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CONSTRUCTABILITY OF TIEDBACK WALL SYSTEMS

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INTRODUCTION

Tiedback walls are now recognized and accepted as a good solution for a variety of structural problems such as retaining walls and bridge abutments in cut situations, landslide stabilization, and repair/support of existing walls.

Acceptable techniques have been developed for anchoring in cohesive and granular soils and in any kind of rock. Methods have been developed for adequately protecting tieback tendons against corrosion and for testing every tieback to verify its long-term, load-carrying capacity.

However, the major problem that the industry faces today is how do we get constructable and economical tiedback walls contracted for and built with minimal claims. This paper will explore the issue of "constructability through a look at specific problems from actual projects. From a research report from the Construction Industry Institute, Austin, Texas (1986), constructability is defined "as the optimum use of construction knowledge and experience in planning, design, procurement and field/operations to achieve overall project objectives." Maximum benefits occur when people with construction knowledge and experience become involved at the very beginning of the project. The design and installation of tiebacks has been developed primarily by specialty contractors; each contractor has evolved its own methods of performing the work, and consequently, many of the techniques are patented and proprietary. The real question is, how do we make effective use of this knowledge and experience during the design phase of the project?

PROBLEMS AND SOLUTIONS

Building from Bottom Up Versus Top Down

A landslide stabilization wall in California was designed by the State DOT similar to ones constructed on 20 to 30 other California highway projects.

From Figure 1, it appears the design is based upon removing all slide material back to the assumed failure plane, and then placing controlled backfill behind the wall as the wall was built from the bottom up, just the opposite from the usual construction procedures for a tiedback wall. This necessitated the closing of portions of the road during construction. The final design consisted of:

- Drilled-in solder piles on five-foot centers.
- Four-inch-thick treated lagging between the soldier piles.
- Double channel galvanized wales.
- Corrosion protected one-inch-diameter GR150 ksi bar tiebacks with minimum unbonded length, minimum anchor length, design load, and maximum tieback testing load specified. (The contractor was allowed to select the tieback installation procedure and drillhole size.)
- A combination of permeable backfill with filter cloth and compacted excavated roadway embankment material.

The specification was essentially a prescriptive specification for the wall, and a performance specification for tieback installation and testing procedure. It is normal to have some tieback failures during the early stages of tieback testing. The high initial failure rate on this project, however, point up the advantage to the owner of using a performance specification. Had the owner specified the tiebacks to be installed a certain way, and they then failed, it would be the owner's responsibility to pay for both the original and the replacement anchors, and any required changes in the installation procedure. With a tieback performance specification as used on this project, the contractor is responsible for successful performance. On this job, after the tieback failures occurred, the grouting procedure was modified and the failed tiebacks were replaced and tested, with no change in contract amount, and no claim submitted to the owner.

Figure 3 shows the process of building the wall from the bottom up with the installation of lowest level tiebacks first. As can be seen, some of the tieback bar extensions using couplers to the front of the wall are very long, up to 20 feet. Backfilling of the lower portion of the wall was accomplished by end dumping crushed rock from the top of the slope to the bottom of the wall. Backfilling around the upper level of tendons was accomplished by end dumping roadway embankment soil from the top of the slope, then compacting the soil with hand held compactors around the tendons. Because the tendons were at an angle, good compaction under the tendon was hard to achieve, and some bending in the bars was observed.

There are potential performance problems with the system designed for this project. The problem occurs if bending is induced in the bar tieback tendon. The bar tendon is a high-strength, post-tensioning tendon with large capacities in tension, but very little capacity in bending. The bending develops when fill is placed over the tendons. The fill tends to

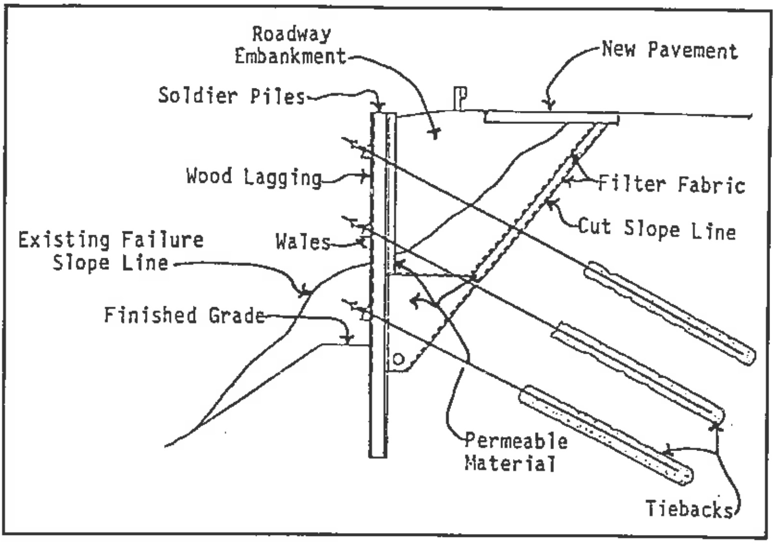

Figure 1

Figure 2 shows the completed wall on this landslide project.

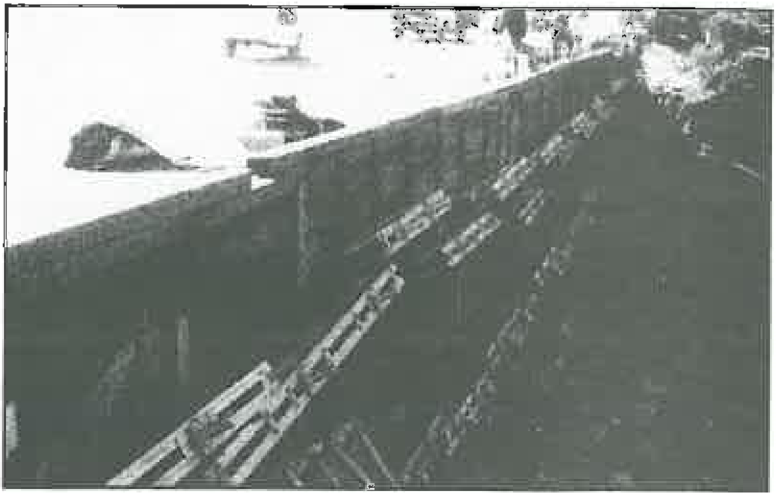

Figure 2

be poorly compacted under the bar, and highly compacted over the top of the bar. Bending also develops when the fill settles after completion of the entire backfilling operation. Further complicating the problem for this wall, one end of the tendon is fixed at the wale, and any rotation will kink and bend the bar against the side of the wale. At the backside of the backfill zone, the tendon is tightly grouted in a small-diameter hole resulting in another point of partial fixity.

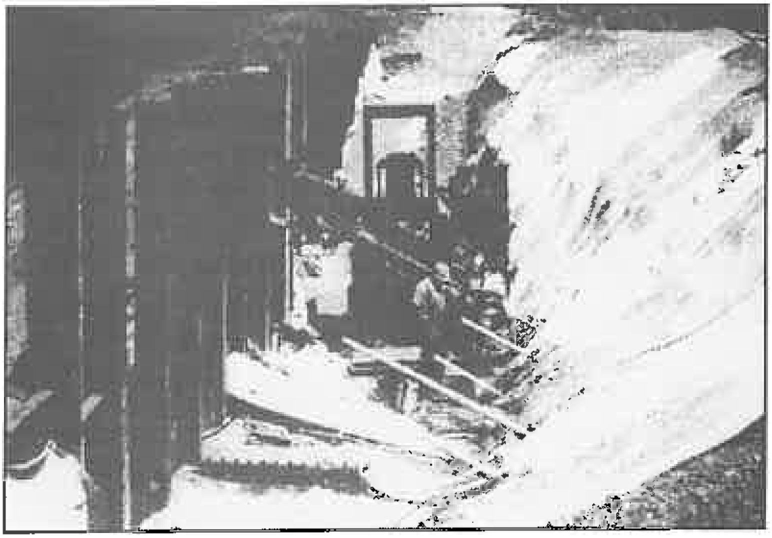

Figure 3

The cost of this California tiedback wall was quite high, in excess of $100 per square foot. Since treated wood lagging was used for the wall facing, there is also the potential for long-term maintenance problems.

Tiedback walls can be built from the top down in landslide situations to solve many of the problems created by the California design approach mentioned above. A project for the Virginia DOT in Christiansburg, Virginia, illustrates the top down approach. VADOT went out for bids for a tiedback wall for an emergency landslide repair. The State's design consisted of drilled-in solder beams socketed into rock, rock tiebacks and a treated timber facing. However, the DOT did allow alternate wall systems designed by prequalified specialty contractors to be bid also. In this case, the successful tieback wall contractor used a patented system consisting of driven soldier beams, temporary wood lagging to support the earth between soldier beams, rock tiebacks, and a precast concrete facing attached to the tiedback soldier beam system (see Figure 4.) This system provided full stabilization of the cut face at all times as the wall was built from the top down, allowing traffic to be maintained on the two-lane roadway as the wall was constructed. Once subgrade was reached in front of the wall, the precast concrete facing and stone fill in the two-foot (plus or minus) space between the back of the precast units and the face of the Siedback system was constructed from the bottom up. Steel straps connect the precast units to the soldier beams, while the stone fill serves as the wall drainage.

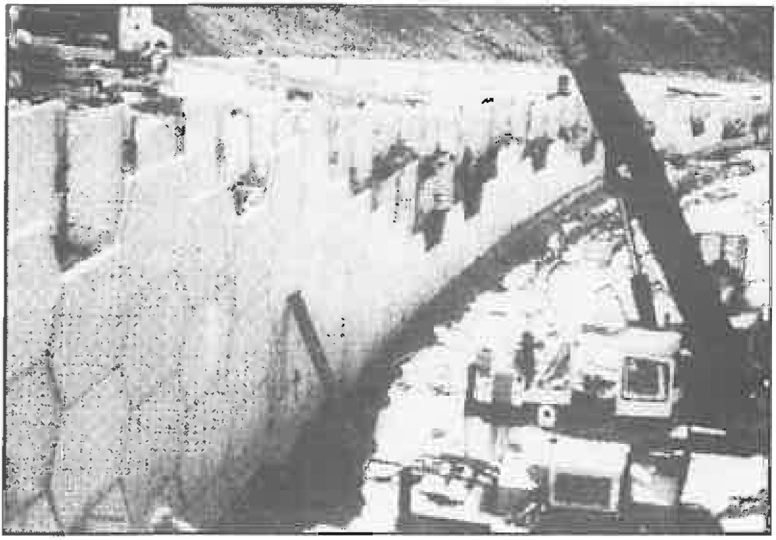

Figure 4

Some of the advantages of the alternate design on this project:

- It used less costly drive soldier beams to rock.
- The two-foot-plus space between the precast facing and the soldier beams allowed the use of external walers to connect the tiebacks to the soldier beams.
- The steel straps system that connect the precast facing to the soldier beams was designed with three degrees of freedom to accommodate the tolerances in driving the soldier beams.
- The use of the precast facing gave a very attractive appearance and eliminated the potential long-term maintenance problem with the treated timber facing.
- Lastly, this relatively small tiedback wall was constructed for approximately $90 per square foot, considerably less than the cost of the above-mentioned California project.

Designing for Tolerances, Flexibility and Allowance for Tiebacks Failing Test Criteria

The designs for the tiedback walls systems must consider the installation tolerances for the soldier beam and wall systems and also incorporate some flexibility into the systems to allow for changes in tieback angles to accommodate changes in soil/rock conditions. Furthermore, as mentioned above, some tiebacks failing the test criteria should be anticipated especially in the initial phases of the work and the designs must allow for the easy installation of replacement anchors.

External Waler Problem

A highway project in northern Illinois was designed as a tiedback, continuous steel sheet pile (PZ4O) wall with a future 12-inch, cast-in-place concrete facing. In order to connect the tiebacks to the continuous steel sheetpile wall, a shop-fabri-

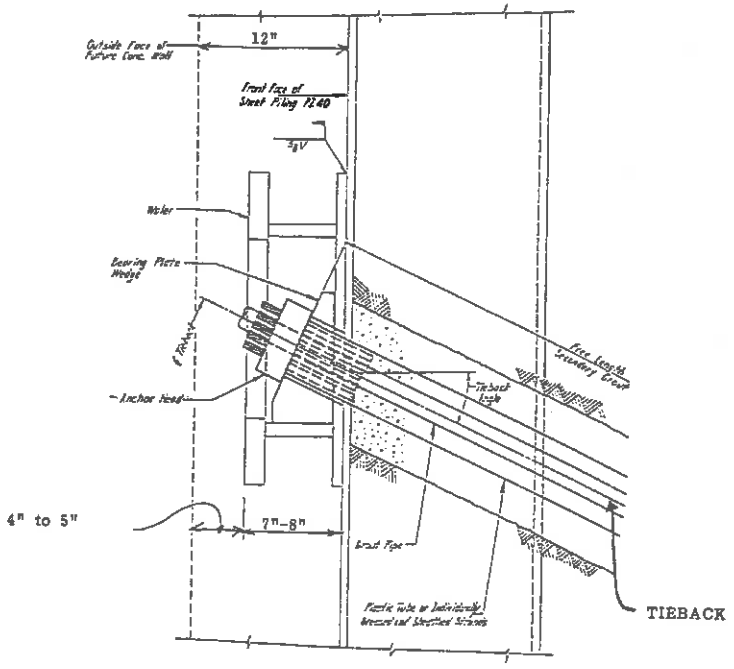

Figure 5

cated welded plate girder-type waler was designed to connect three to five tiebacks and fit within the future 12-inch concrete facing (see Figure 5). The intent was to install relatively large-diameter soil anchors (12-inch-plus/minus-diameter) at the center line of every second or third outboard pan of the steel sheetpile system. After the tiebacks were installed, the prefabricated waler with a five-inch-diameter hole in the back plate of the waler at each predesigned anchor location would then be set over the tieback tendons and welded to the steel sheetpile wall. Large solid steel bearing plate wedges would then be used to set against the plate of the waler to achieve the tieback angle.

In the field, the PZ4O sheetpiling could not be driven to the proposed tip elevation due to the very hard driving and the specified one-eighth-inch batter away from the cut could not be achieved. Furthermore, when the actual locations of the interlocks of the PZ40 sheetpiling were measured in the field, it was determined that the interlock to interlock distance of the double steel sheets ranged from approximately 3.1 to 3.6 feet, instead of the exact dimension of 3.28 feet on which the layout of the holes in the waler for the tiebacks was based.

This resulted in extensive delays to the project as each waler section had to be specially shop fabricated to match the actual as-driven location of the sheetpiling. In addition, extensive blocking with steel wedges was required in the field behind the waler to fill the gaps of up to three inches, since the face of the steel sheetpiling did not line up with the back of the shop-fabricated walers. Figure 6 shows the external waler utilized on this highway project. It should be noted that the as-designed waler system provided no allowance for replacement tiebacks for those failing the testing criteria. As a result, further delays occurred during the approval process for supplemental walers for the replacement tiebacks.

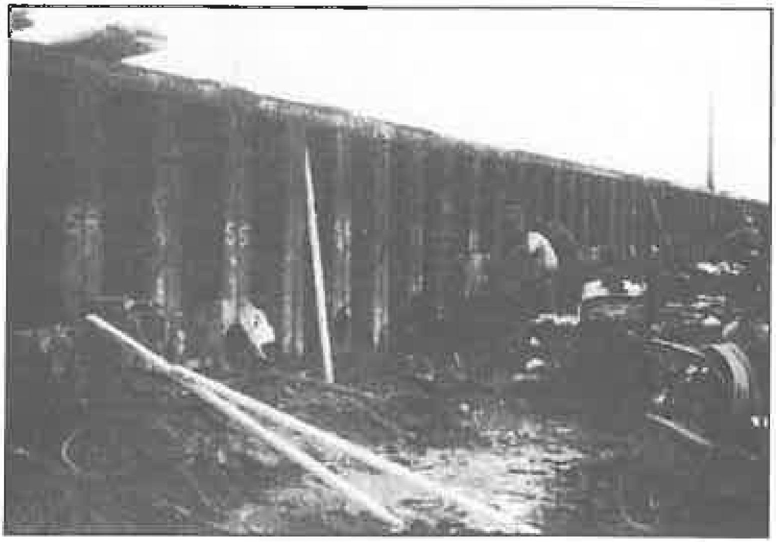

Figure 6

Since these supplemental walers would not fit in the future 12-inch concrete wall, the concrete wall thickness had to be increased significantly. Lastly, the as-designed waler system allowed absolutely no flexibility in changing the tieback angle to handle changes in soil conditions which were encountered in the field. This caused further problems in the project. Needless to say, several claims were filed due to delays and redesign costs on this project.

A good solution to the design problems encountered on this project is illustrated by a project for the I-10 Freeway widening in Phoenix, Arizona. This project was designed by the State DOT's consultant as a gravity retaining wall for the cut situation resulting from the highway widening. However, the DOT did allow alternate patented tiedback wall systems by approved specialty contractors to be incorporated in the bid documents. An alternate tiedback wall system was selected by the prime contractor for the retaining wall construction. This tiedback wall consisted of double P-27

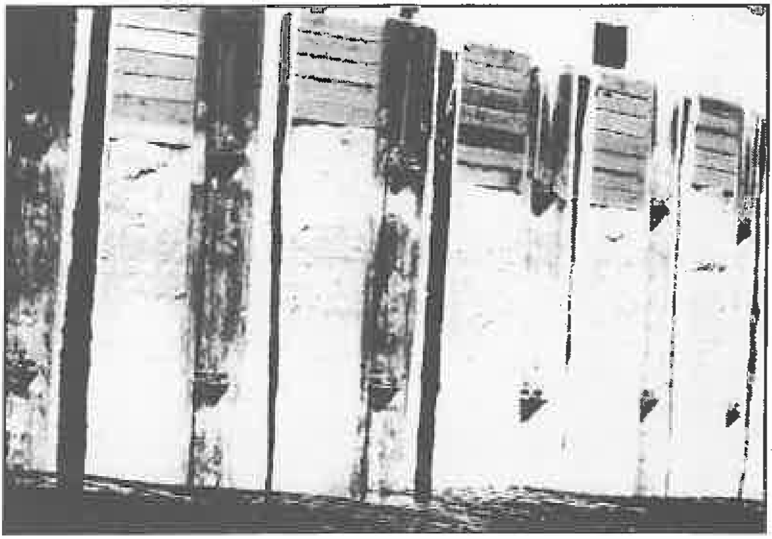

Figure 7

steel sheetpiles (patented) for the soldier beams with the tiebacks going through a hole cut in the center of each soldier beam (see Figure 7). The tiebacks were situated in the recessed pan of the double sheetpiles and connected to the sheetpiles with welded double channels. As a result, the tieback connections did not project into the 12-inch concrete facing. Further, this type of connection detail allowed for changes in the tieback angle and also the installation of replacement tiebacks as required. This tiedback wall system would have been appropriate on the above Illinois highway project, since the designer's fear of soil squeezing between individual soldier beams never materialized due to the stiff to hard soils encountered. The Arizona tiedback wall was constructed for approximately $50 per square foot including a colored architectural concrete wall facing, while the above Illinois highway wall, including the future concrete facing, was bid for roughly $75 per square foot.

Recessed Waler Problem

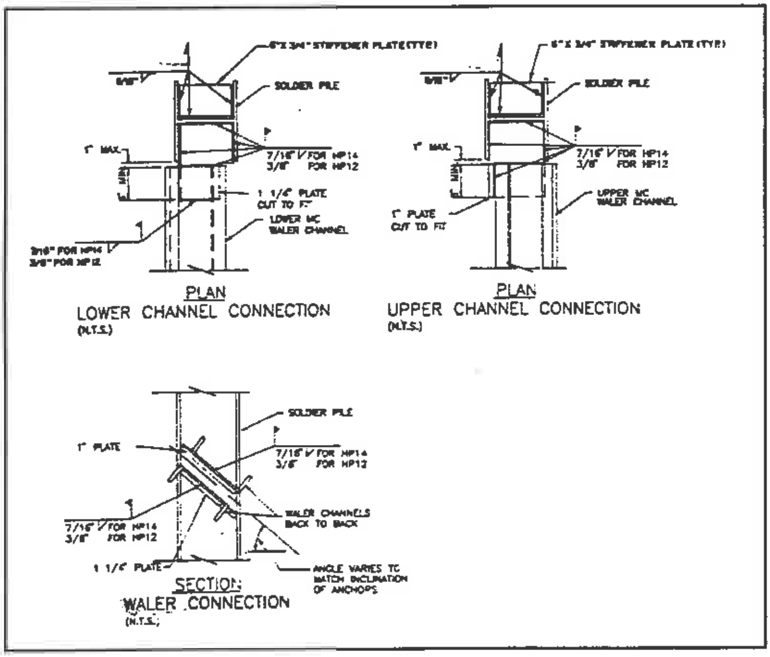

Figure 8

Another highway project in northeastern Illinois further illustrates the problem with tieback connection details. In this underpass project, the design consultant elected to use drilled-in soldier beams with H-pile sections. The tiebacks were connected to the H-piles with a recessed double channel system located between the flanges of the H-piles as shown in Figure 8. This waler system required considerable hand excavation behind the flanges of the H-piles, along with extensive difficult field burning and welding in order to make the waler fit properly within the as-constructed soldier beam locations. Further, the potential for rotation of the soldier beams during stressing was another problem, since the tiebacks were not concentric to the center of the H-piles and over-excavation behind the back of the H-piles would probably be necessary. The design also required all the soldier beams and walers to be shop painted and the over-excavated zone for waler installation to be completely filled with grout. Thus, the waler connection details on this project were quite expensive.

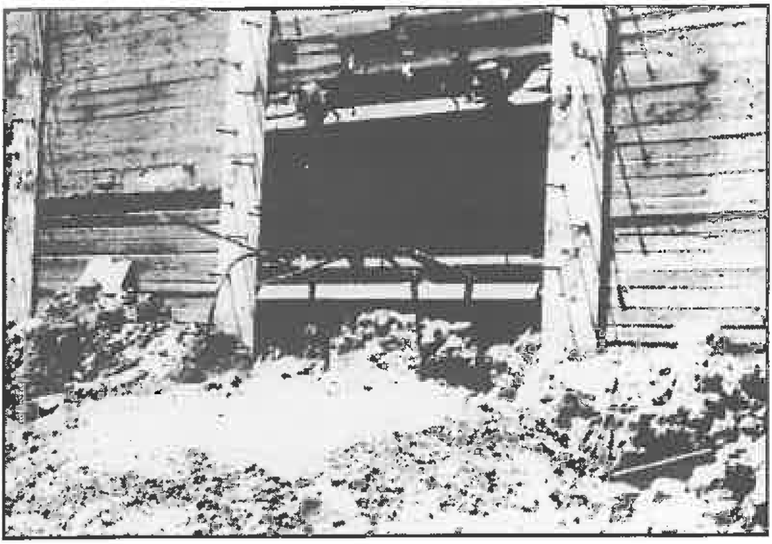

Figure 9

The prime contractor on this project decided to do the permanent tiebacks themselves, even though they had virtually no permanent tieback experience. The lower section of the double channel waler was welded in place prior to the tieback installation. The tiebacks were then installed using a 14-inch-diameter auger. This resulted in the tieback centerline being significantly above the centerline of the five-inch space between the double-channel waler. Furthermore, a very high percentage of the initial tiebacks on the project failed the testing criteria, necessitating the installation of a considerable number of replacement tiebacks and walers (see Figure 9). This resulted in extensive delays and extra costs on the project.

An Ohio DOT underpass project in Lima, Ohio, illustrates a good solution to the tieback/waler connection problems on the above northeastern Illinois highway project. The design consultant for ODOT in the preliminary design stage discussed the project with specialty contractors to get their input. As a result, the designer decided to design and specify the location, size and length of the soldier beams, along with the location and design loads for the tiebacks. Drilled-in soldier beams were selected using double-channel sections with the channel sizes being specified. A performance specification was utilized for the tieback work, allowing the contractor to determine the installation method, tieback diameter and anchor length necessary to develop adequate load capacity to satisfy the anchor testing acceptance criteria. In addition, the contractor was allowed to determine the horizontal spacing between the double channels of the soldier beam to satisfy the requirements for his tieback drilling method, along with details for connecting the tiebacks to the double-channel soldier beams. Further, the tieback work on this project was restricted to a list of prequalified specialty contractors.

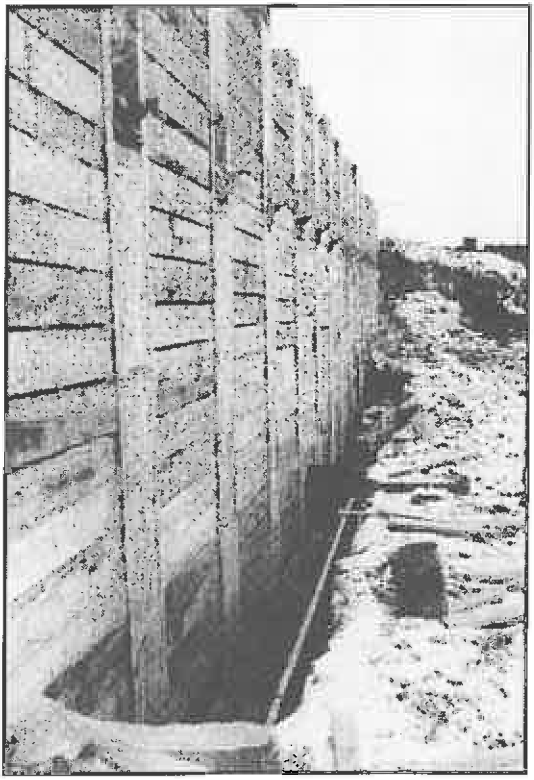

Figure 10

Figure 10 shows the simple tieback to soldier beam connection details used on this ODOT project. This connection was concentric to the centerline of the soldier beams, recessed so as not to project into the cast-in-place concrete wall facing, and flexible to allow for change in the tieback angle. The installation of replacement of tiebacks for those failing the testing criteria would have been very easy and inexpensive with this connection detail, although no replacement tiebacks were required on this project. This tiedback wall was completed on schedule, without any claims for extra costs. The bid price for the Lima, Ohio tiedback wall with the concrete facing was approximately $60 per square foot, compared to roughly $65 per square foot for the northeastern Illinois tiedback wall including the concrete facing.

Alternate Wall Approach to Retaining Wall Construction

A Houston, Texas highway project represents a very successful approach to contracting for tiedback wall construction. The Harris County Toll Road Authority constructed Beltway 8 to completely encircle the City of Houston. A one-mile section of the new road was slated for construction through an area with a large number of commercial establishments on the north end and through an existing neighborhood to the south. In an effort to minimize its impact on the area, this section was designed as a depressed roadway. The typical cross-section consisted of the depressed main lanes flanked by frontage roads on either side at grade.

The original design called for reinforced earth type retaining walls along both sides of the depressed main lanes. However, contractors were allowed to submit voluntary alternate retaining wall systems at bid time. The bid documents contained a performance specification which set the following parameters for alternate retaining wall systems: 1) the minimum design earth pressure was specified; 2) corrosion protection requirements were outlined; and 3) either cast-in-place or precast concrete was allowed but the architectural finish was to be exposed aggregate.

Contractors were required to bid on the quantity of walls shown in the plans and to submit a traffic control plan for construction of the optional wall.

Figures 11 and 12 show typical cross sections through the proposed roadway with both the tiedback alternate and reinforced earth type wall superimposed. In comparing the two, it becomes clear that the permanently tiedback wall offers many advantages over the fill-type wall which was originally specified.

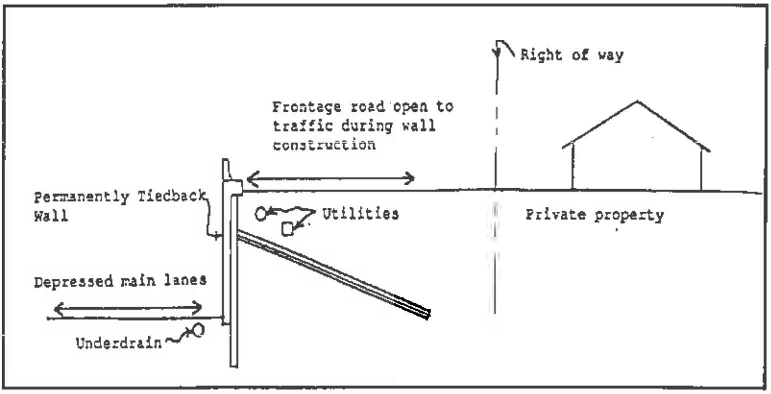

Figure 11

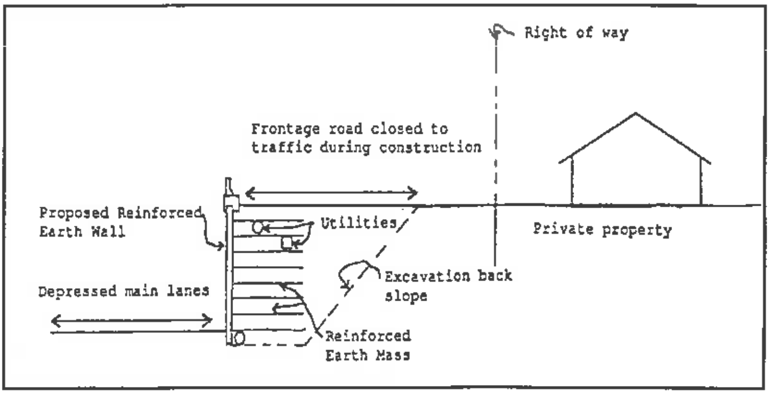

Figure 12

The primary advantage was that the tiedback wall allowed for earlier completion of the frontage roads, thereby greatly simplifying traffic control while shortening the construction schedule. The owner and the general contractor both realized the potential benefits of the alternate and as a result it was accepted.

The four main structural elements of the wall are the soldier beams, lagging, tiebacks and precast concrete facing. The soldier beams, lagging and tiebacks provided the temporary excavation support which was required in order to excavate for the depressed main lanes while maintaining traffic on the frontage roads. The addition of an appropriate level of corrosion protection provided for the long term integrity of the permanent structure. In addition, in order for the soldier beams, tiebacks and concrete facing to act as a structural system, a connection between the soldier beams and facing was required. A cast-in-place concrete closure was used to accomplish this purpose.

Soldier beams were fabricated from double channels. A double-channel section was chosen since it allowed for placement of the tieback through the center of the soldier beam, eliminating the need for external walers, while applying the tieback force concentrically to the soldier beam. Each soldier beam was installed in a predrilled hole, taking care to position the double channels properly prior to backfilling the annular space around the soldier beam with lean concrete. Following soldier beam installation, the cast-in-place coping was installed. Lagging was installed in lifts which did not exceed five feet to prevent caving of the soil between soldier beams. Workmanship was critical in order to prevent formation of voids behind the lagging due to removal of too much soil. Figure 13 shows the tiedback walls once subgrade was reached.

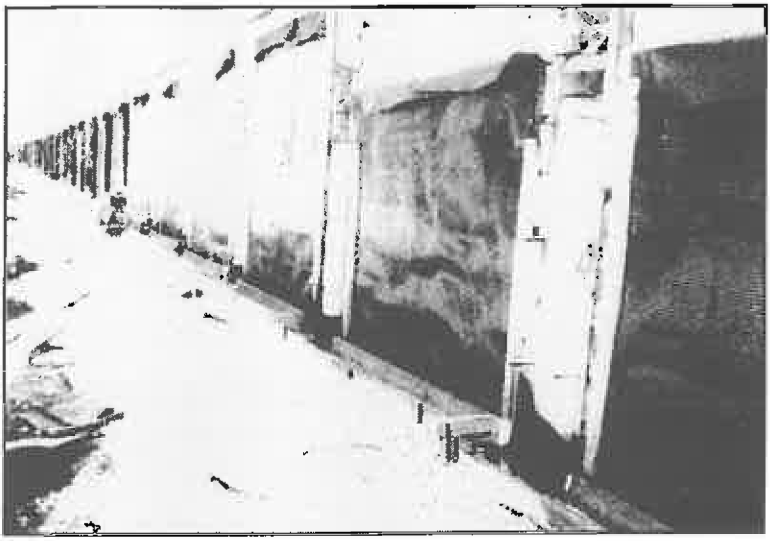

Figure 13

Provision of adequate drainage for the soils behind the wall was necessary since the design was based on a free-draining system. For this reason, the entire face of the wall was covered with a prefabricated drain mat which was attached to the lagging prior to installation of the wall facing. The prefabricated mat collected any water and allowed it to flow by gravity down the face of the wall and empty into the underdrain which ran full length along the front of the wall. Since there would be a four- to six-inch space between the precast concrete facing and the drain mat, backfill was placed behind the precast panel to fill the void. In order to eliminate the need for compaction, cement stabilized sand was used.

Finally, the precast concrete panels were erected using temporary straps welded to the soldier beams to hold them in place until the concrete closure was poured. Figure 14 shows the completed project open to traffic. It is estimated that the use of permanently tiedback walls saved six months on this project. The tiedback walls on this project including the precast facing were constructed for roughly $40 per square foot.

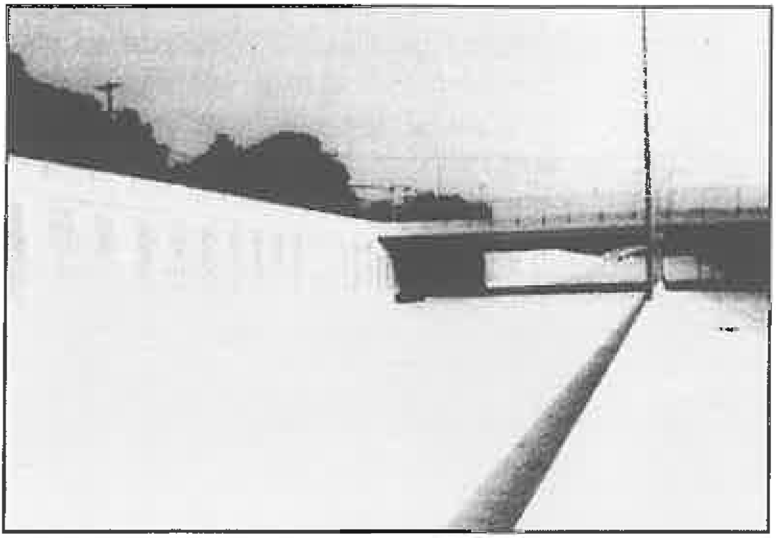

Figure 14

CONCLUSIONS

Where specialty contractors have had input during the design phase or contractor designed alternate tiedback walls have been allowed during the bid stage, successful tiedback wall projects have resulted. On these projects, constructable and economical tiedback walls have been contracted for and build without claims or delays.

It appears that the best contracting approach is to allow alternate tiedback wall designs by prequalified specialty contractors to be incorporated in the bidding documents along with the owner's retaining wall design. If this approach is not possible, then at the very least, a performance specification approach should be utilized for the tieback work. The contractor should be allowed to select the tieback installation procedure, drillhole size, anchor length required to satisfy the testing requirements, and tieback connection details compatible with his drilling method and the wall installation tolerances. Further, the tieback work should be restricted to only qualified and experienced specialty contractors. The advantage to the performance specification method is that the contractor is responsible for successful performance. Thus, any tiebacks which fail the testing criteria will be replaced by the contractor with no extra cost to the owner.

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