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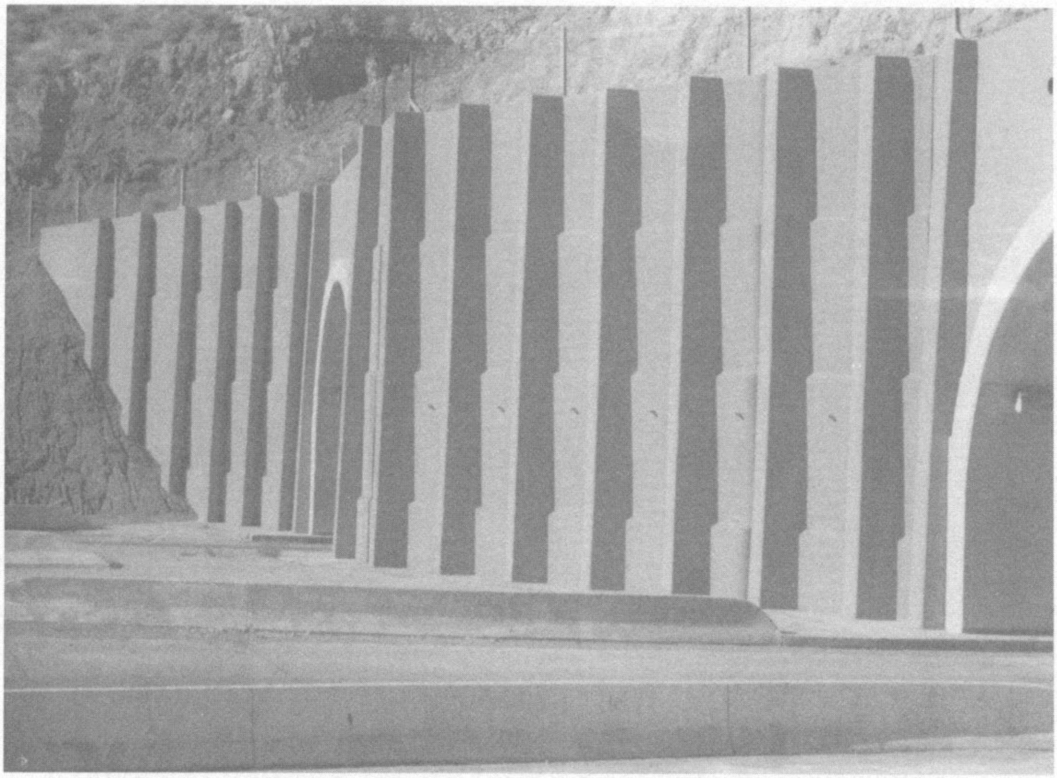
PERMANENT GROUND ANCHORS

Volume 1, FINAL REPORT



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16. Abstract

Ground anchors, often called tiebacks, are structural elements which receive their support in soil or rock and act to retain earth masses and/or applied structural loads. The Federal Highway Administration recognized that the use of permanent ground anchors in highway cut sections could affect substantial benefits in both economy and safety. The specific purpose of the permanent ground anchor demonstration project was to introduce the concept of permanent ground anchor use into American construction practice. A manual numbered FHWA-DP-68-1R and titled "Permanent Ground Anchors" was prepared and several thousand copies distributed to highway engineers. Permanent ground anchors on several projects were monitored to validate the concepts addressed in FHWA-DP-68-1R. This report summarizes the results of both the field monitoring and the history of the permanent ground anchor demonstration project.

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I. INTRODUCTION

Ground anchors, often called tiebacks, are structural elements which receive their support in soil or rock and act to retain earth masses and/or applied structural loads. Temporary ground anchor systems were introduced in the United States several years ago to support excavations while the permanent facility was installed. This temporary support system gained wide acceptance because of economic and safety aspects. However, American engineers hesitated to accept the permanency of ground anchors for a variety of reasons; particularly, a perceived lack of design and construction experience and documented design techniques.

The Federal Highway Administration (FHWA) recognized that the use of permanent ground anchors in highway cut sections could affect substantial benefits in both economy and safety. The economy results from elimination of temporary support systems and reduced right-of-way considerations. Safety is improved by eliminating cramped excavations cluttered with delicate bracing, and reducing the time and area required for standard construction methods. Special benefits accrue in urban areas where adjoining facilities must be supported during construction. Often the area saved by utilizing permanent ground anchors can eliminate the need for underpinning nearby structures.

The specific purpose of the permanent ground anchor demonstration project was to introduce the concept of permanent ground anchor use into American construction practice. A manual numbered FHWA DP-68-1R and entitled "Permanent Ground Anchors" was prepared and several thousand copies distributed to highway engineers. The manual contains a comprehensive review of current design and construction methods. The recommended guideline procedures insure that agencies adopting permanent ground anchors will follow a safe rational procedure from site investigation to construction. Close attention was given to presentation of suggested general specifications and plan details. These contract documents provide the transition from design analyses to field construction and frequently decide the success or failure of new concepts such as this. Every effort was made in these sample specifications to allow the experienced anchor contractor to use innovative methods or equipment in construction. Such specifications are needed to encourage contractors to seek cost-effective improvements to current anchoring methods.

The information in the DP-68-IR report was primarily based on:

1. existing technical literature on ground anchors,

2. reports from FHWA research projects performed from 1979-82, including **FHWA/RD81/150** through 152 (3 volumes), "Permanent Ground Anchors," and **FHWA/RD82/047,** "Tiebacks," (reference copies of

which are available to the public from the National Technical Information Service, Springfield, Virginia, 22161),

3. field inspections of permanent anchor projects during and after construction,

4. cooperative efforts between Federal and State engineers to prepare design calculations, plans, and specifications for pilot test projects,

5. instrumentation of selected permanent anchors.

In 1984, formal presentations of the demonstration project were made to public agencies. The presentation consisted of four, 1-hour segments, which introduced and briefly explained the detailed information contained in the manual. The object of the presentations was to reach as many engineers as possible in a short period of time to promote the concept of permanent ground anchoring. Over 50 demonstration presentations were made in a 2-year period to engineers in 42 States. Figure 1 indicates the States where presentations have been given. In-depth technical assistance was then provided to highway agencies on a one-to-one basis when specific projects arose. Currently, 31 States have either constructed permanently anchored structures, or currently have permanently anchored projects in design. Numerous specialized presentations on construction, inspection, or specification preparation have also been completed. A videotape on construction inspection has been prepared for use by highway agencies.

During the demonstration presentations, several proposed highway projects with permanently anchored structures were identified as candidates for instrumentation and performance monitoring. Cooperative Agreement Work Orders were issued to those agencies. The Work Orders provided a work plan and a schedule for reimbursement of funds necessary to instrument, monitor, and report on the long-term performance of the permanently anchored structures. The period of time for monitoring was generally 5 years or less. Accepted reports from five such demonstration projects are included in the appendices of this report.

Coordination with technical groups has resulted in the preparation of standard specifications to nationally regulate the construction of permanent ground anchor walls. In 1986, the Post Tensioning Institute published "Recommendations for Prestressed Rock and Soil Anchors." More recently, Task Force 27, AASHTO, ARTBA and AGC Joint Committee, has prepared both a construction specification and an inspector's manual for permanent ground anchors. Approval and dissemination by AASHTO of both documents are anticipated in 1990.

II. DESCRIPTION AND BACKGROUND

Within the past 20 years, many ground reinforcement techniques have been successfully introduced to American civil engineering practices after an extended period of use in Europe. The latest and possibly the most significant entrant is the permanent ground anchor. More precisely, the permanent ground anchor referred to in this report is a corrosion-protected, prestressed, cement-grouted tendon which may be installed in soil or rock. Very broadly described, a ground anchor is a device which mobilizes and transfers a resisting force from the ground to a structural element such as a wall or slab. Although similar in function and looks, the permanent anchor, is not to be confused with the temporary tieback or mechanical anchor or resin rock bolt. In the remainder of this report, the word "anchor" when used shall mean permanent ground anchor unless otherwise specifically stated. Figure 2 shows a schematic of a typical anchor.

These anchors are generally inserted in a hole which is drilled or driven into soil or rock. Certain basic anchor terms will now be introduced which will be used throughout this report. Specific anchor details will be reserved for explanation in applicable sections.

Basic anchor components frequently referred to are:

1. The prestressing steel--commercially available in single or multiple wires, strands, or bars comprising:

   a. the bond length--that portion of the prestressing steel fixed in the primary grout bulb, through which load is transferred to the surrounding soil or rock, and

   b. the unbonded length--that portion of the prestressing steel which is free to elongate elastically and transmit the resisting force from the bond length to the structural element (i.e., the wall face, etc.).

2. The anchorage--a device usually consisting of a plate and an anchor head (or threaded nut) which permits stressing and lock-off of the prestressing steel.

3. The grout--a portland cement based mixture which provides corrosion protection as well as the medium to transfer load from the prestressing steel to the soil or rock.

Anchors were introduced in the 1930s and, by the 1960s, were in common use for major structures of all types. The keys to successful widespread use in Europe were both social and technical. The scarcity of land available for construction, particularly in urban areas, required excavation and retention techniques that could be accomplished with minimum disturbance to land owners or the traveling public. Anchored walls substantially reduced the amount of land required for construction while also reducing the project cost. Equally as important was the assurance that this technique was safe and could be easily controlled in construction. European engineers spent many years developing and refining public design and construction codes for anchors. Based on field experience and long-term observation, these codes guaranteed the safety of each anchor by requiring testing to beyond proposed design loads. Continuing historical development now relates mainly to refinement of corrosion protection systems, load transfer of anchor forces into the ground, the form of tension members, and grouting methods. In some countries, anchor contractors must pass acceptance tests before being allowed to install anchors. These acceptance tests involve installing and excavating, for government inspection, a large number of anchors according to the prevailing code. The data from such tests, although very costly, has contributed much to the development of anchor use worldwide.

Until the late 1970s, the only common use of anchors in the United States was to support temporary excavations. Although the United States' first permanent soil anchor was installed in Detroit, Michigan, in 1961, relatively few public agencies had incorporated anchors in major permanent structures as of the inception of this demonstration project. The reasons for this hesitancy were:

1. the scarcity of American anchor design and construction experience; i.e., how do we design it and who can we trust to properly install it?

2. the concern of anchor permanency against long-term corrosion or creep; i.e., how long will anchors last and safely carry design loads?

3. the delineation of proper areas for cost-effective application; i.e., where and how many do we use?

4. the constraints of contracting procedures used by public agencies; i.e., how do we insure quality from the low bidder?

In 1979, FHWA Demonstration Projects Division (FBWA-DPD) authorized project development to begin on the permanent anchor project. A project manager and a technical advisory committee were appointed. A work plan was developed to study existing anchor technology and installations; determine areas where additional work was needed; update existing technology; prepare a basic design manual; and solicit test installations on highway projects. The objective was to provide highway agencies with adequate knowledge to permit confident, routine use of permanent anchors.

III. PROJECT DEVELOPMENT

Resolution of Technical Concerns

A review of existing technical literature on anchors confirmed that most work had been done by the Europeans. Unfortunately, little documentation of design methods for anchors was available. This information void was a direct result of how anchor work was contracted for in Europe. Nearly all European anchoring is done on a design-construct, turnkey basis by specialist firms who, in many cases, are pre-qualified to do anchor work by the government. These firms have developed proprietary design and construction procedures which are not released even to their clients.

For successful introduction of anchors into the United States, the contracting approach promoted by the demonstration project would need to conform to the current competitive bid procedures used by State agencies. This approach required both general design guidelines and a detailed construction specification. A three-pronged path was chosen which involved initiation of research in design aspects, field inspection of on-going permanent anchor construction projects, and development of an easy-to-understand yet comprehensive construction specification.

In 1980, two basic design questions remained to be answered before the demonstration project could proceed--documentation of both techniques to determine anchor capacity and longevity aspects of both anchor materials and bond strengths. The former question was addressed by awarding research contracts to three experienced anchoring firms--Soletanche-Rodio, Nicholson, and Stump-Vibroflotation, who independently prepared design manuals respectively numbered FHWA RD 81/150; 81/151; and 81/152. Each manual contained a detailed explanation of the firm's general design procedure as well as three documented case histories illustrating use of the design procedure and the computations for a test project provided by FHWA. Although each firm used different analyses, the basic method of design was the same; i.e., the critical failure surface was located and the bond zone of the anchor founded beyond the failure plane. Load testing of all installed anchors was considered an extension of design as no design method existed to reliably predict, from subsurface data, the exact bond zone dimensions necessary to safely carry a particular anchor load. These two concepts provided the basis for the current anchor design practice in the United States.

The longevity aspects were addressed by the Schnabel Foundation Company in FHWA RD 82/047, "Tiebacks." In this publication, methods of corrosion protection for permanent anchors were detailed and recommendations given as to their use. The creep behavior of anchors was also thoroughly investigated. Specific recommendations were presented for anchor testing procedures and acceptance criteria to insure long-term anchor load capacity at acceptable deflections. Lastly, contracting guidelines for permanent anchor work were presented. Important concepts such as pre-qualification of anchor contractors, performance-type specifications, and shared design responsibility between owner and contractor were recommended for reliable, cost-effective anchor work.

In reviewing the uses of permanent anchors, the permanently anchored retaining wall application was by far the most common and economically attractive. A decision was made to concentrate the design section of the FHWA DP 68 manual on permanent anchor wall design. The design procedure initially adopted for the demonstration project relied heavily on concepts developed from braced wall systems as well as the aforementioned research efforts. In technical areas where conflicting observations or theories could not be resolved, the design procedure chose the more conservative position. The rationale for this decision was that instrumentation of initial anchored wall installations would be encouraged. Highway agencies could then compare actual measured parameters with assumed. As a database was developed, various parameters could be confidently changed to less conservative values.

In 1979-80, concurrent with the above research efforts, the Post Tensioning Institute formed an ad-hoc committee to revise the existing guidelines for anchor use. The committee was composed of anchor contractors, producers, consultants and users. The resulting publication, "Recommendations for Prestressed Rock and Soil Anchors," printed in 1980 and revised in 1986, established national standards for design and construction of anchors. These standards, which were written in a simple format, were adopted by many private and public organizations as the basis for their construction specifications. Much of the information in this publication was used to develop the guideline permanent anchor specification for the demonstration project.

The resulting construction specification, published in the FHWA DP-68 manual for permanent anchors, was a performance-based specification. This type of specification was a departure from the prescription-type specifications used by public highway agencies on other highway items. The proposed anchor specification contained some prescription verbiage to control the materials used and certain basic construction operations. However, the contractor was permitted, with few constraints, to choose and control the method of drilling, the tendon type, the drilled hole diameter, the bond zone dimensions and the total anchor length. The performance aspect was that the contractor was responsible to produce an anchor which would pass certain acceptance test criteria established in the specification before receiving payment for the anchor. In short, the contractor was responsible for determining anchor installation procedures to obtain a desired anchor capacity selected by the agency.

The key element in the performance specification was pre-qualification of the contractor who would perform the anchor work. Permanent anchoring was recognized by researchers, technical groups, and construction inspectors to be a specialty type of work. Furthermore, successful introduction of permanent anchoring into highway agencies depended on their first project being a success. Few agencies had any construction personnel who were knowledgeable of proper permanent anchor construction techniques. Specifying a specialist would permit the construction personnel to observe proper techniques and develop inspection expertise which could be used on later projects where the agency relaxed the pre-qualification criteria.

Cost-Effectiveness of Permanent Anchors

After technical concerns had been addressed to the satisfaction of the technical advisory committee, the permanent anchor technology was ready to be disseminated. Early in the demonstration project, data had been collected from a few permanent anchor projects done prior to 1980, which indicated the per-square-foot wall cost to be between $30 and $40. At that time, standard concrete retaining walls in cut situations were averaging about $75 per square foot. However, the cost effectiveness of the design technique and the performance specification approach needed to be demonstrated before promoting routine consideration of permanent anchor systems nationwide to highway agencies. A review of cost data from a few private and public anchor wall projects indicated a cost of about $45 per square foot of wall face. Two State highway agencies, Georgia and Maryland, were identified by FHWA regional geotechnical engineers as having projects in design which were appropriate for a permanent anchor alternate design.

The project manager provided design computations, plans, and specifications for an alternate anchor wall design at both locations. In Georgia, both the alternate anchor wall design and the standard Georgia DOT retaining wall design were included in the contract documents for the I-75 project with instructions that contractors were to bid one or the other. The final bid tabulation showed that seven of the eight contractors who submitted bids (including the low bidder) had selected the alternate anchor wall design. The bid price for the anchor wall alternate was about $36 per square foot; about 40 percent lower ($410,000) than either the "as bid" or Engineers' estimate for the standard Georgia retaining wall. In Maryland, the estimated cost of the anchor wall design was so much less than the standard design that the standard design was deleted from the contract. The "as bid" price for the anchor wall was about $36 per square foot; a savings of approximately 40 percent ($461,335) over the conventional design. Two anchor walls constructed in Washington State during the same time period had bid prices between $41 and $44 per square foot. It was evident that a permanent anchor wall design was economically competitive with standard designs currently in use for walls in cut.

Permanent Ground Anchor Manual

In 1984, FHWA-DPD published definitive recommendations in DP-68-1, "Permanent Ground Anchors," to answer those previously stated concerns of public agencies who were hesitant to specify permanent anchors. This manual presented, in detail, all basic concepts necessary for a highway agency to incorporate permanent anchors on a project. Chapters were included on application criteria, site investigation, principles of anchor design, corrosion, anchored system design, load testing/stressing, preparation of plans/ specifications, and construction control. The manual was organized in a manner consistent with the phases of a typical highway project. The emphasis in the manual was on identifying applications where anchors could be used successfully; providing a rational, step-by-step procedure for producing a safe, yet cost-effective design; and establishing basic construction controls to assure a quality final product. The final section of the manual contained a sample problem and detailed numerical solution which demonstrated the use of the information presented in the preceding chapters.

As clearly stated in the abstract, the manual was not intended to present state-of-the-art procedures, but rather to serve as an introduction to basic anchoring concepts. The objective was to present basic information in simple, straightforward terminology to provide the practicing highway engineer with adequate knowledge to successfully contract for permanent anchor work.

Demonstration Project Accomplishments

The project accomplishments can be measured in terms of technology transferred to highway agencies, number of highway agencies adopting permanent anchors for routine highway applications, performance of anchor walls designed based on the guideline procedure, and cost effectiveness of permanent anchor designs nationwide.

Technology transfer is an important element of any demonstration project. Presentations of permanent ground anchor technology were requested and completed in 42 States to over 3,800 engineers while the project was active. The project manual, "Permanent Ground Anchors," was reprinted three times due to heavy demand, with about 5,000 copies being distributed nationally. The manual is currently available from the National Technical Information Service, Springfield, Virginia 22161, under accession number PB85 1780107/AS. In addition, about 500 copies of both the research publication "Tiebacks" (FHWA RD82/047) and the Post Tensioning Institute's "Recommendations for Prestressed Rock and Soil Anchors" were distributed nationally to highway agencies.

At the inception of the project, only three State highway agencies were employing permanent ground anchors on construction projects. The project manager provided detailed technical assistance to those highway agencies interested in alternate designs involving permanent anchors. This assistance involved preparation of typical design computations, specifications and plans for specific projects, or review of consultant-submitted designs. At present, 31 States are using permanent anchors; nearly all are using the design procedures outlined in the FHWA DP-68 "Permanent Ground Anchor" manual. All walls constructed using these design procedures have performed satisfactorily after construction. No walls have failed to perform their design function, whether the project involved restraint of adjacent buildings, highways or utilities. The design method has been proven to produce a stable wall system in a variety of imposed loading situations. The only question which remains to be answered by future observation and research is the degree of conservatism of the method. In the March 1988 reprinting of the "Permanent Ground Anchor" manual, the minor changes that were made to the example problem design procedure were the result of observations of the performance of recently constructed anchor walls.

Interestingly, the cost effectiveness of permanent anchor walls, even those designed by the admittedly conservative, original procedure in the manual, far exceeds that of other possible wall designs in cut situations. Other changes may result when additional research is completed and evaluated by highway agencies.

Some highway agency engineers were reluctant to specify a new technology which did not have a history of use in their State. To address these concerns and to stimulate highway agency interest in permanent ground anchors, the Demonstration Projects Division offered to provide funds for instrumentation and long-term evaluation of anchor walls. The objectives of the performance evaluation were both to prove to the agency that permanent anchors did perform in the long term and to provide highway agencies with hard data which could be used to refine their design procedures. The 8 projects selected for construction monitoring cost $406,475 to instrument and evaluate. The reported savings from 4 of these projects totaled nearly $20 million.

In the past 10 years, the total square footage of permanent anchor walls being constructed has increased dramatically. The first anchor wall projects were scattered geographically and involved wall areas less than 20,000 square feet. Recent projects, such as I-215 in Salt Lake City, Utah; I-90 in Seattle, Washington; I-10 in Phoenix, Arizona; and I-20 in Dallas/Ft. Worth, Texas, all involved wall areas greater than 100,000 square feet. Even relatively small anchor wall projects such as I-90 in Wallace, Idaho, and I-35 in Duluth, Minnesota, contained in excess of 40,000 square feet of permanent anchor wall.

In 1989, 2 million square feet of anchor wall construction is projected. Based on previously documented savings, this wall area use translates into a savings in excess of $70 million in 1989.

As highway agencies began adopting permanent anchor walls into routine project designs, the emphasis in the demonstration projects shifted to construction control. During 1986-88, the project manager completed presentations to construction inspectors in 15 States. These efforts were usually done at the project site just after construction had begun, both to determine which methods the contractor would use and to allow inspectors to identify areas where training should be focused. Frequently, the contractors' personnel were invited to attend these presentations to see the inspection procedures which would be used on the project.

Continuing Developments in Permanent Anchors

By design, the purpose of a demonstration project is to introduce new technology into routine use by highway agencies and establish national guidelines for safe, cost-effective use of the technology. On October 1, 1988, those goals were judged by FHWA to have been fulfilled and subsequently the permanent ground anchor project was removed from active status. However, by the latter stages of the project, involvement was sought of other technical groups within the highway community to control the future direction of permanent anchoring.

The AASHTO-AGC-ARTBA Joint Committee Task Force 27 on Ground Modification was formed on the recommendation of FHWA. A ground anchor group has been formed within the Task Force to develop future design and construction standards. The intent is to provide AASHTO with standards for national distribution. Currently, three efforts are underway in the group. A permanent ground anchor generic specification, a ground anchor construction inspection manual, and a design guide for build-down retaining walls. The specification has been approved by the Task Force and sent to AASHTO for approval. The inspection manual and design guide were submitted to the Task Force for approval in early 1990.

The increase in permanent anchor use has generated many new questions about anchor design and construction techniques. However, unlike the early research efforts for this project, these questions relate not to proving whether anchors work but to refinements to optimize current procedures. Highway agencies who have adopted permanent anchors into routine construction practice have initiated operational research which will lead to either improved techniques or increased anchor usage. An example of these efforts is the Washington State DOT study on seismic response of tieback walls. The objective of this study is to expand anchor use into seismically active areas by developing rational modifications to current static design procedures. An upcoming major study, funded by FHWA's Office of Research in 1989, will focus on refinement of those design factors dealing with soil-structure interaction. Items such as bond zone load transfer factors, earth pressure distribution, and soldier pile design are expected to be analyzed.

In regard to national standardization of anchor testing procedures, the American Society of Testing Materials (ASTM) has formed subcommittee D18.11. The goal of the subcommittee is to prepare an ASTM standard for tensile load testing of individual anchors. The standard will include details of the apparatus used to apply and measure the load, the apparatus for measuring movements, the loading procedure, safety requirements, and recording of data. An appendix on proper presentation of test data will be included.

Although **FHWA's** role in actively promoting permanent ground anchor use has been phased out, the interaction during the preceding years with other technical groups has insured continuing national development of anchor technology in the future. FHWA will continue to provide technical assistance on future anchor designs or technical reviews of new anchor technology. The role of continued promotion and development rests now with the technical groups of the highway community.

IV. DEMONSTRATION PROJECTS SUMMARY

One of the objectives of Demonstration Project No. 68 was to convince highway agencies to monitor construction performance and long-term behavior of permanent ground anchored structures. Seven States participated, each application varying some degree from the other either in terms of soil conditions, anchored wall design, or anchor type. Detailed reports by the project's principal investigators of the results of instrumentation and interpretation of wall performance are included in the appendices of this report, except for the Pennsylvania DOT tied back abutment project which was only constructed in 1988. The following executive summary of each project highlights basic design and construction information as well as the primary conclusions for each project.

Widening of Existing Urban Interstate Highway
I-75, Atlanta, Georgia

The widening of I-75, which is in a cut section through downtown Atlanta, presented several major problems such as very limited right-of-way, existing utilities and buildings, traffic maintenance of 100,000 vehicles per day, and a short time-frame for construction. A permanent anchored wall design was selected for use in a critical area near 5th Street, where 30-foot high cuts would be required near existing facilities. The general soil conditions consisted of varying mixtures of micaceous sands and silts over bedrock. These soils are frequently described as saprolite which denotes residual products of rock decomposition where deep rock weathering has occurred in a wet, humid climate.

Demonstration project funding for instrumentation, interpretation, and reporting on wall performance was provided in July 1981 to Georgia DOT under a Cooperative Agreement. In turn, Georgia DOT contracted with Law Engineering/Geoconsult International to perform most of the prescribed tasks in the Demonstration Project

Cooperative Agreement. The principal investigators were Messrs. David Mitchell of Georgia DOT and Thomas Richardson of Law Engineering Consultants. A special task, unique to this first ground anchor demonstration project, was development by a specialist of a basic, reliable instrumentation plan for permanent ground anchor systems. The intent was to develop, install, evaluate and, if successful, recommend this instrumentation package on future anchor installations. The instrumentation report prepared by Mr. John Dunnicliff is attached to the Georgia I-75, Atlanta report in the appendix.

Figures 3A to 3E show three stages of construction of the anchored wall including the finished product in 1984 and 1988. All visual observations and instrument measurements confirm that the wall and anchors are performing as anticipated in design. Long-term measurements were taken on 60 vertical and horizontal survey points established on or behind the wall during construction. The measurements showed that the movements which occurred indicated active earth pressure conditions and ceased shortly after construction was completed. The survey points still available for reading indicate no definable wall or ground movement has occurred since 1983.

The measurement of anchor load in selected tendons has been done periodically since 1983, Three different instruments were used to monitor load--load cells, rod telltales, and wire telltales. Strain gages were not used due to problems involving both attachment to the prestressed strand tendon and the range of expected microstrains. Although erratic readings were noticed in various instruments during construction, those instruments which have continued to function to the present indicate that the load carried by the anchors has remained relatively constant, with a range of only 3 kips. A few anchors stabilized at loads which were slightly higher or lower than the lock-off load, indicating variance with the magnitude or distribution of assumed lateral earth pressure at that location. These variations had no effect on wall performance.

Since completion of the I-75 anchored wall at 5th Street, Georgia DOT has completed permanent anchor walls on 12 other highway projects in the Atlanta metropolitan area. The success of permanent anchor construction has caused Georgia DOT to routinely permit alternate designs involving anchored walls on highway projects.

Repair of Urban Interstate Highway Retainina Wall I-95, Baltimore, Marvland

In 1974-75, a 900-foot long wall with a maximum height of about 25 feet was built to retain an earth cut for Interstate 95. A steep natural slope rose from the top of the wall to the nearby Mount Carmel Cemetery. The natural surface drainage of this area was toward the wall. In addition, the subsurface drainage from the temporary cut face indicated a groundwater flow toward the wall. Unfortunately, during wall construction, a clay material was placed as backfill for the wall, effectively preventing any drainage. Over a 4-year period, the natural water surface behind the wall rose from below the wall footing to within 1 foot of the backslope surface. The hydrostatic pressure increase caused substantial movement of the wall. Spalling of wall joints and base translation caused an upheaval of the I-95 pavement when the passive resistance in front of the wall was exceeded (see Figures 4A-4B). Slope inclinometers, which were installed shortly after movement began, showed the location of the active and passive failure surfaces.

The State immediately installed horizontal drains to lower the water level and temporarily stabilize the movement. Analysis of the structural condition of the wall disclosed no major planes of weakness. A lateral earth pressure analysis disclosed that additional lateral assistance was required to establish an adequate minimum safety factor of 1.5 against future sliding. The method chosen for wall repair could neither disturb the ground behind the wall nor infringe on the safe clearance distance to the I-95 pavement. The Interstate Division of Baltimore City, which had responsibility for design, selected a permanent anchor repair solution.

The stability of each wall panel was determined by lateral earth pressure analysis for the worst hydrostatic condition. From this analysis, the additional amount of resisting force was computed for each panel to ensure a 1.5 safety factor. The soil conditions behind the wall indicated that the anchors could safely develop a design capacity of 50 tons. The number of anchors per panel was determined by dividing the total additional required resistance in each panel by the design anchor load of 50 tons and rounding it off to the next whole number. The anchors were located at the required resultant pressure point on each panel.

The specification for the permanent anchors contained a prequalification clause to ensure that only an experienced permanent anchor contractor was permitted to bid the work.

The performance-type specification also allowed the contractor to choose the most appropriate anchor type, dimensions, and installation procedure to achieve the required design load. A patented anchor type known as TMD was selected by the contractor as the best method to achieve the design load in the project soils (see Figure 4C).

The TMD anchor has a substantial advantage over the other anchor types installed in cohesive soils in that several stages of grouting and regrouting can be performed in each anchor to develop he required capacity. High pressure grouting in cohesive soils must be done with care as application of excessive pressures will fail the clay surrounding the bond zone, resulting in very low anchor capacities. All 98 anchors on this project achieved the desired test capacity and were accepted (see Figure 4D). After lockoff, all anchor heads were encapsulated with plastic, greasedfilled caps to prevent corrosion (see Figure 4E). The FHWA-DPD funded monitoring equipment for the wall to assess long-term performance of the permanent anchor solution. The final report, which is included in the appendix, indicates that wall movement has stabilized and the anchors are performing successfully.

The benefits of performance-type specifications containing a pre-qualification statement were shown on this project. The work was professionally and cost effectively completed within the allotted time frame. The Interstate Division of Baltimore City project engineer could not remember a project where better relations existed between the contractor and the State.

In December 1981, a Cooperative Agreement was signed with Maryland DOT to document wall behavior. The performance monitoring and reporting for the permanent anchor wall instrumentation were done by the Schnabel Foundation Company with Messrs. David Weatherby and Harold Ludwig as co-principal investigators. The installation and monitoring of slope movement and water levels at the wall site were handled for Maryland DOT by Messrs. Paul Wardenfelt of the Interstate Division of Baltimore City and David Martin of the Bureau of Soils and Foundations, as co-principal investigators.

The data obtained from this instrumentation was significant in several aspects. The major concern for using anchors at this site was the presence of fine grained soils in the anchor bond zone. The anchor instrumentation verified that these soils could safely withstand the required anchor loads without deflection. However, the selection of the proper anchor type played a significant role in obtaining the necessary capacity. The performance specification permitted the contractor to select the anchor type best suited to the site soil conditions and load requirements. The TMD regroutable anchor which was selected proved to be both the optimum anchor type for the site and of such a configuration that instrumentation could be reliably installed.

Later, in preparation of a generic anchor specification, FHWA would recognize that the anchor contractor was the most knowledgeable to select the best anchor type for the project conditions.

The analysis of the data from the project instrumentation showed a gradual transfer of load from the front of the bond zone to the middle and rear third of the bond length. Also, a short section of the grout column in front of the load zone was observed to transfer load to the soil. This pointed out the need to both begin the bond zone at an offset distance behind the assumed failure surface and to require weak grout in the free stressing length.

Long-term measurements of the deflection of the wall face indicate only minor movements have occurred with the net effect that the wall has moved into the slope. This may be indicative of conservatism in estimating the required force to stabilize the original wall instability.

The instrumentation system employed for these anchors was the most reliable of all the demonstration projects. A few general observations on the success of the instrumentation are:

- The instruments were selected and installed by a specialist instrumentation contractor.
- Although strand tendons were to be used in production anchors, bar tendons were used in instrumented anchors to optimize instrumentation reliability.
- Duplicate instrumentation was placed on the bar tendon and TMD external tube to insure reliable data collection.

<u>Pre-design Test Anchor Program</u>
<u>I-90, Seattle, Washington</u>

During the preliminary design phase of I-90 in Seattle, Washington, a review was made of the preliminary designs to support high cut slopes along the proposed alignment. A preliminary cost-estimate of $24 million had been made for cylinder pile walls to retain these cuts. An alternate design using permanent ground anchored walls estimated at $6 million had been suggested, but concern existed about long-term anchor capacity in the clay subsoils. To evaluate long-term performance, a pre-design $150,000 test anchor program was proposed. The program was developed to establish design criteria and construction control procedures which would insure long-term anchor support in the project soils. In June 1983, a Cooperative Agreement was signed between the Demonstration Projects Division and Washington State to provide $50,000 in funds for instrumentation of, and reporting on, test anchors installed in the over-consolidated clay deposit at the project site. Washington State designated Mr. Robert Josephson as principal investigator and selected Mr. Garry Horvitz of Hart-Crowser and Associates to be the co-principal investigator. The test anchor site is shown in Figures 5A-5D.

The test anchor program was designed to use anchor types and installation procedures which were common to permanent anchor construction in the Northwest. For that reason, a 12-inch diameter, non-pressure grouted anchor was selected, although it was generally agreed that higher pressure, regroutable anchors would provide higher capacities at shorter lengths. Bar tendons were used to facilitate instrumentation, although multiple bars needed to be installed in the anchors which were tested to pullout to insure tendon failure did not occur prior to soil bond failure.

The testing procedure was directed at establishing the relationship between anchor load and creep. Short bond lengths would be used to permit determination of ultimate capacity with reasonably sized test equipment. Although temporary anchors in these over-consolidated clays had been loaded to high values, it was suspected that design loads based on short term pullout tests would be subject to excessive long-term movement. The basic test procedure chosen was as described in detail in FHWA RD 81/150, which is based on the French Standards for permanent anchors. The end result of these tests is to determine the "critical creep tension," i.e., load beyond which unacceptable creep occurs.

The testing confirmed the suspicion that the critical creep tension would be substantially less than the ultimate load measured on the pullout test. In fact, the critical creep tension was one half of the ultimate load. Based on these results, the ultimate bond stress between the grout bulb and the clay was estimated and used to determine that the desired design load could be achieved in a reasonable bond length. The test anchors were locked off at various percentages of the critical creep tension and monitored for several years. The results of the monitoring were that only minimal long-term creep was observed.

Several permanently anchored walls have been completed on I-90 based on the results of this study. These walls are all performing satisfactorily with no evidence of movement or distress. Short-term testing procedures developed in the pre-design anchor test program were used in construction to verify the long-term capacity of anchors on the I-90 project.

In summary, the use of a $150,000 test anchor program by the Washington DOT resulted in a savings of $18 million on I-90 as well as providing valuable information for private projects, which have since been designed for permanent anchors in the over-consolidated clays in Seattle.

Correction of Landslide
KY-227, Carroll County, Kentucky

In 1983, the Geotechnical Section of the Division of Materials, Kentucky Department of Highways, was involved in the design of a landslide stabilization on KY-227. The landslide, which had been active for several years, affected about 400 linear feet of roadway. Solutions to the problem were limited as the roadway location was bounded by a marginally stable, uphill slope and a railroad located downhill from the road. The 25-foot depth to the slide surface ruled out shear key construction or removal of poor materials while the use of horizontal drains only increased the safety factor to 1.1. The application was well suited for a permanent ground anchor solution, but the Department had not designed and let a permanent anchor project at that time. The Department was concerned about employing this new technology at a site where an on-going landslide required permanent stabilization in a short time period.

The solution was to adopt a shared responsibility design-construct approach to a permanent ground anchor design. The Department's geotechnical engineers progressed borings, performed lab tests, selected soil strength values, and performed stability analyses to determine the resisting forces required to stabilize the landslide. A unique specification was developed to permit alternate permanent ground anchor solutions to be designed by qualified anchor firms. Specific experience requirements were listed for the anchor design firms. Interested firms were required to submit detailed designs to the Department for approval within a given time-frame before the project was bid. The Department provided a package of geotechnical information, the resultant force to be resisted by the anchor wall, and specific structural design requirements for the anchor wall design. The submitted designs were required to include complete design calculations, detailed construction drawings, and any special notes or specifications needed to supplement the Department's submittal. Each firm's calculations were to be presented clearly so that engineers unfamiliar with permanent anchor walls could review the information in a short time.

The Department formed an internal review board consisting of structural, geotechnical, and construction engineers to study the submitted designs. These initial reviews were very time consuming, particularly because different anchor firms used different design methods to achieve a final anchor wall system to resist the given force.

The board realized that the original design criteria supplied to the contractors needed to be clarified to permit all alternate designs to be prepared on a common basis. Items such as the design pressure diagram to be resisted, the use of wall friction in the soldier pile design, drainage requirements, and the design procedure for wood logging were redefined. The specialty contractors were requested to revise their original designs and re-submit. The re-submitted designs were reviewed by the board in a short period of time and the project let on schedule. Although certain other deficiencies in the construction specifications were found after contract award, the project proceeded smoothly to completion.

Kentucky benefited from their contracting approach to this project in several ways. One, they did not possess the in-house expertise to design a permanent anchor wall before this project. The prebid design approach permitted exposure to several different wall concepts and design philosophies. After completion of another similar permanent anchor wall by the prebid method, Kentucky believes sufficient in-house design knowledge exists to permit assumption of some design details and use of a performance specification which would permit post bid alternates.

Secondly, the use of a pre-qualification requirement for the permanent anchor design and construction insured that only experienced permanent anchor specialty firms would be eligible for this work. This minimized the amount of construction inspection necessary to obtain a quality product. Kentucky inspectors were able to observe the specialist contractor's methods, quality control procedures, and equipment in order to develop confident inspection techniques for future projects.

Thirdly, the prebid specification is a good vehicle to implement the cost-effective technology of permanent anchoring on public projects. The agency establishes the basic design framework and permits several experienced contractors to compete for the most cost-effective design.

The Carroll County wall (and a subsequent anchored wall in Campbell County) has been a successful use of permanent anchors to stabilize a landslide. The instrumentation indicated that by November 1985, movement of the wall and highway had virtually stopped.

An inspection of the completed permanent anchor wall by the FHWA project manager on October 15, 1987, indicated that the roadway behind the wall was stable. No evidence of any movement was observed in the roadway or guardrail (see Figures 6A-6C). However, two problems affecting durability of the wall face were observed. Termite infestation was observed in a few of the treated wood lagging sections, which comprise of the final wall face (see Figure 6D). Similar problems have been reported on other permanent walls faced with treated wood. It is postulated that the wood lags develop cracks during initial stressing of the anchors to the test load; i.e., commonly 1.33 to 1.50 of the design load. In fact, random lags may actually be subjected to higher stresses as distribution of load is not uniform across the wall face due to the unevenness of the soil cut face on which the lag bears. These cracks extend through the treated skin and into the untreated wood core which is eventually attacked by the termites. Highway agencies should carefully assess the use of wood lagging as the permanent, load-bearing face for permanent anchor walls, particularly in locations where routine inspection and maintenance are not feasible.

The inspection also disclosed that the "Tapecoat TC Mastic," used as protective coatings on exposed steel surfaces, was blistering and peeling. Corrosion of the waler was observed beneath the peeled coating (see Figure 6E).

<u>Lateral Support of Bridge End Slopes</u>
<u>Dimond Boulevard - Anchorage, Alaska</u>

In 1985, a Cooperative Agreement was executed with the Alaska Department of Transportation to provide funds for instrumenting the agency's first permanent ground anchor installation. The project involved construction of an anchored wall to support the existing end fills and abutments on the Dimond Boulevard project in Anchorage. Traffic would be maintained on the existing structure during construction. These walls were unique in that resistance had to be provided for both vertical and lateral loads from the abutments which were supported on spread footings located above the wall in the end fill. The walls were required because the under road, Dimond Boulevard, was being widened and lowered to provide increased clearance under the existing structure. The principal investigator was Mr. Thomas Moses of Alaska DOT.

Installation of soldier piles beneath existing structures poses problems, particularly when the pile length required is greater than the available clearance. The solution used for pile installation was to close one lane to traffic on the existing bridge, drill holes in the deck between girders, and install the piles through the deck to the designed embedment into the ground. After completion of the pile installation in one lane, the piles are cut off below deck level, the holes sealed, and traffic restored in that lane while the operation begins in the next lane. The total time for installation of all piles was less than 1 week using this method.

One unexpected problem about these holes arose during construction when an extremely heavy rain occurred. The drainage from the deck entered a few open holes and poured down on one end slope causing erosion and settlement of one abutment. A solution to this problem is to require deck holes to be temporarily sealed against water infiltration immediately after drilling and permanently sealed immediately after the soldier beam is installed.

The anchors were installed into the existing granular approach fill at levels below the existing abutment footing. Adequate vertical and horizontal clearance existed for the anchor drilling operation such that traffic could be maintained on Dimond Boulevard when required during the construction.

Although the final report for this project has not been submitted, observations made for a year after the construction indicate the anchored wall is functioning as designed (see Figure 7). It does appear that the wall moved <u>into</u> the backslope a small amount which caused a decrease in the lockoff load on the tendons. The reasons for this movement and decrease in load may be better known when the final report is received in 1990.

<u>Urban Railroad Grade Separation
North Street Project, Lima, Ohio</u>

The North Street project, which is located in an old, congested area of downtown Lima, Ohio, was the State's first permanent anchor project. The project right-of-way was very limited, requiring underpinning of adjacent structures (see Figures 8A-8C) as part of the permanent anchor wall construction. Only small wall movements could be tolerated due to the proximity of the structures to the wall. In addition, the bond zone soils were predominately fine-grained with respective liquid limits and plastic indices generally above 30 and 15. These soils are at the lower end of soil types which are considered suitable for permanent ground anchors.

In late 1985, a Cooperative Agreement was executed between FHWA and the State of Ohio to provide funds for monitoring the performance of permanent anchors on this project. The co-principal investigators were Mr. Richard Engel of Ohio DOT and Mr. Mark Lockwood of the H. C. Nutting Company, consultants for this project.

The project construction specifications were developed on a performance basis and required that a permanent anchor specialty contractor construct the anchored wall. All anchors were required to be tested before lockoff with payment to the contractor based on acceptance criteria for the tests. This specification became a critical factor in the success of the project as the Ohio DOT construction engineers had no experience with inspection of permanent anchor wall construction. The specialty contractor who was the successful bidder, Schnabel Foundation Company, made every effort to explain the proper construction procedures and assist in training the project inspectors. Project inspectors photographed numerous steps in the wall construction to provide training materials for inspectors on future anchor projects. Although this project was difficult in terms of both surface and subsurface problems, the construction proceeded smoothly and without incident to completion.

This project, more than any other, demonstrated the value of both pre-qualification of specialty contractors, and the use of performance type specifications for permanent anchor work. A major objective of the instrumentation was to determine the movements and loads transferred to the soldier piles as successive levels of anchors were stressed. The data, available at the end of construction, indicated that the vertical load on the soldier pile increased rapidly as the excavation proceeded to grade and as each successive row of anchors was stressed. Of the 59 kips estimated in design to be the maximum vertical load, 55.4 kips were transferred below grade. This initial data suggests very little load transfer above grade between the soldier pile back face and the soil face being supported. This tends to confirm the conservative design approach of selecting an angle of wall friction of zero when calculating earth pressures against permanent anchor walls.

A second interesting observation was the decrease in load carried by the first level of anchors when the second level was tensioned. This indicates the need in design to check the construction situations where the first anchor level has been installed and excavation has proceeded to below the second anchor level. In some cases, this stage will produce the maximum load to which the level one anchors will be subjected.

Two other points of interest are the relatively large cyclic movements in both north-south wall deflection and the temperature range noted 15 feet behind the wall. Movements of 0.2 inches appear to have occurred in channel number 93 between winter and summer. Detailed temperature measurements of the soil both behind the wall and in the anchor bond length were taken.

The detailed report in the appendix contains figures which are updated to show nearly 1 year of readings, although the text only contains preliminary comments on the period up to about 3 months after construction. The final report on this project is not due until December 1990. Figures 8D-8H show anchor installation and the completed wall.

Tieback Bridse Abutment
Ramp Q, I-279, Pittsburgh, Pennsylvania

In late 1987, PennDot entered into a Cooperative Agreement with FHWA to instrument and monitor the performance of a tied back bridge abutment in Pittsburgh, Pennsylvania. This is only the second major application of constructing a permanent anchored bridge abutment in the United States. The reason for the design was potential lateral instability of the slope on which the abutment would be constructed. The principal investigator for this study is Mr. James Withiam of D'Appolonia, consultants for this project.

At the writing of this report, the abutment construction has been successfully completed but no conclusions have been developed regarding performance of permanent anchors.

V. REHABILITATION OF STRUCTURES WITH PERMANENT GROUND ANCHORS

During the progression of the permanent anchor project, the most cost-effective application of the technology was in rehabilitation of structures. Permanent anchor designs for rehabilitation projects were relatively straight forward and accomplished within a short time.

The equipment required for permanent anchor work is relatively small, readily available nationally, and easily mobilized. The materials are common construction items available nationally in a short time frame. All these factors point to anchor use for rehabilitation work, particularly when the project repair must be accomplished in a short time frame.

The following two projects are examples of walls for which the demonstration project manager provided technical assistance to achieve fast, cost-effective repair.

Hope, Idaho, Cemetery Wall Rehabilitation

A 34-foot high by 200-foot long retaining wall was built in 1975 to preserve a pioneer cemetery located above the proposed grade just west of Hope, Idaho. The wall was designed with a flexible face of precast reinforced concrete segments (stretchers) interconnected by vertical steel rods. Lateral support of the flexible panels was achieved in the lower 12 feet with rock bolt tiebacks, in the middle 8 feet by gravity wall design, and the upper 14 feet by deadman anchors. Following construction, the stretchers began to crack and spall and the face began to tilt. A study of wall conditions in 1978-79 concluded that interaction of the vertical rods and reinforcing steel of the stretchers was causing the reinforcing steel to break out of the stretchers in the lower 12 feet of the wall (see Figures 9A-9B).

It was recommended that the wall be strengthened in this section and that long-term corrosion of unprotected steel wall elements be considered in the rehabilitation.

The FHWA Western District Federal Division was assigned responsibility for the wall repair. The remedial treatment had to accomplish several objectives:

- not distress the delicate structural stability of the existing wall or disturb the cemetery,
- maintain a safe minimum clearance distance from the highway,
- provide long-term corrosion resistance,
- be cost-effective.

Fortunately, subsurface conditions at the site were adequately defined by the site geology and records of the existing rock bolt installation. The subsurface conditions consisted of a mixture of sand, silt, and rock fragments overlying rock at relatively shallow depths. Concerns for long-term corrosion and the need to reinforce the existing wall with minimal disruption to the site, combined with favorable subsurface conditions, led to a permanent ground anchor solution.

The permanent anchor design was complicated by the delicate condition of the existing wall face. Normally, the anchors would be drilled through the wall and then stressed against the existing wall face to above design load. However, the thin wall face could not withstand any concentrated load. The available clearance to the adjacent roadway allowed placement of a 16-inch thick reinforced concrete face over the bottom 12 feet of the existing face. Although this thickness was adequate to distribute the anchor design load over the face area, test stressing the anchors to above design load on this new face was not deemed prudent.

Since the wall length was short, an alternate testing procedure was used whereby two pre-production anchors would be performance tested to over 200 percent of design load against the natural ground just beyond the ends of the wall. After successful tests were performed, the contractor was required to install the production anchors with the same materials and procedures used for the pre-production testing. Drainage that was occurring through the existing gapped wall face was designed to be carried by pipes placed through the new solid wall face (see Figures 9C-9E).

The production anchors were bid on a "per-ft-of-anchor-installed" basis rather than the more common per-anchor basis because it was impossible to proof test each installed anchor. It was also necessary for the designer in this case to assume full responsibility for establishing a guaranteed "safe" anchor. Therefore, the anchor hole diameter, grout pressure, drilling procedure, free length, and bond length were specified in the plans. Normally, the contractor would bid on a per-anchor basis; determine all anchor dimensions except minimum, free, and bond lengths; and prove the design load could safely be held by testing each anchor. In this project, the production anchors were stressed to a 25-kip lockoff load. The measured movement of all anchors at that load was within the acceptable limits established from the pre-production test anchors.

The contract time for construction was 90 days, which would have been met except for some unexpected weather conditions. The two pre-production performance test anchors were installed at a bid price of $1,500 each. The approximately 1,900 feet of production drilling and grouting was completed for the 61 wall anchors, which were double corrosion-protected l-inch diameter bars. The bid price per linear foot of production anchor was $30 versus an estimated actual cost per foot of $25 by the contractor.

Based on the success of this project, it appears that permanent anchors can be successfully used as an alternate method of repair for other thin-faced walls such as metal bin or concrete cribbing.

Nevada, Carlin Canyon Portal Rehabilitation

The portal walls of the Interstate 80 Carlin Canyon Tunnel in Nevada were built in the 1970s, using a unique lateral support system. Galvanized steel tie rods were fixed into the concrete wall face and extended back to anchors in the nearby rock slope. These rods were designed to resist the lateral pressure generated by the backfill that was subsequently placed. However, after 8 years of service, one of the portal walls began to move outward at an excessive rate. To stop this movement, the State removed the backfill from the failing wall sections. The tie rods that were unearthed during backfill removal failed due to severe corrosion, particularly near the wall-rod interface. A closer examination showed active corrosion on all parts of the galvanized rods. As conditions were similar behind all other wall panels, any remedial design selected would have to apply to all panels. The choices were to reconstruct the walls or re-establish permanent lateral support for the existing walls. The State DOT selected permanent anchors to provide the required lateral support to the existing walls.

Two problems were overcome in the permanent anchor design. First, the thickness of the existing wall was inadequate to support and distribute the required permanent anchor loads (45 to 70 tons per anchor). This problem was resolved by casting vertical concrete beams at specified center-to-center distances along the panels. The 1 3/8-inch diameter single-corrosion-protected bar anchors were placed through and stressed against the beams, which were adequately reinforced to sustain the stressing load and distribute the force over the panel height. The second problem only occurred at panels where the backfill had been removed. Permanent anchors are normally post-tensioned to the required proof load after installation. However, passive resistance behind the excavated panels was insufficient to allow stressing the anchors to the test loads without damaging the wall. In addition, backfill should not be placed and compacted around anchors that have previously been installed. Backfill compaction operations can damage the corrosion protection of the permanent anchor and can cause bending of the tendon free length under the compactive load. Such a backfill procedure was used in the original portal construction and reportedly caused inward wall deflections due to bending of the rods.

To prevent these problems, the State required backfill to be placed in stages and compacted behind those wall panels to about 3 feet above each successive row of anchors. The anchors in each lower row were stressed and locked off before the backfill was placed to the next higher row. No attempt was made to pull the deflected wall back to its original position for fear of structurally damaging the panels. Drainage was reestablished behind the excavated panels by handing vertical drains down the back face and connecting them to a positive outlet before backfilling.

The specification for the anchors was performance based; i.e., a pre-qualification statement was included to ensure the work was awarded only to an experienced permanent anchor contractor. The contractor was responsible for determining the actual required anchor bond length to develop adequate load capacity to satisfy anchor testing requirements for the design loads on the plans.

Within the specification, the contractor was allowed to use his expertise to determine tendon type, drilling method, grouting pressures, multiple grouting techniques, and bond length variations to produce the most cost-effective anchor. The State accepted or rejected each anchor on the results of either performance or proof tests that were done on the installed anchors. The 64 anchors were bid on a per-unit basis at an average cost of $2,800, which included labor, materials, drilling, stressing, and testing. The actual anchor work was completed within 3 months. The entire project, from design through construction, took about 18 months. The final wall is shown in Figures 10A and 10B.

VI. CONCLUSION

The objective of Demonstration Project No. 68 was to introduce, nationally, the concept of permanent ground anchor use into routine construction practice. This objective has been accomplished through a multi-dimension program of research, technology transfer, technical assistance, and interaction with both public and private organizations involved in permanent anchoring. As documented in the text of this report, the volume of permanent anchor work in the United States is multiplying yearly. State highway agencies are now considering anchors as routine alternatives to conventional techniques rather than as research objects.

Although the Demonstration Project has ended, the mechanism is in place for further refinement and promotion of permanent anchor technology. Organizations such as AASHTO, ARTBA, AGC, ASTM, and the Post Tensioning Institute have on-going committees studying permanent ground anchor standards and applications. Furthermore, FHWA and other government organizations are advancing programs for research to optimize the design procedures now in common use.

Figure 1. Demonstration Presentations Completed

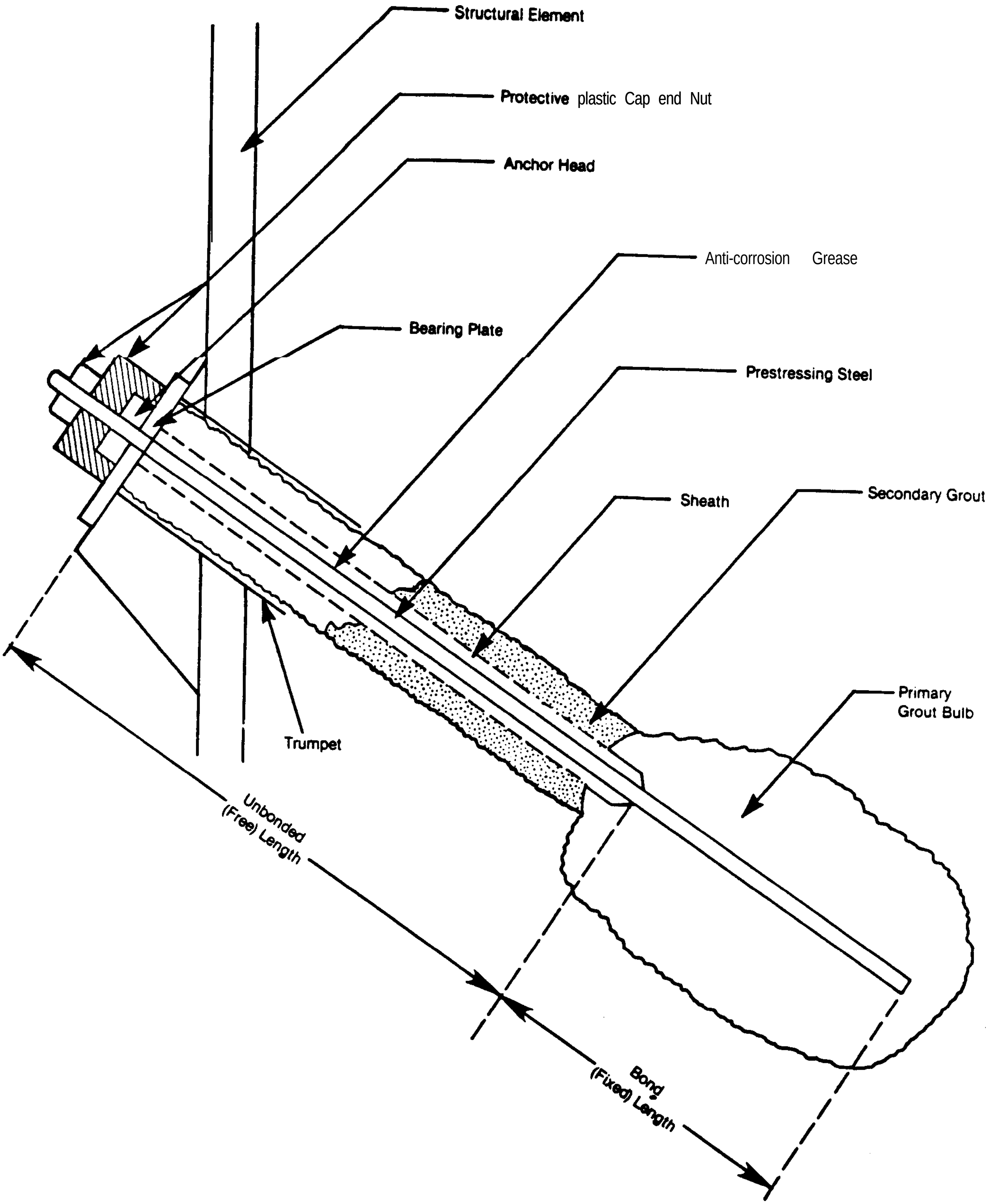
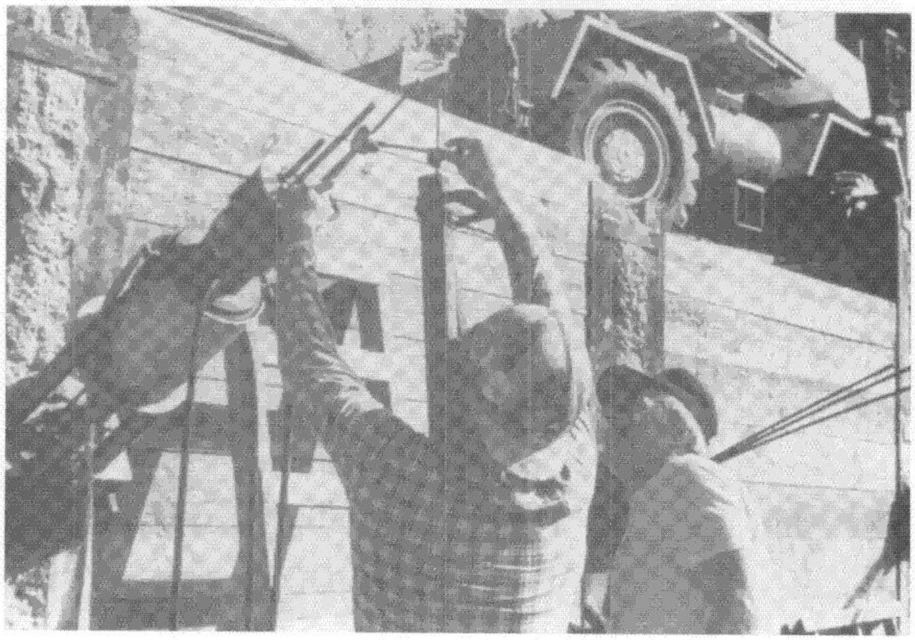
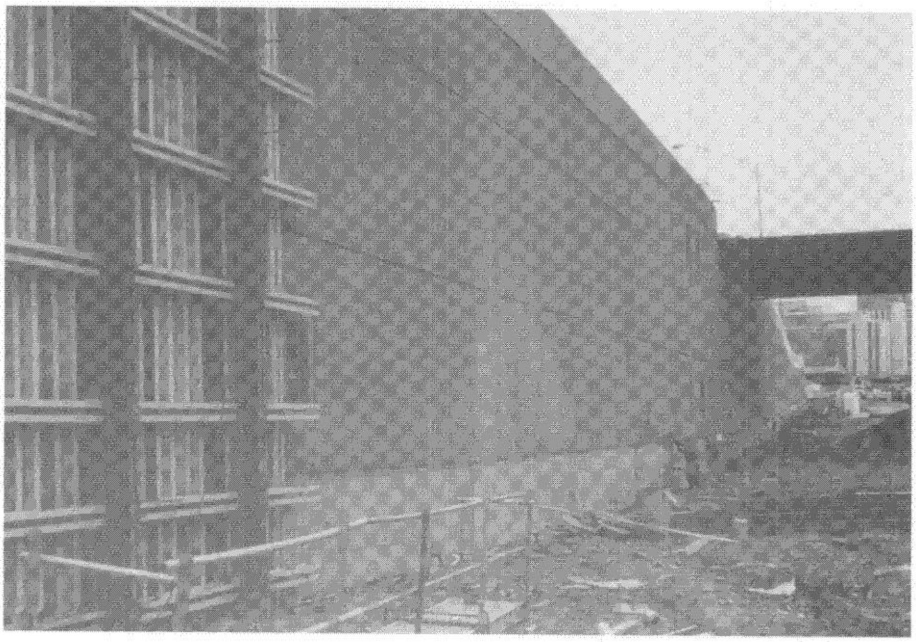


Figure 2 Simple Schematic of a Permanent Anchor

Figure 3.--Georgia I-75 Project

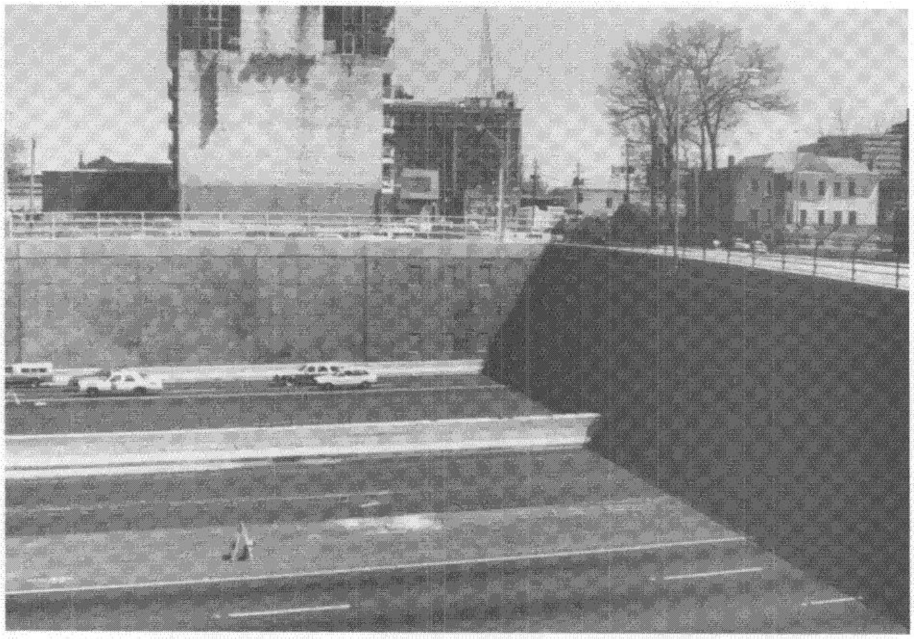


3A.--Testing of First Anchor Row

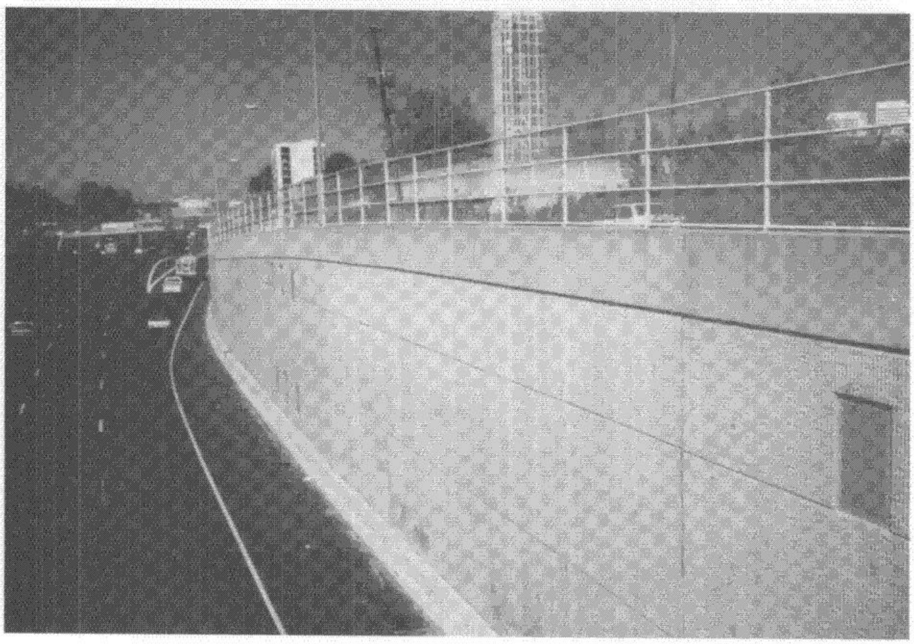


3B.--Forming Concrete Wall Face Over Anchors

Figure 3.--Georgia I-75 Project (con.)



3C.--Final Wall, 1984



3D.--Wall, 1988

Figure 3.--Georgia I-75 Project (con.)

3E.--Stable Roadway, 1988
Above Wall - No Pavement Cracks

Figure 4.--Maryland I-95 Project

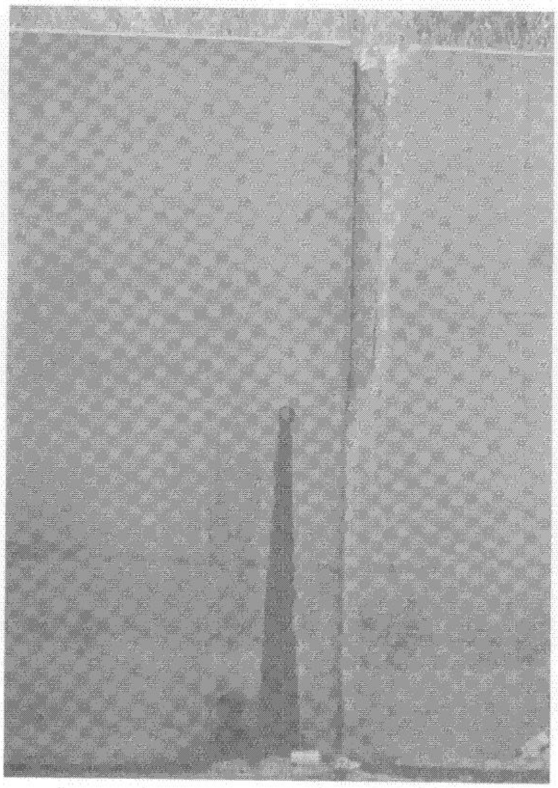
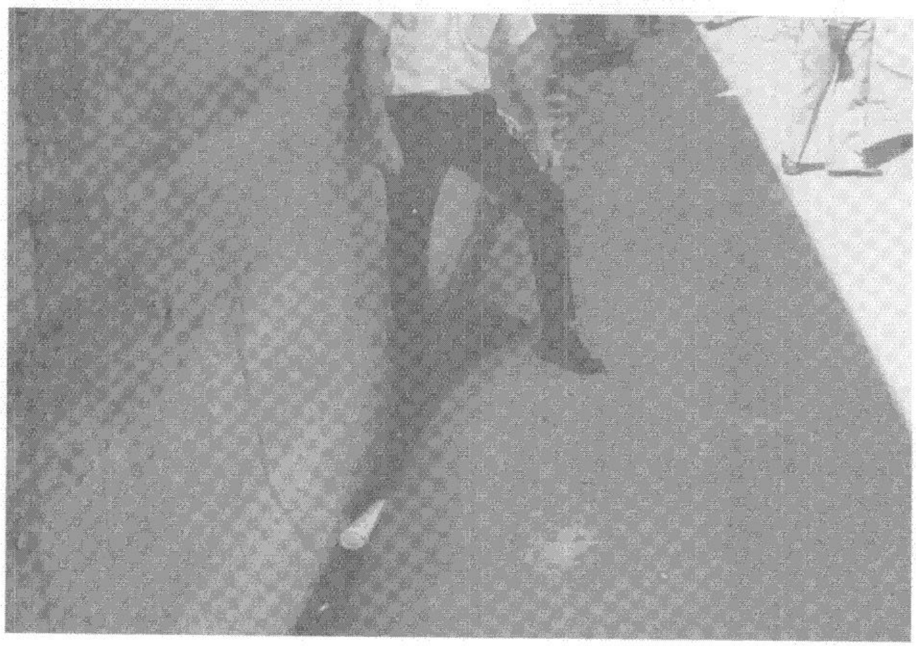
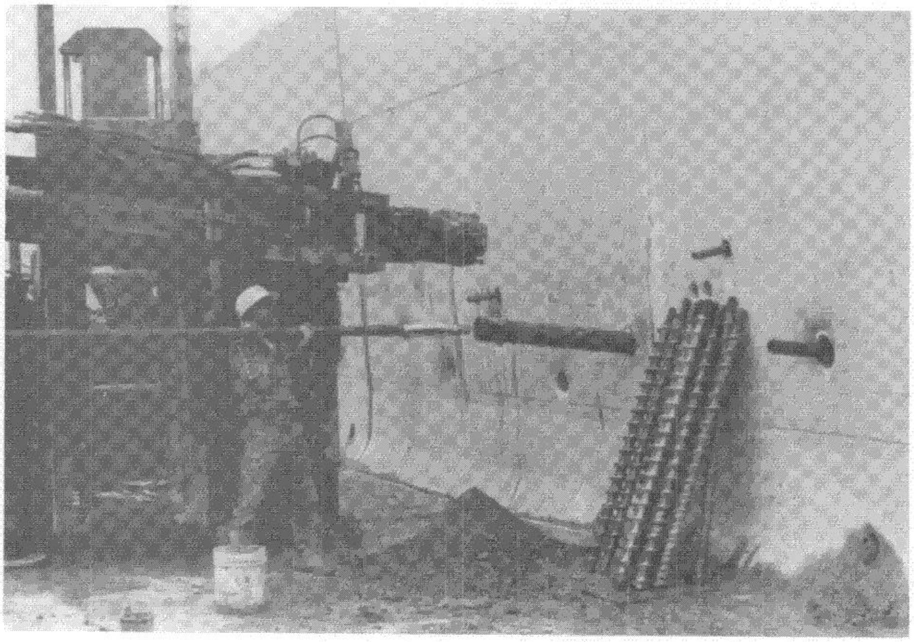


Figure 4A.--Wall Joint Spalling, 1980

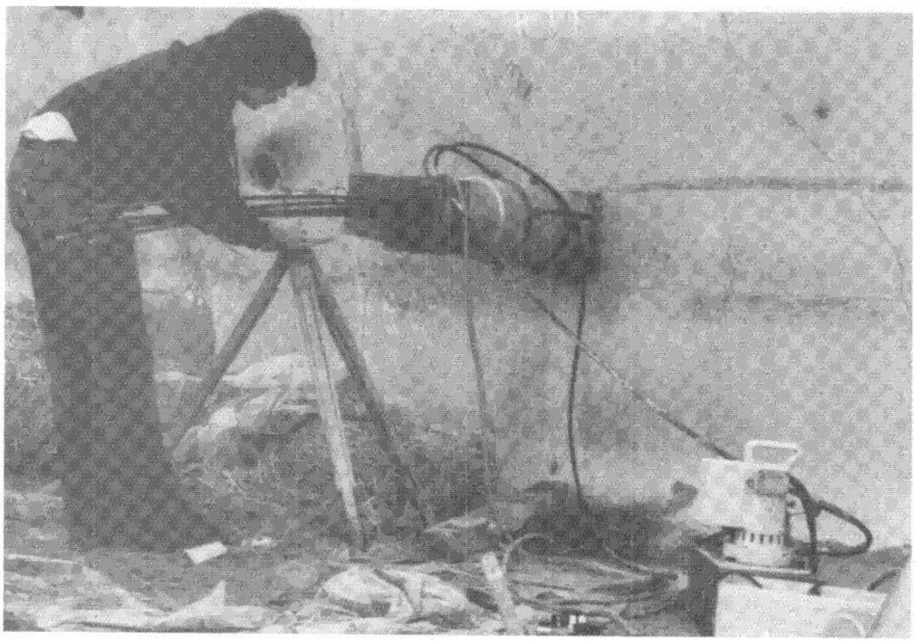


4B.--Wall Base Translation, 1980

Figure 4.--Maryland I-95 Project (con.)



4C.--TMD Anchors Installed, 1981



4D.--Anchor Testing

Figure 4.--Maryland I-95 Project (con.)

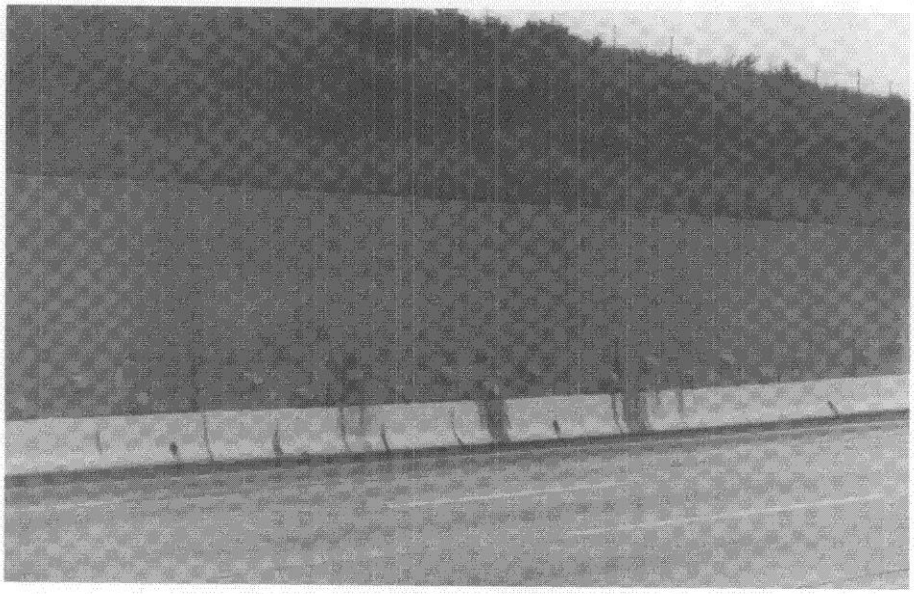
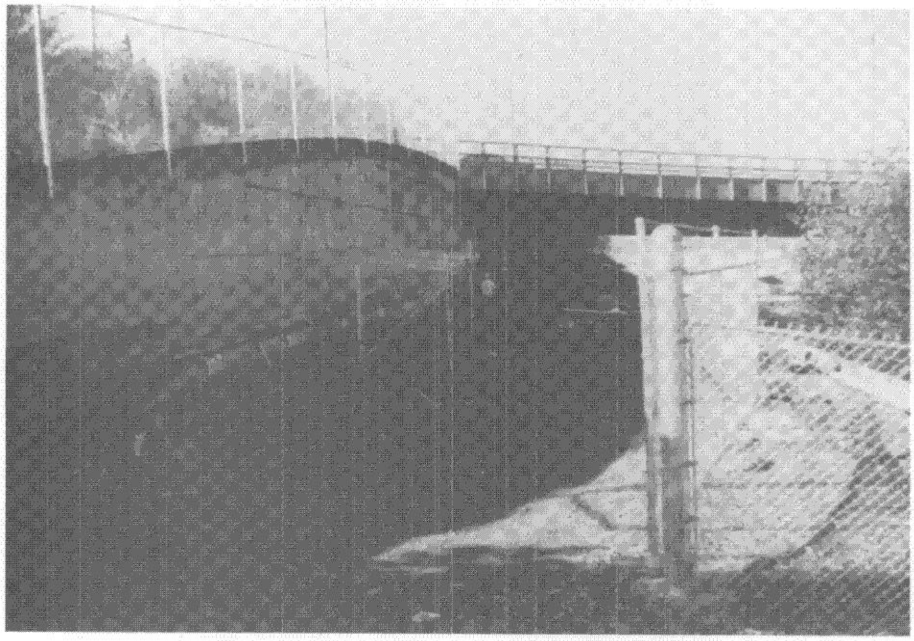
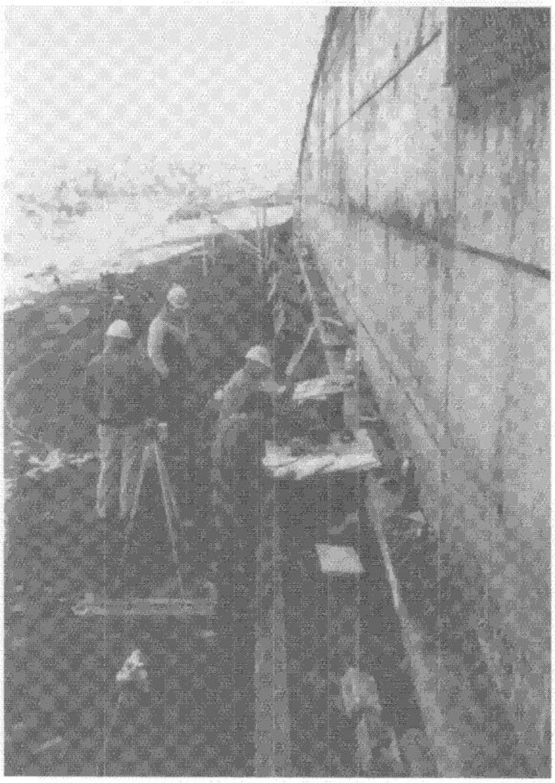


Figure 4E.--Final Wall, 1984

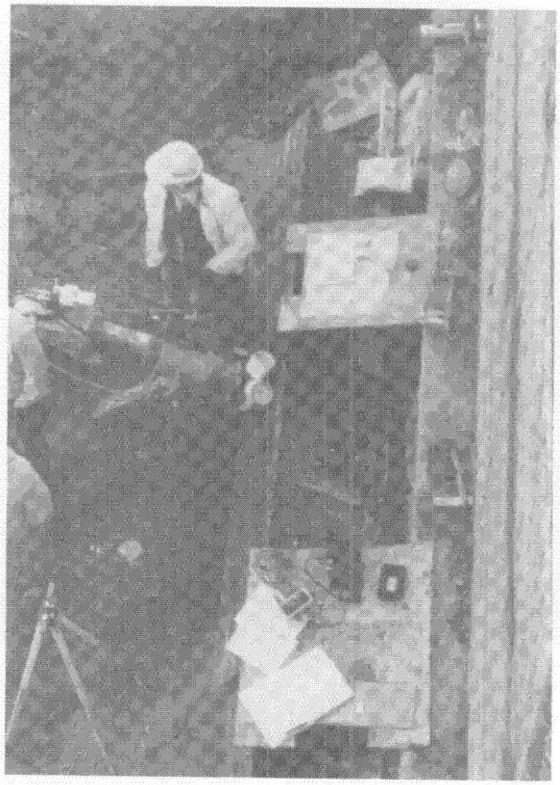
Figure 5.--Washington I-90 Project

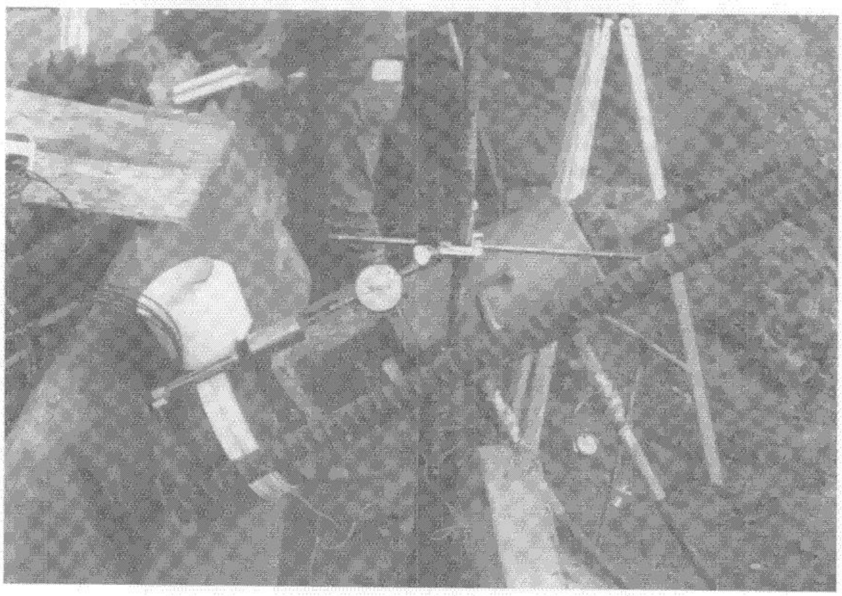




Figures 5A and 5B
Anchors Installed Through Existing Cylinder Pile Wall

Figure 5.--Washington I-90 Project (con.)





Figures 5C and 5D
Instrumentation for Anchor Testing

Figure 6.--Kentucky Route 227 Project

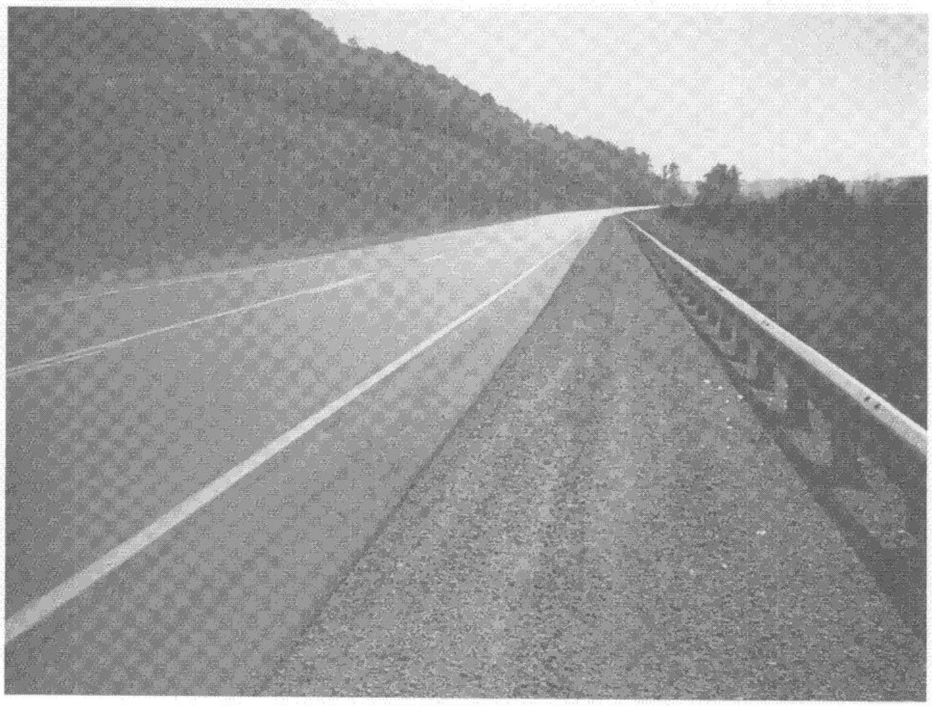
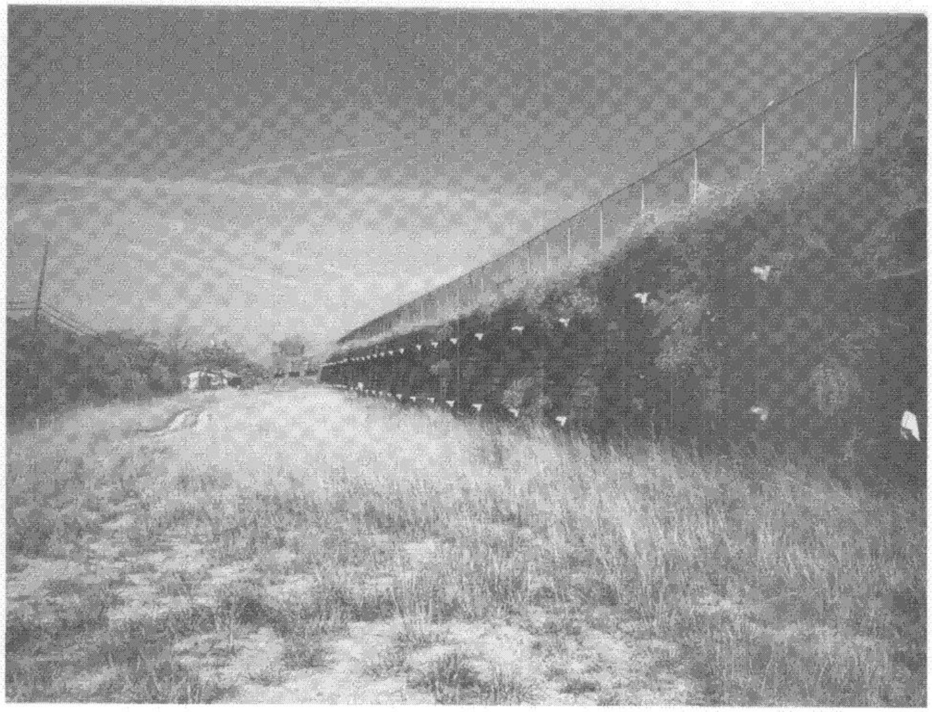


Figure 6A
Embankment Stable With No Evidence of
Movement 3 Years After Construction

Figure 6.--Kentucky Route 227 Project (con.)



Figures 6B and 6C
Views of Wall Face 4 Years After Construction

Figure 6.--Kentucky Route 227 Project (con.)

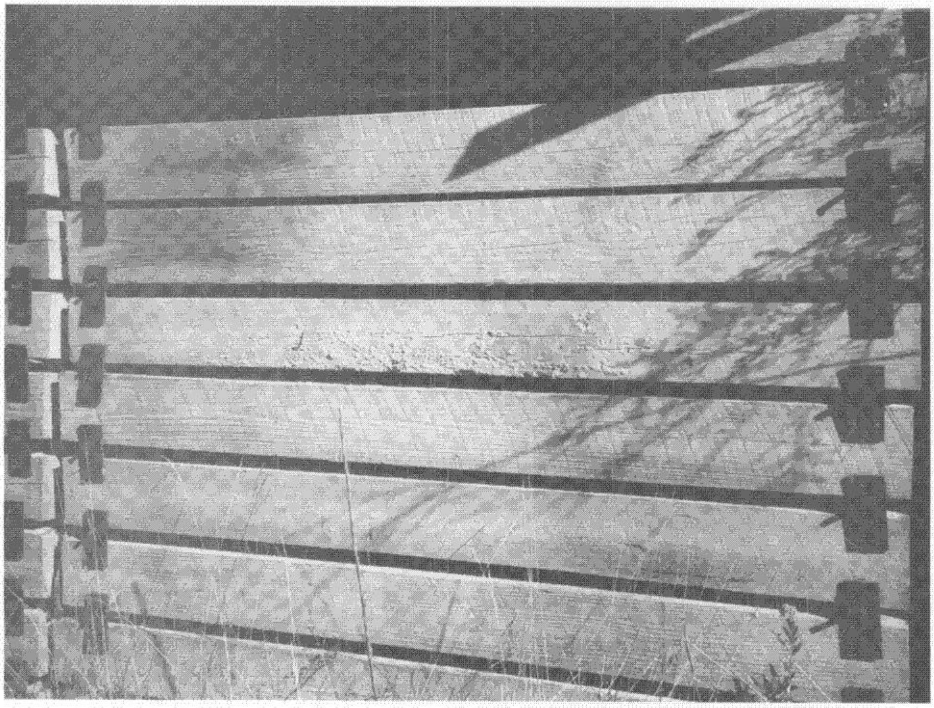
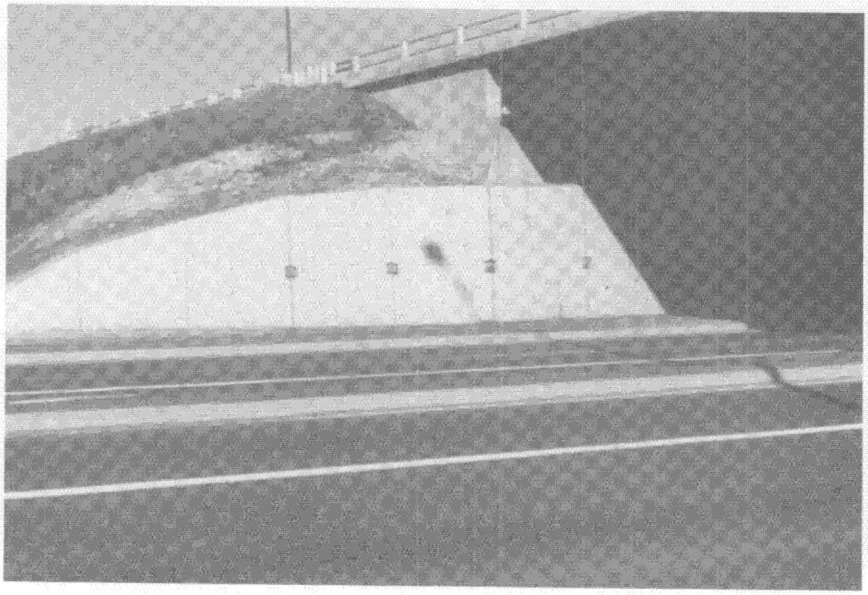


Figure 6D
Termite Infestation of Permanent Treated Wood Face

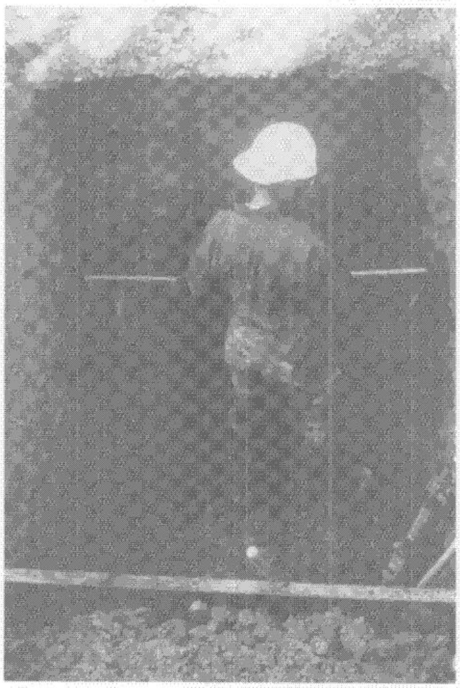
Figure 6E
Blistering and Peeling of Protective Coating on Waler

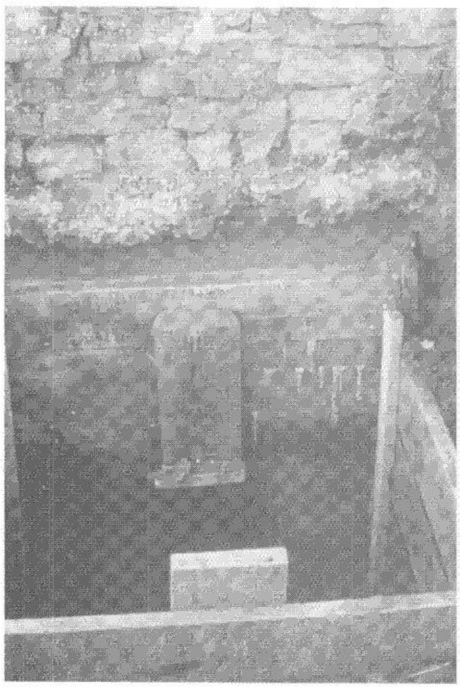
Figure 7.--Alaska Dimond Boulevard Project



Completed Dimond Boulevard Wall

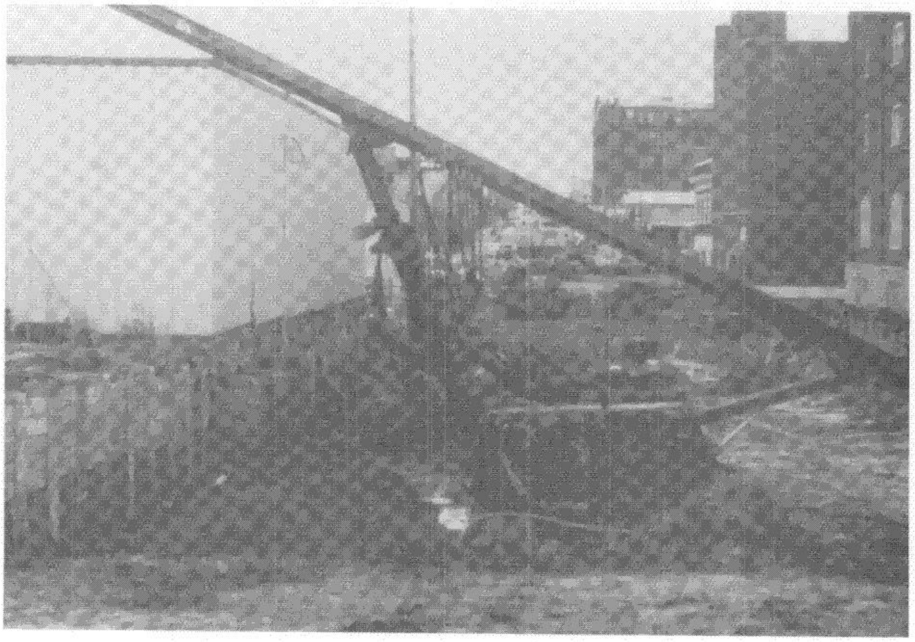
Figure 8.--Ohio Lima Project





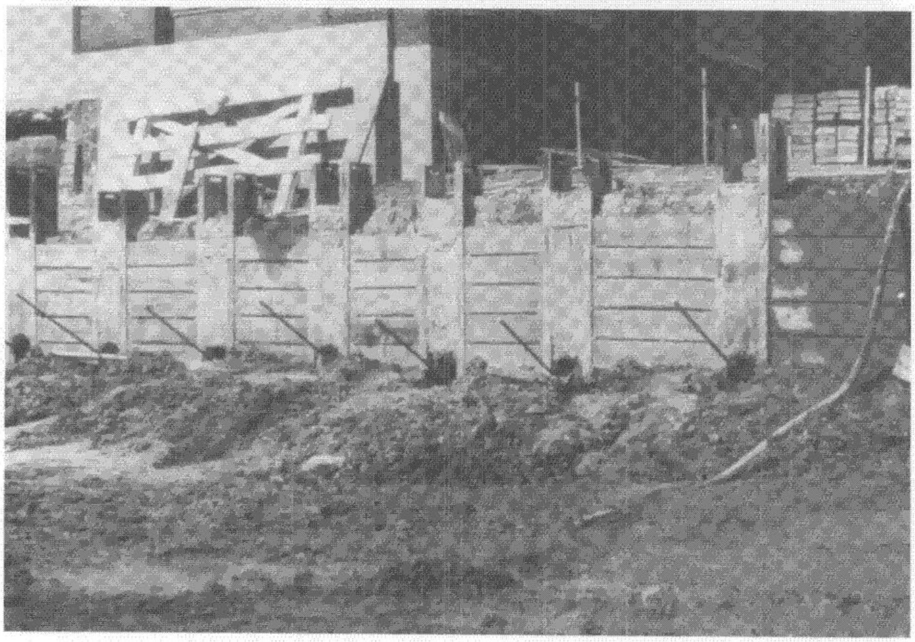
Figures 8A, 8B, and 8C.--Building Underpinning Operations

Figure 8.--Ohio Lima Project (con.)



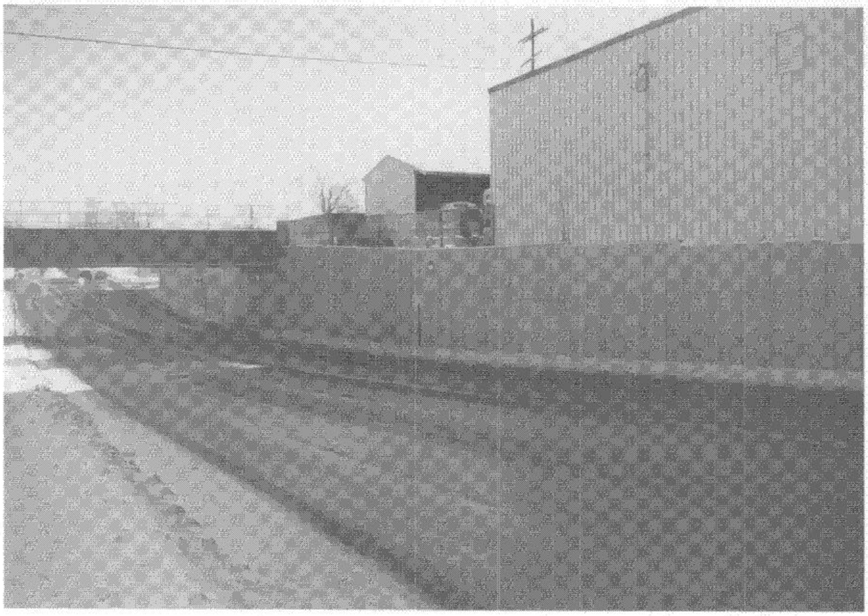
Figures 8D and 8E.--Anchor Drilling

Figure 8.--Ohio Lima Project (con.)



8F.--First Level Anchors Installed

Figure 8.--Ohio Lima Project (con.)



Figures 8G and 8H
Opposing Views of Completed Walls, 1989

Figure 9.--Idaho Hope Project

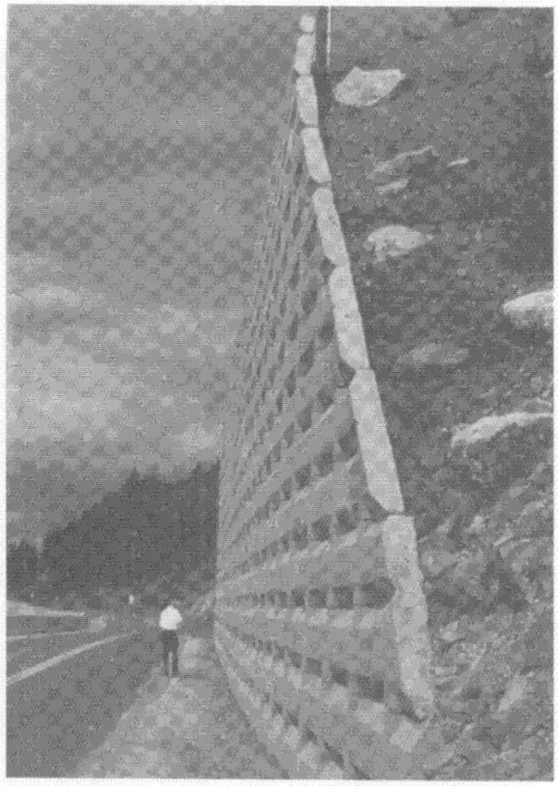


Figure 9A.--Hope Wall Condition, 1980

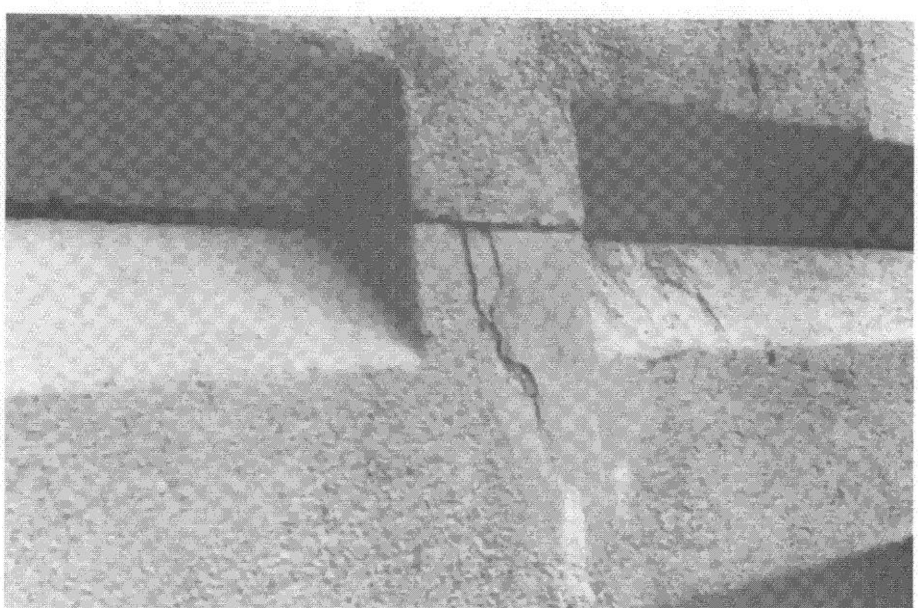


Figure 9B.--Closeup of Crack in Lower 12 Feet of Wall

Figure 9.--Idaho Hope Project (con.)

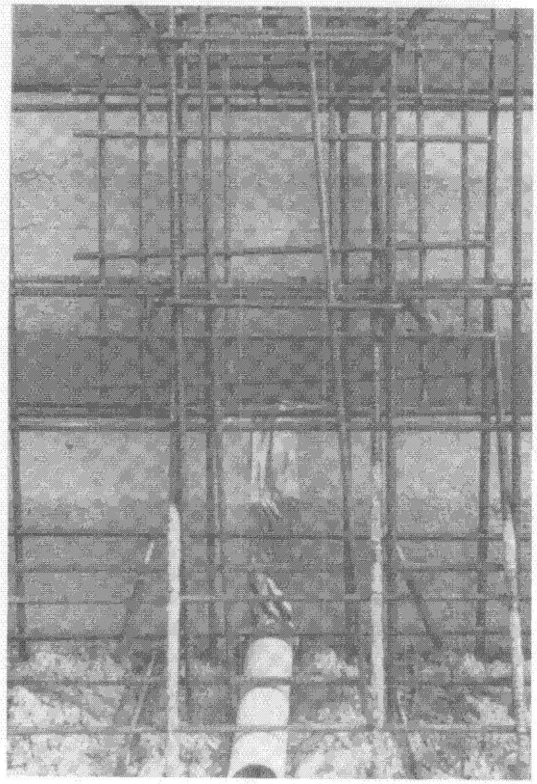
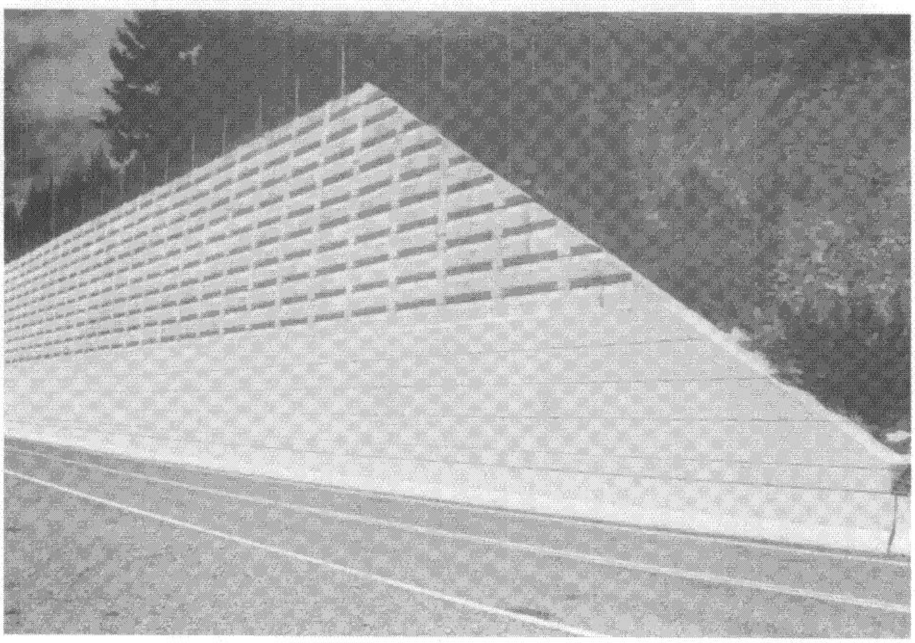


Figure 9C.--New Reinforced Fascia Wall
Poured Prior to Anchor Installation



9D.--Completed Anchored Wall Repair, 1981

Figure 9.--Idaho Hope Project (con.)

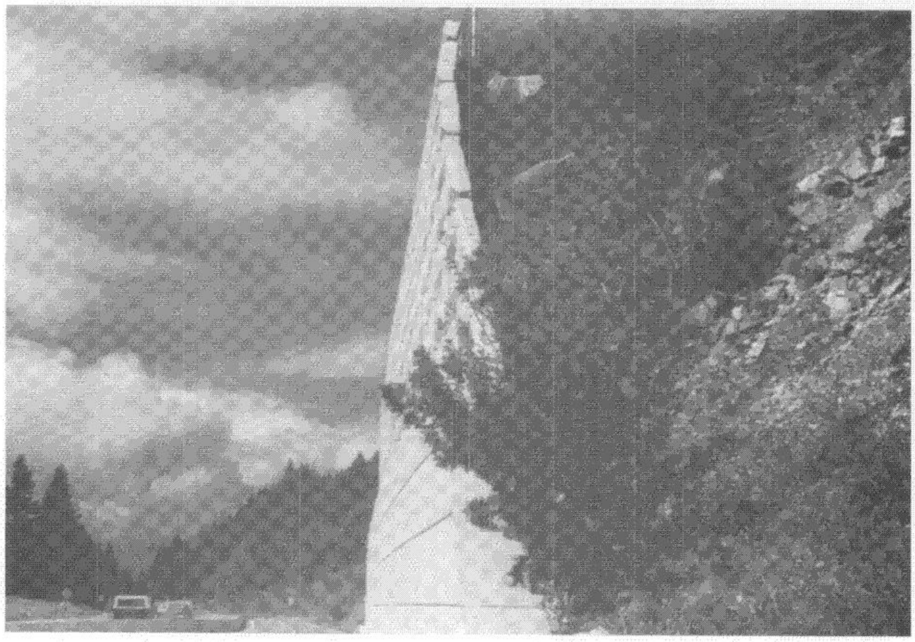


Figure 9E.--Note Small Thickness of Wall Repair

Figure 10.--Nevada Carlin Canyon Project

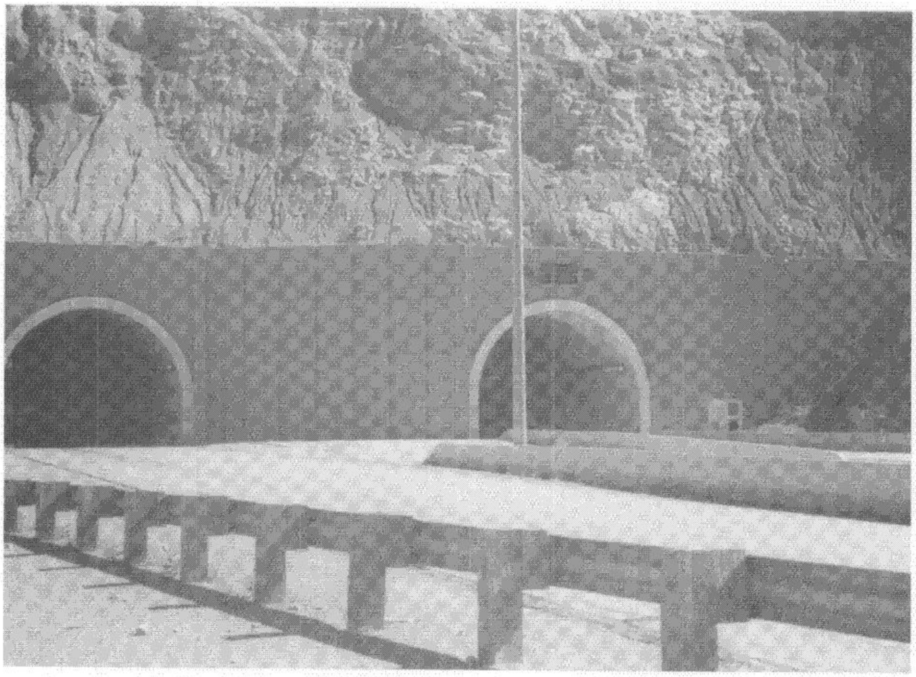


Figure 10A.--Completed West Portal, Carlin Canyon Tunnel
Vertical Beams Contain Anchors

Figure 10B.--Completed East Portal, Carlin Canyon Tunnel