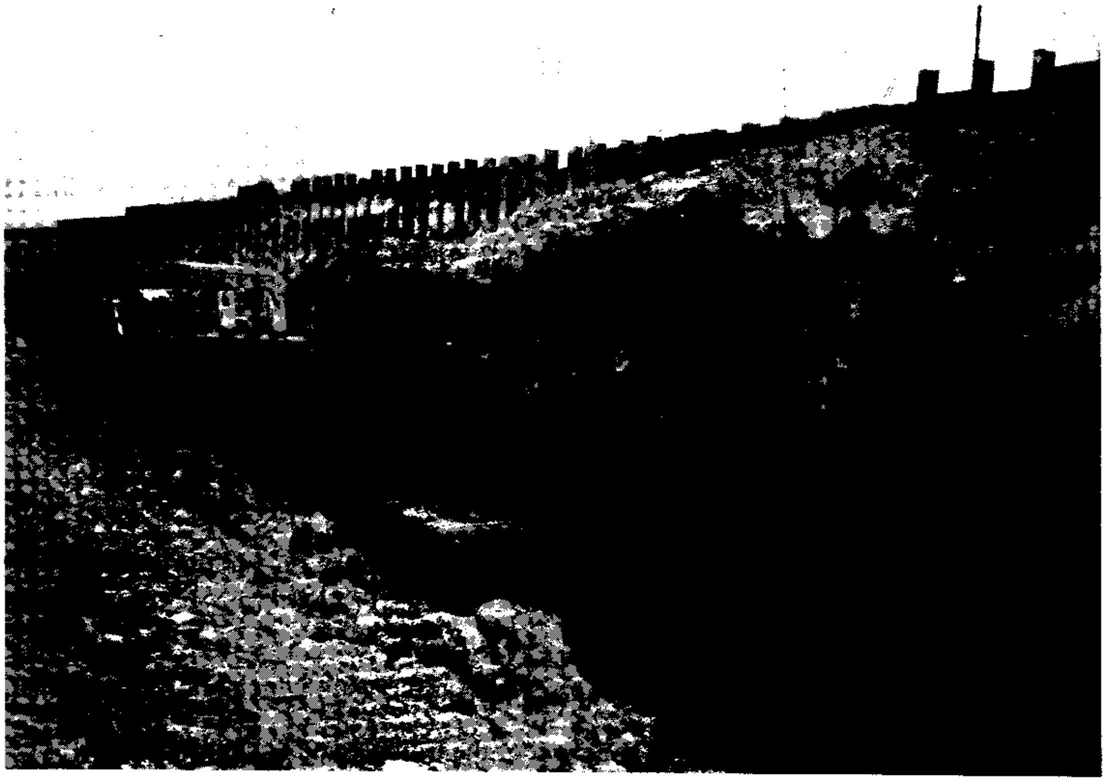


Figure 3. Mass Excavation of Tiebacks with Bulldozer

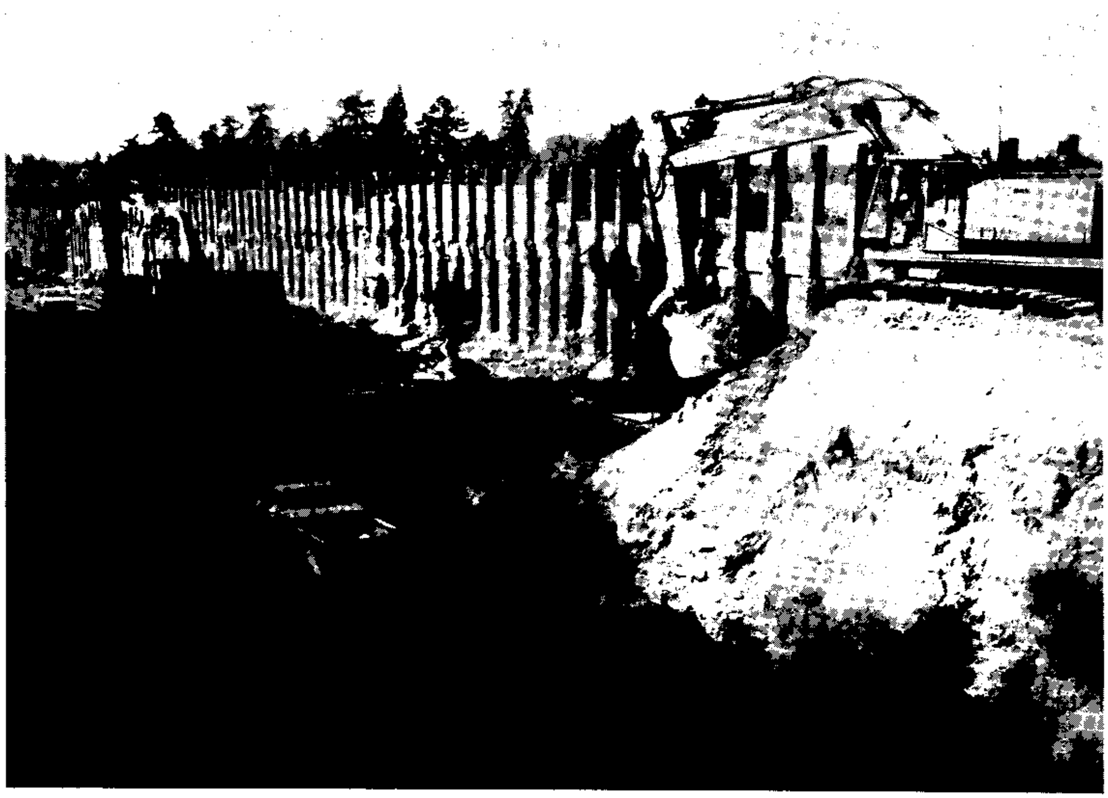


Figure 4. Mass Excavation of Tiebacks with Backhoe

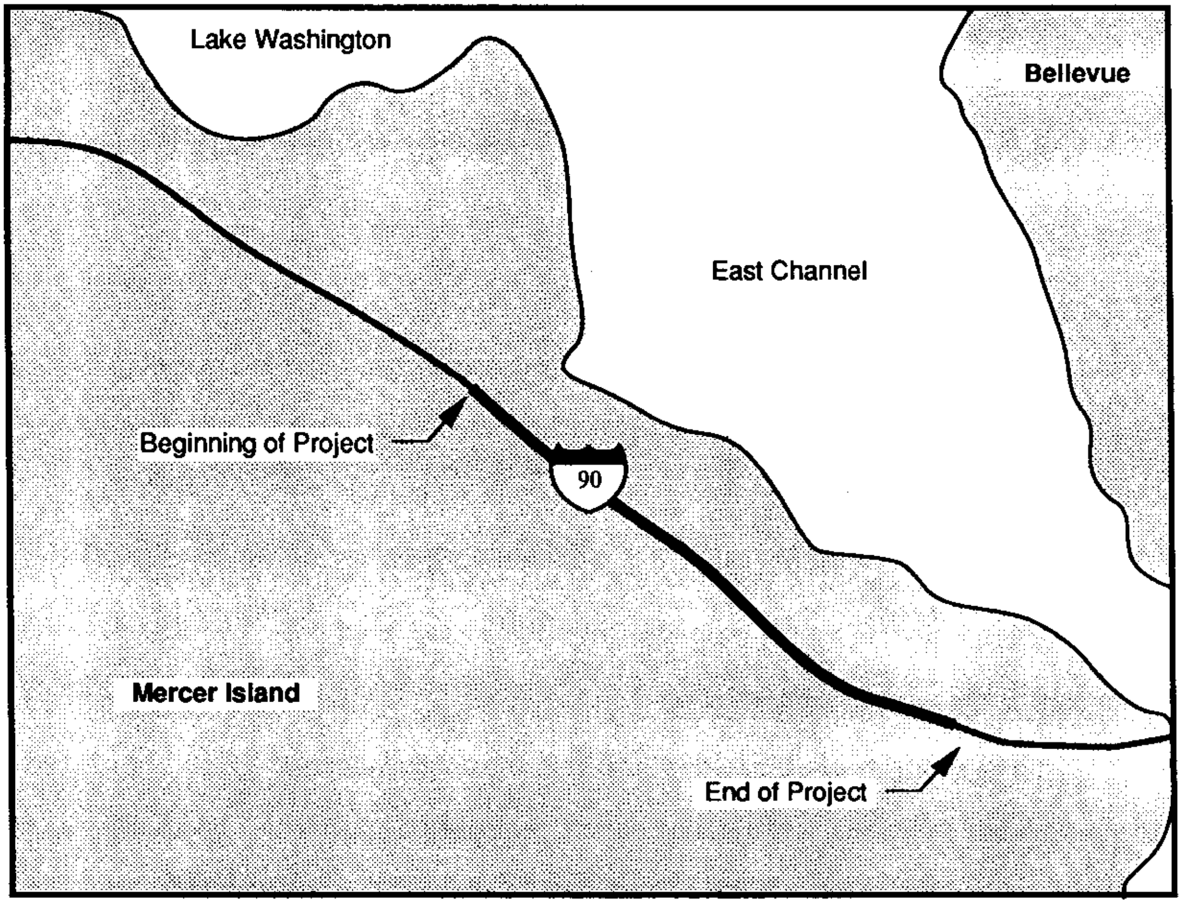


Figure 5. Site Location

for the soldier piles. The anchor tendons were required to meet the ASTM standards for 150 ksi threaded prestressing rod (ASTM A-722) or 7-wire, 270 ksi prestressing strands (ASTM A-416). Anchor tendons were required to have double corrosion protection. The soldier pile wall was tied back with the lowest tieback approximately at the boundary between the soldier pile and slurry wall sections.

WALL DESIGN

WSDOT specifications required that the walls be constructed to resist pressure diagrams of the type shown in Figure 6. A no-load zone of the shape shown in Figure 7 was specified, and tiebacks were required to extend a minimum of 15 ft beyond the no-load zone. Soldier piles were spaced at 5 ft intervals, except in the composite wall section where the spacing was increased to about 8 ft.

RESULTS OF FIELD OBSERVATION

As previously indicated, observation of many tieback characteristics was impeded by construction methods and schedules. Excavation was performed by dozers and backhoes, which considerably disturbed the tiebacks (Figure 8) and usually prevented close, detailed observation when they were exhumed. The construction sequence, during periods of rapid local excavation, often prohibited observation because the ground level was lowered so rapidly that access to upper tiebacks was not possible (Figure 9). At other times, however, the construction process allowed close observation of the type shown in Figure 10.

Fixed Anchor Zone

Generally, the characteristics of the fixed anchor portions of the tiebacks were very difficult to observe because the tiebacks were destroyed during excavation. In general, they appeared to be well-constructed and evenly spaced (Figure 11), though some evidence of uneven spacing due to uneven auger wandering was occasionally observed (Figure 12).

In the great majority of all anchors that could be observed, the anchor tendon was well-centered (Figure 13), though a few cases of uneven centering were also observed (Figure 14). In

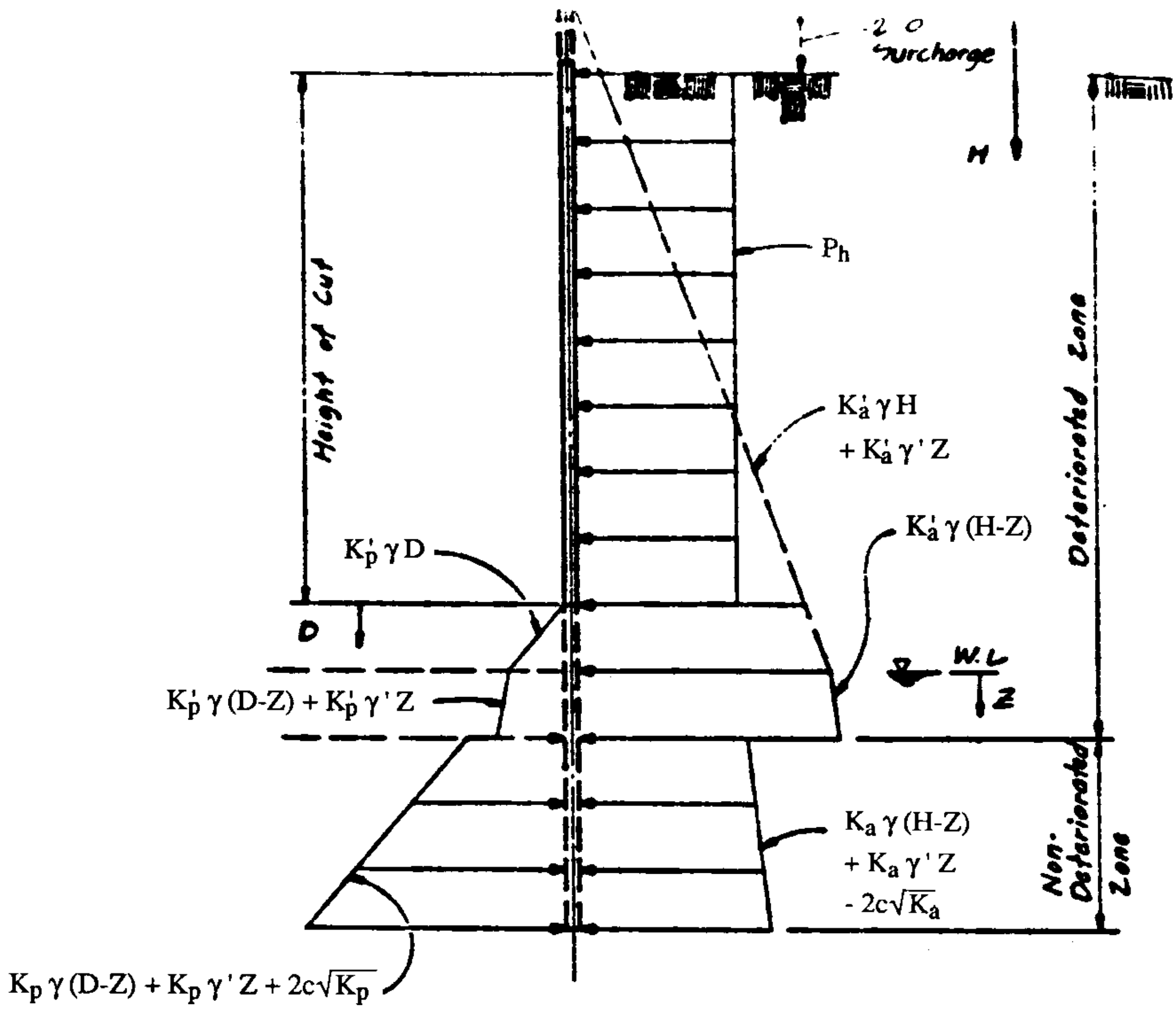


Figure 6. Design Pressure Diagram for Typical Section of Tieback Wall

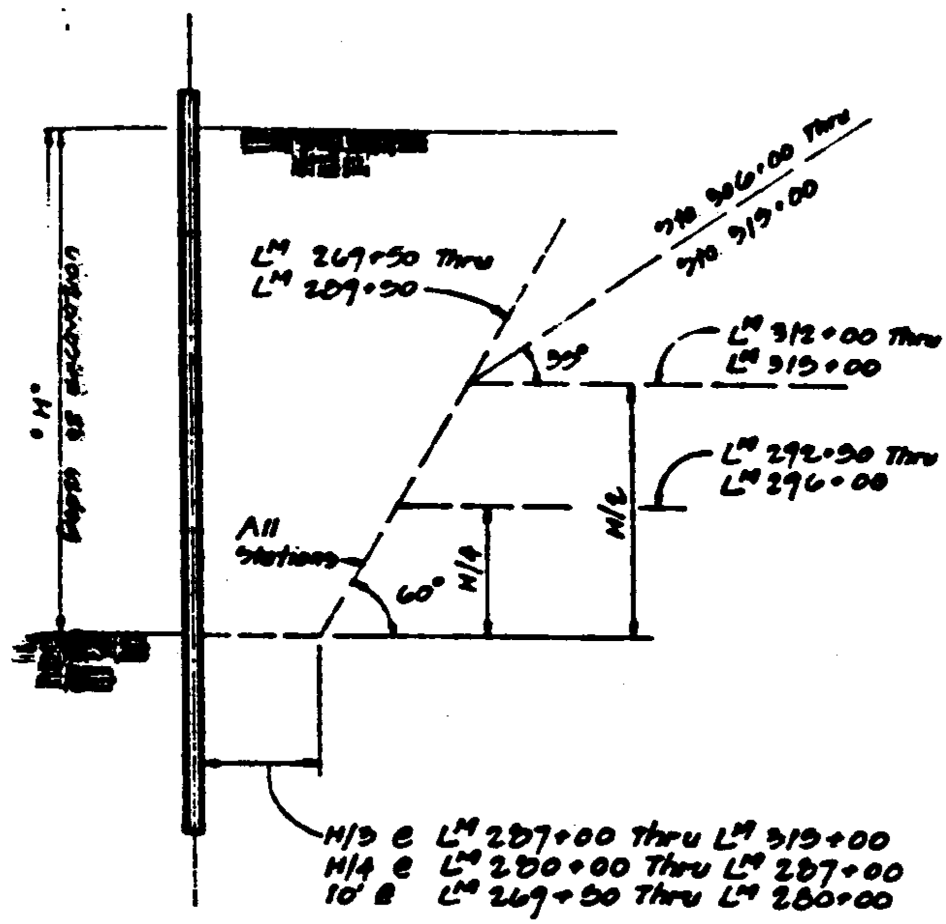


Figure 7. Geometry of No-Load Zone for Typical Section of Tieback Wall

Figure 8. Typical Disturbance Caused by Mass Excavation with Bulldozers and Backhoes

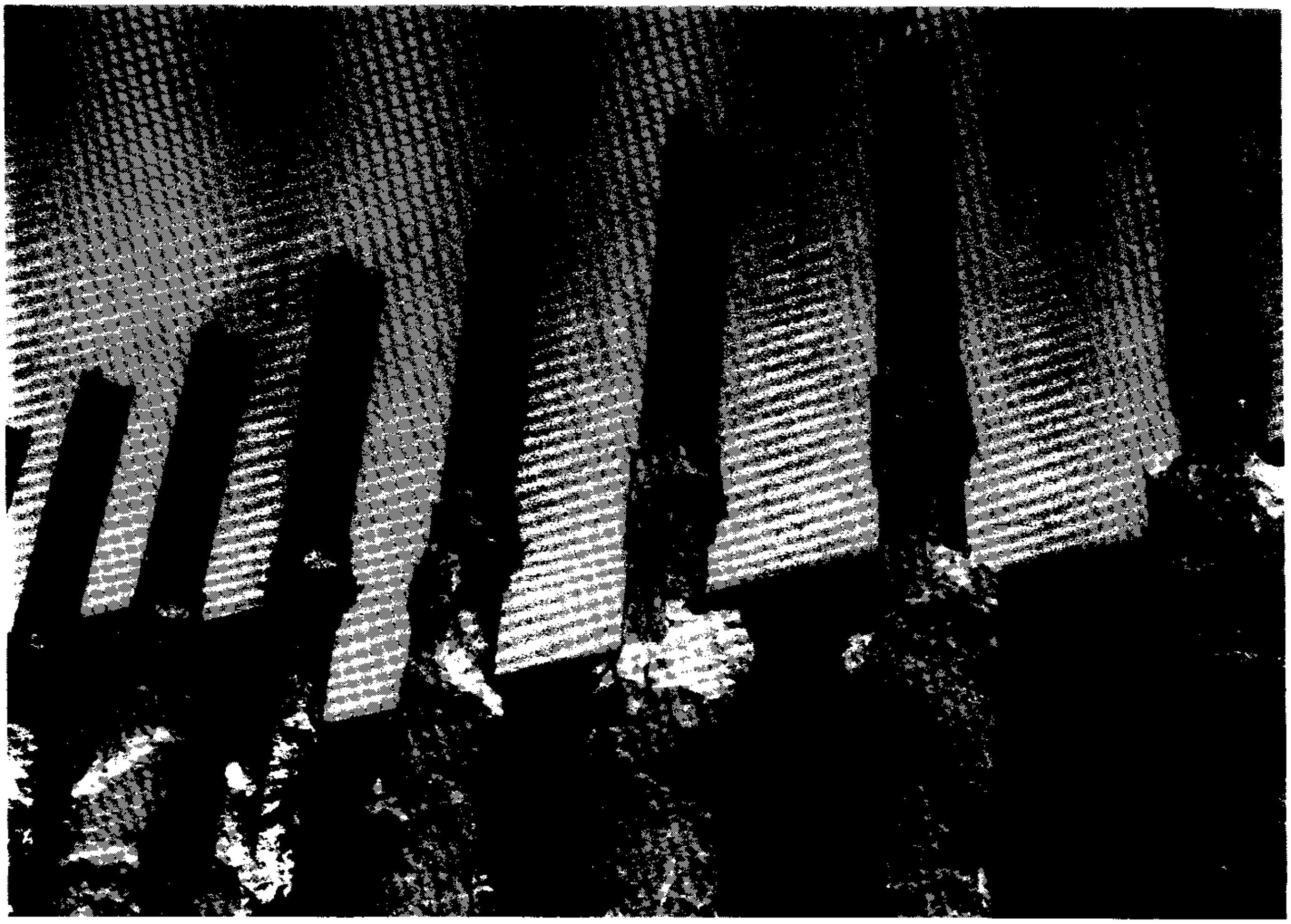


Figure 9. Example of Inaccessibility of Tiebacks Due to Rapid Local Excavation

Figure 10. Close Examination of Tieback Characteristics by Student Assistants

Figure 11. Evenly Spaced Tiebacks at Anchor Zone (Soldier Piles 769-772).
Note proper centering of anchor tendon within grouted anchor.

Figure 12. Unevenly Spaced Tiebacks. Anchor tendons appear to be fairly well centered.

Figure 13. Properly Centered Anchor Tendon

Figure 14. Poorly Centered Anchor Tendon

one location just west of the project site, access to 71 exposed anchors was available for a short period. Observations of anchor tendon centering indicated that 23 (32.4 percent) were virtually perfectly centered, 31 (43.7 percent) were located within one-quarter of the anchor radius of the center of the anchor, and three (4.2 percent) were located farther than that from the center of the anchor. Anchor centering of 14 (19.7 percent) of the tiebacks could not be observed because of excessive excavation disturbance.

No Load Zone

Observation of tendon characteristics in the no-load zone was also difficult. Many of the tendons were mangled (Figure 15) during excavation or cut off so close to the wall (Figure 16) that reliable, consistent observations in the no-load zone were impossible.

Anchor Head/Trumpet Zone

The best observations that could be made were those of the anchor head and trumpet area. In this area, observations of anchor tendon corrosion and grease leakage from the trumpet were possible. Even these observations, however, were complicated by the facts that

- A number of anchor tendons had been exposed to rainfall before they were observed, and
- Many of the anchor tendons were disturbed enough during excavation that observers had difficulty determining whether grease leakage occurred during the period of service of the tieback or during excavation.

As a result, the general state of disturbance of each tieback was also noted to identify any correlation between disturbance and other characteristics. As illustrated in Figure 17, disturbance of the tiebacks ranged from negligible to severe.

For each tieback, the observed corrosion was classified in the field as none, mild, significant, or could not tell. Grease leakage from the trumpet was also field classified as none, mild, significant, or could not tell. Disturbance of the anchor tendon was field classified as none, little, moderate, or severe. As previously mentioned, the three student assistants worked together in the early stages of the project to develop consistent criteria for each of the field classifications. The results are shown in Appendix A and discussed in the following section of the report.

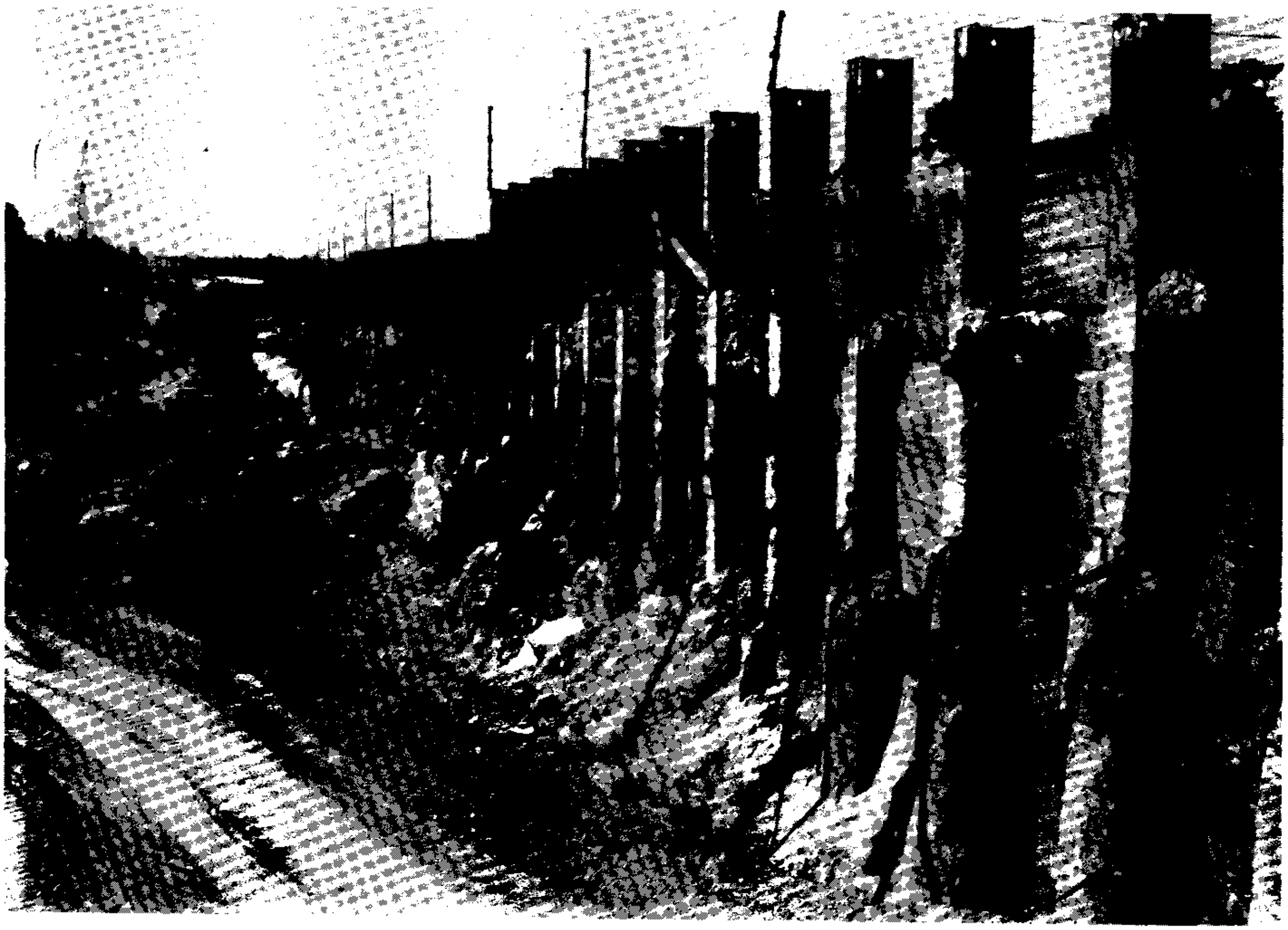


Figure 15. Highly Disturbed Anchor Tendons in No-Load Zone

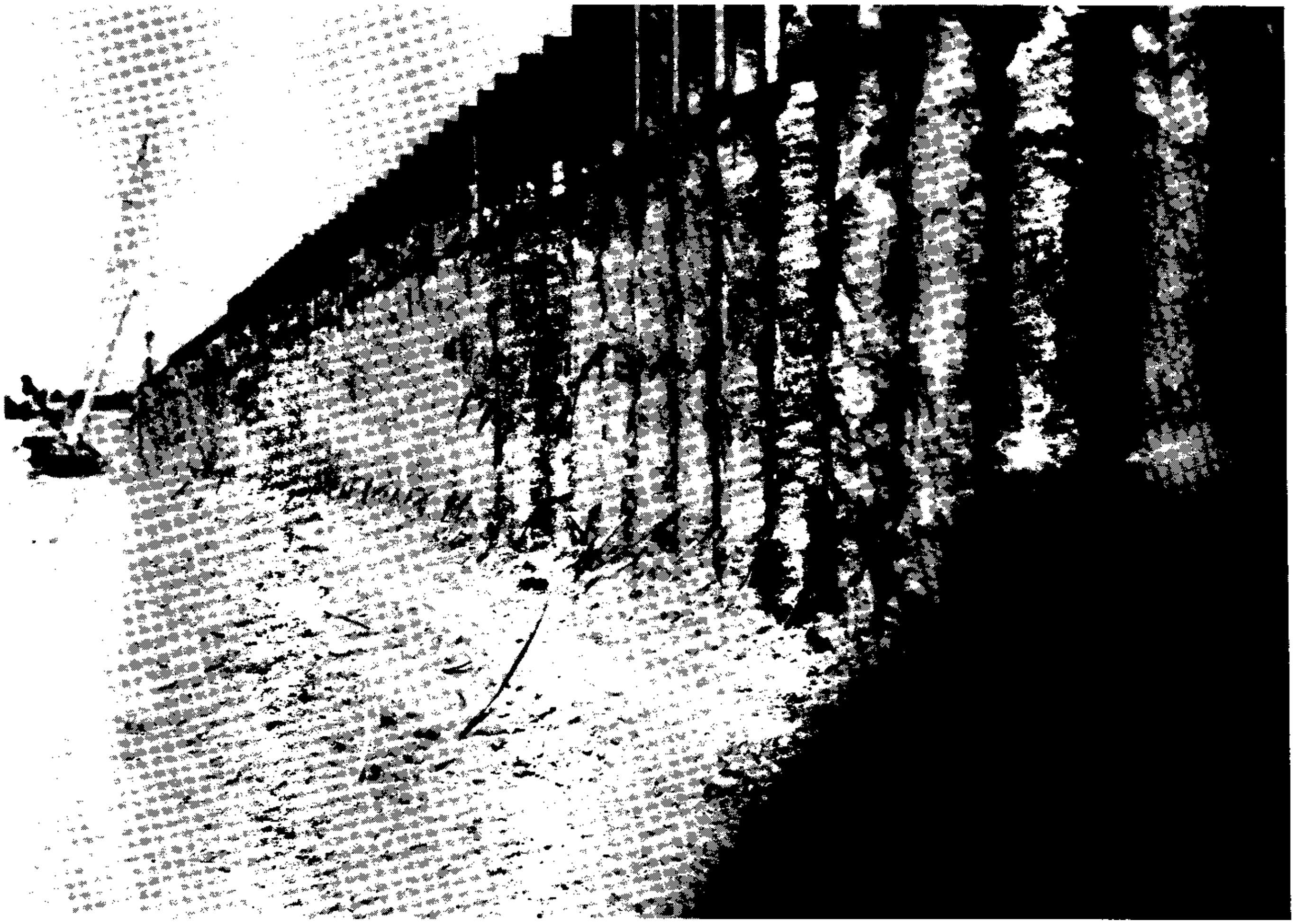
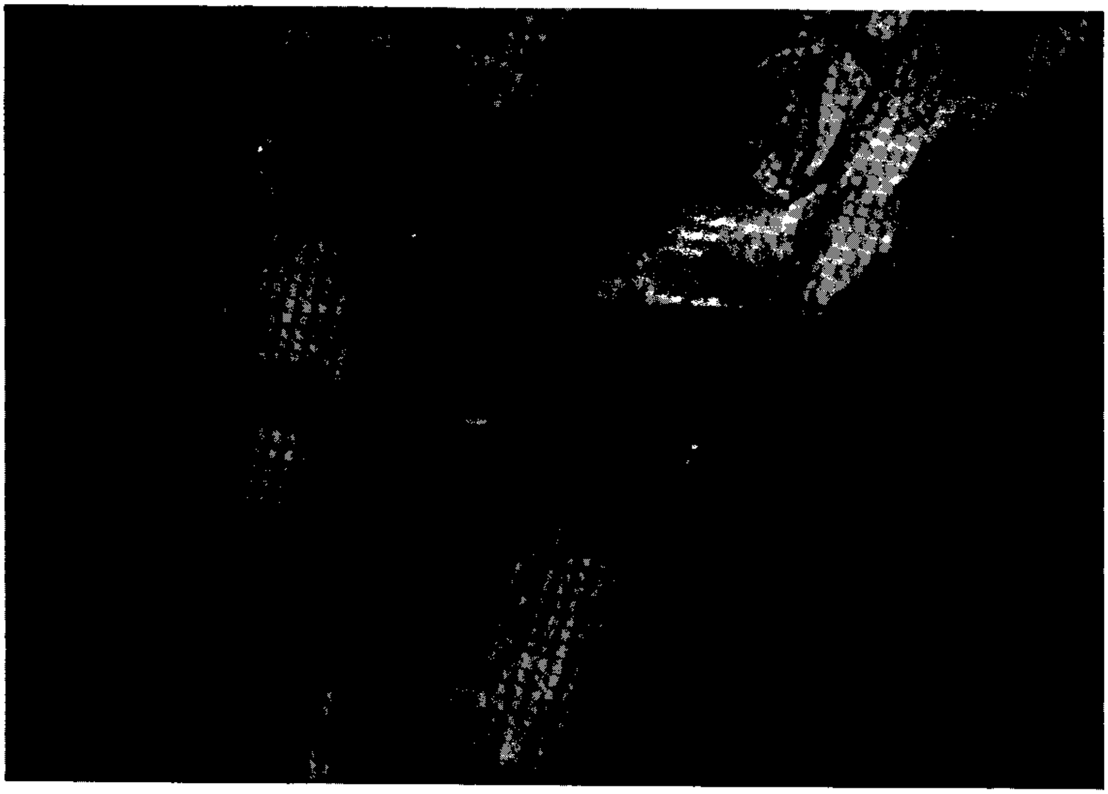


Figure 16. Anchor Tendons Cut Such That Characteristics in No-Load Zone Could Not Be Observed

Figure 17. Variable Tieback Disturbance in Anchor Head/Trumpet Zone

Evidence of corrosion of the outer surface of the trumpet, and of the soldier pile and web stiffeners near it, was commonly observed as illustrated for two unidentified tiebacks in Figure 18. Though some of this corrosion could have occurred after the wall had been removed from service, the locally increased levels of corrosion in the immediate vicinity of the anchor head assembly suggested that most did occur before excavation. In a permanent wall, in which the soldier pile and anchor head would be covered by a cast-in-place concrete facing, much less corrosion would be expected.

a)



b)

Figure 18. Examples of Corrosion in Anchor Head/Trumpet Zone. Notice localized corrosion in vicinity of web stiffeners and on outer surface of trumpets.

INTERPRETATION AND APPRAISAL

The nature and schedule of construction dictated that only qualitative observations of tieback characteristics could be made. Because the influence of weather and tieback disturbance was uncertain, the results of the entire observation program must be considered and interpreted together, rather than as individual observations.

ANCHOR TENDON CORROSION

The observations of anchor tendon corrosion were notable for the lack of significant corrosion. In 375 of the 944 tiebacks that the researchers attempted to observe, it was impossible to determine whether corrosion had occurred. Of the remaining 569 anchor tendons, however, no corrosion was observed in 560 (98.4 percent). Evidence of mild corrosion was observed on only 9 (1.6 percent) anchor tendons, and *significant corrosion was not observed on any anchor tendon.* The distribution of observed tieback corrosion is shown graphically in Figure 19.

TRUMPET GREASE LEAKAGE

Observations of grease leakage from the trumpet, which would indicate increased potential for corrosion in the anchor head zone, were complicated by physical disturbance of the anchor tendon and trumpet during excavation. Figure 20 shows examples where mild grease leakage was observed with little and moderate tieback disturbance. At some locations, it appeared obvious that the observed grease leakage was exacerbated, if not wholly caused, by anchor tendon disturbance. As a result, the grease leakage observations must be interpreted in conjunction with observations of the level of anchor tendon disturbance.

Grease leakage observations were attempted on 995 tiebacks. Observations could not be made on 148 of these, generally as a result of inaccessibility for proper examination.

No evidence of grease leakage was observed for 451 (53.2 percent) of the remaining 847 tiebacks, regardless of the level of disturbance. Mild or significant grease leakage was observed for 274 (32.3 percent) and 122 (14.4 percent), respectively; however, the rate of leakage observation was correlated to the level of disturbance. The results are summarized in Table 2.

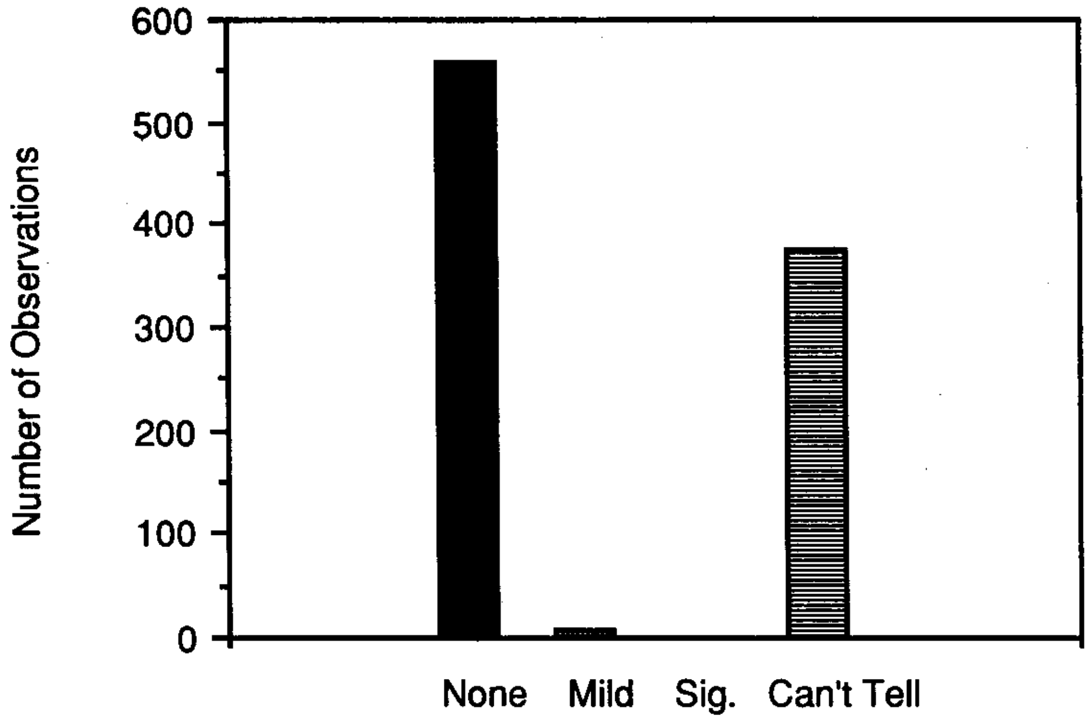


Figure 19. Observations of Anchor Tendon Corrosion

a)

b)

Figure 20. Observations of Mild Grease Leakage with (a) Little Anchor Tendon Disturbance, and (b) Moderate Anchor Tendon Disturbance

Table 2. Correlation Between Amounts of Grease Leakage from Trumpet and Anchor Tendon Disturbance

Grease Leakage from Trumpet	Disturbance of Tie Rod			
	None	Little	Moderate	Severe
None	119	189	107	36
Mild	44	117	73	40
Significant	4	27	41	50
Can't Tell	6	13	45	84

The most useful of these observations were those for which no evidence of anchor tendon disturbance was visible. As illustrated in Figure 21, over 71 percent of the undisturbed trumpets exhibited no noticeable leakage, and only 2.4 percent exhibited significant leakage. Even for those in which significant leakage did occur, evidence of significant corrosion of the anchor tendon was not apparent.

Correlation between the amount of grease leakage and the amount of anchor tendon disturbance was significant, as indicated in Table 2 and in Figures 22, 23, and 24, which show respective grease leakage observations for little, moderate, and severe disturbance. Figure 25 illustrates the distribution of anchor tendon disturbance associated with observations of significant grease leakage. Even for those in which significant leakage did occur, evidence of significant corrosion of the anchor tendon was not apparent.

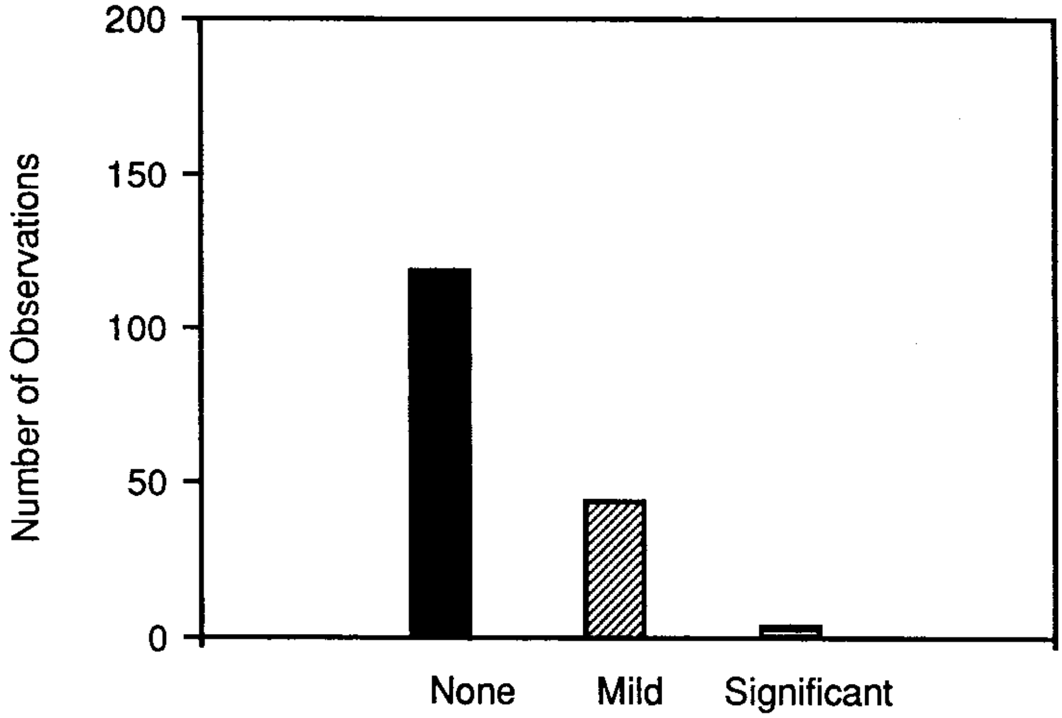


Figure 21. Distribution of Grease Leakage Observations among Trumpets for Which No Disturbance Was Observed

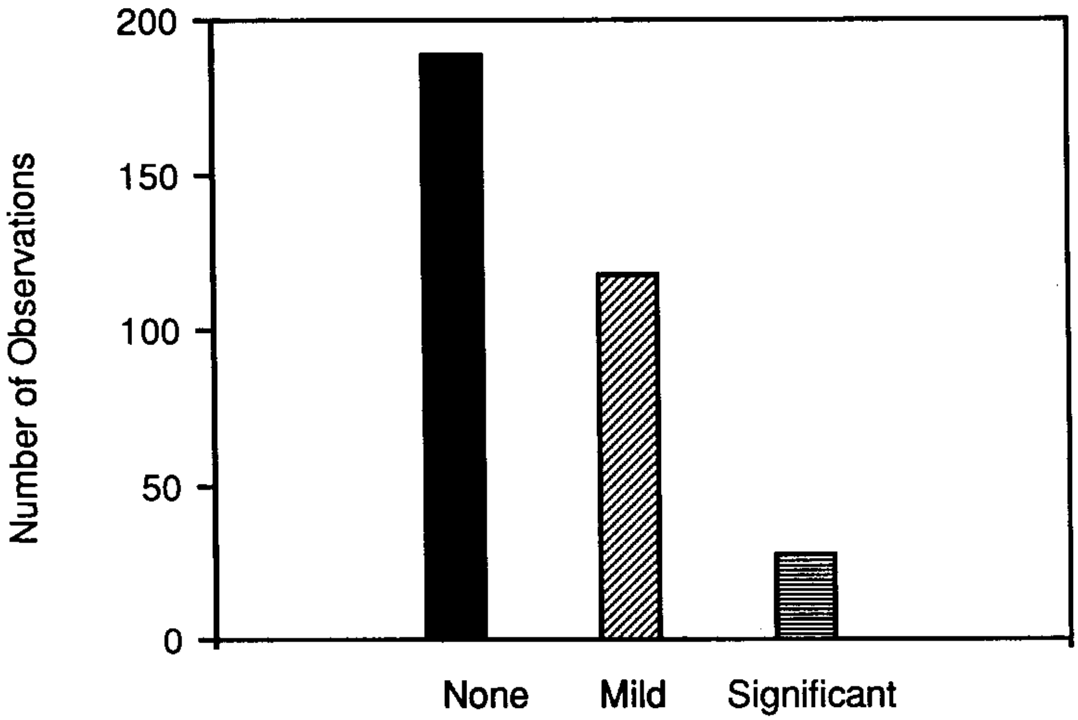


Figure 22. Distribution of Grease Leakage Observations among Trumpets for Which Little Disturbance Was Observed

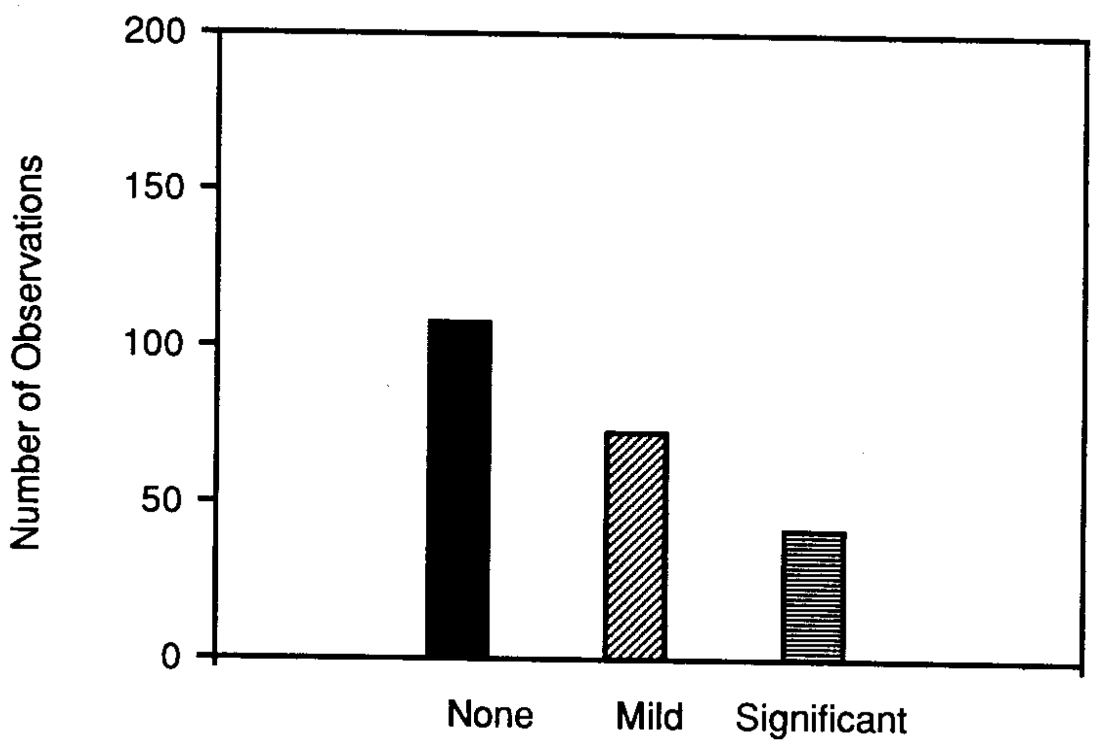


Figure 23. Distribution of Grease Leakage Observations among Trumpets for Which Moderate Disturbance Was Observed

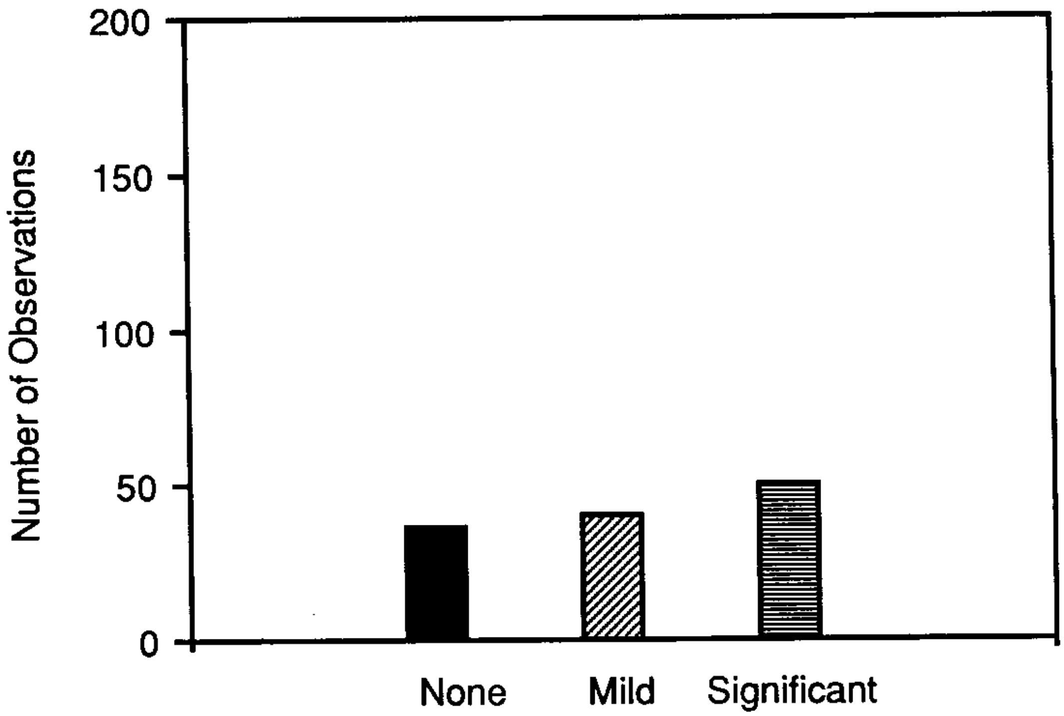


Figure 24. Distribution of Grease Leakage Observations among Trumpets for Which Severe Disturbance Was Observed

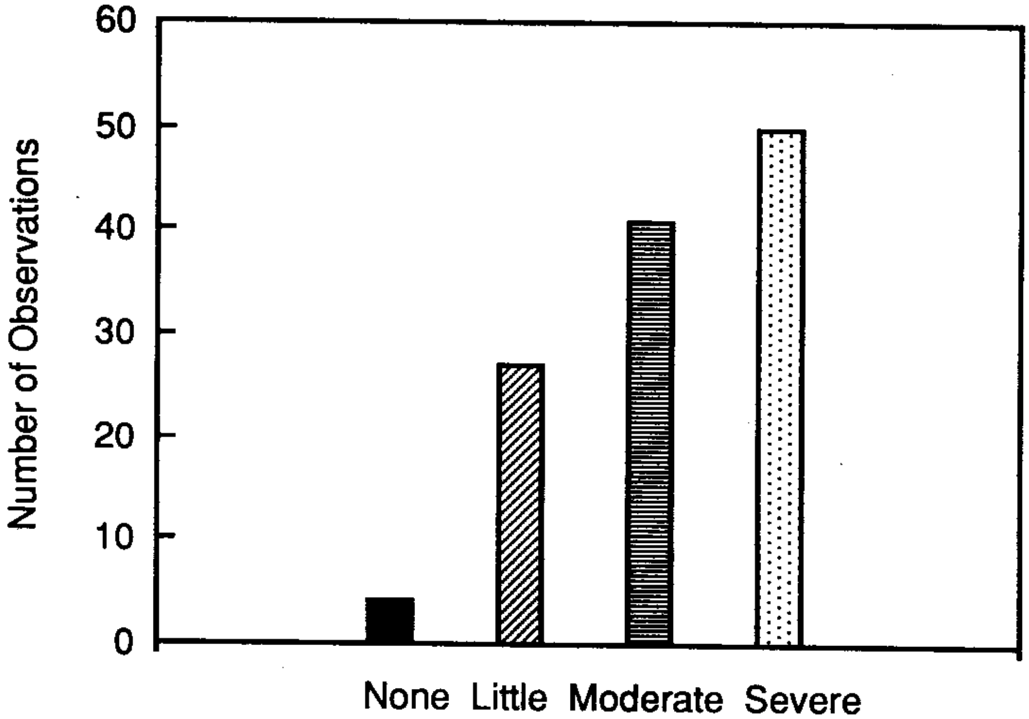


Figure 25. Distribution of Tie Rod Disturbance Observations for Tiebacks with Significant Trumpet Grease Leakage Observations

CONCLUSIONS AND RECOMMENDATIONS

Despite the difficulties of making quantitative measurements and observations of in-situ tieback characteristics in the field, several conclusions can be drawn from the largely qualitative observations that were made.

The geometric spacing of the tiebacks appeared to be generally quite uniform. Wandering of augers during tieback drilling is a commonly observed phenomenon that may be of concern in certain soils. While the absolute magnitude of auger wandering could not be determined in the field, the relative magnitude of wandering appeared to be uniform, i.e., the augered holes wandered by about the same amount and in the same direction.

Centering of the anchor tendon within the augered hole was generally good, although some instances of significantly off-center anchor tendons were observed. Anchor tendons that are badly off-center in the anchor zone may reduce the capacity of the anchor by limiting the capacity of the tendon/grout bond. In tieback designs in which the grout cover is relied on for some degree of corrosion protection, off-center anchor tendons are undesirable both because they lower the thickness of grout cover and because they can lead to increased levels of cracking in the grout.

Significant corrosion was not observed on any of the anchor tendons that could be examined in the field. Though mild corrosion was observed on a very small percentage of anchor tendons, it appeared likely that at least part resulted from exposure to rainfall after excavation. In general, however, the corrosion protection measures employed along the anchor tendon appeared to be very effective.

Evidence of grease leakage at the end of the trumpets was observed at a number of tieback locations. While physical disturbance of the tiebacks during excavation was undoubtedly responsible for much of the observed leakage, leakage was also observed at a number of tiebacks that appeared to be undisturbed. In general, the amount of leakage at undisturbed tiebacks was small, but it was significant at several locations.

WSDOT has been a national leader in the use of tiebacks for excavation support in both temporary and permanent applications. The performance of tieback walls on WSDOT projects has been quite satisfactory and has produced considerable savings on construction costs. On the basis of observations made in the field, no specific changes to the current WSDOT design methods and specifications for tiebacks appear to be necessary.

The importance of properly centering anchor tendons in augered tieback holes, already described in the WSDOT Ground Anchor Inspection Manual, should be re-emphasized to inspectors, particularly those involved with permanent tieback projects.

Specification of a positively sealed trumpet should be considered for all permanent tieback installations. The trumpets observed in this investigation overlapped the outer layer of anchor tendon corrosion protection, but did not use a positive seal. Though the rate of observed leakage was quite small, and though occurrence of grease leakage does not directly lead to the occurrence of corrosion, the potentially dire consequences of corrosion in the anchor head/trumpet area requires that such a specification be considered. As an alternative, grout sealing should also be considered.

IMPLEMENTATION

The research investigation described in this report provided evidence that the current WSDOT design procedures and specifications for tiebacks are generally quite satisfactory. The research did indicate that the necessity for properly centering anchor tendons should be re-emphasized to inspection personnel, and that the use of positive grease seals between tieback trumpets and anchor tendons should be considered for all permanent tieback installations.

Implementation of these recommendations should improve the reliability and performance of tieback supported structures.

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