GEOTECHNICAL RESPONSES TO ENVIRONMENTAL AND GEOLOGICAL CONSTRAINTS ALONG INTERSTATE-70 GLENWOOD CANYON, COLORADO

by

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ABSTRACT

Glenwood Canyon is located in northwestern Colorado, about 150 miles west of Denver. Created by the Colorado River, it is approximately 12 miles long and up to 3000 feet deep. It has provided an important transportation route for many years. Currently U.S. Highway 6 and the Denver and Rio Grande Western Railroad pass through the canyon.

The Glenwood Canyon section of Interstate-70, now under construction, has been controversial. For almost 30 years, a series of proposals and counter-proposals have been made. Alternative designs evolved and were subjected to extensive public debate. The final approved design incorporates very high standards of aesthetic and environmental protection.

Implementation of the conceptual design plans has required the analysis of many complex geotechnical problems and the use of innovative designs, especially for structures on talus slopes.

INTRODUCTION

Authorization for the addition to the Interstate system of Interstate-70 from Denver westward to meet Interstate-15 in Utah was given in 1958. Selection of the route for Interstate-70 was controversial at many locations and construction has involved several important engineering achievements, including the Eisenhower Tunnel under the Continental Divide at an elevation of 11,000 feet and the innovative environmental and engineering works on Vail Pass. However, no section of Interstate-70 has been subjected to more debate and public scrutiny than the section through Glenwood Canyon.

Glenwood Canyon is in northwestern Colorado, just east of the town of Glenwood Springs, approximately 150 miles west of Denver (Figure 1). The Canyon was formed by the incision of the Colorado River. It is about 12 miles long and has served as an important transportation link for many years, since both the Denver and Rio Grande Western Railroad and U.S. Highway 6 currently occupy the canyon floor.

The Glenwood Canyon section is one of the final portions of Interstate-70 under construction. Interstate-70 to the west through Glenwood Springs was completed by 1970. This included a short section within the western end of the canyon involving a short tunnel. The section of Interstate-70 to the east of the canyon was completed by 1980. Figure 2 shows the general geography of the remaining portions of the canyon and includes the names of the principal design sections which will be referred to in this paper.

When the Colorado Department of Highways (CDoH) first considered building the Interstate-70 route through Glenwood Canyon, it seemed obvious that geology would be an important factor in design and construction of the project. The steep topography and rocky canyon walls give a strong first impression that problems in this setting would be concerned primarily with the bedrock. However, this has not proven to be the case. Largely due to environmental considerations, the highway was designed to minimize the amount of rock cutting required and, with the exception of proposed tunnel construction at two locations, the major geologic problems encountered have involved recent, unconsolidated deposits of talus and fine-grained, compressible sediments.

GEOLOGIC CONSTRAINTS

Glenwood Canyon traverses the southern flank of the White River Uplift, a broad dome-like feature which covers several thousand square miles. Deformation of the rocks is expressed along the river as a broad arch which spans the length of the canyon from east to west. The youngest sedimentary rocks are present at roadway level at both ends but occupy a progressively higher topographic position toward the middle of the canyon, where the oldest sediments are 700 feet above the river and Precambrian rocks are exposed along the highway. This deformation also produced numerous faults and frac tures throughout the area, and resulted in jointing which is most commonly expressed as two sets opposed 90 degrees to each other. In the sedimentary rocks, these are usually perpendicular to the bedding.

DESCRIPTION OF BEDROCK UNITS

The oldest rocks in the canyon consist of Precambrian metamorphic and igneous types, identified as quartz-biotite schists and greenstones, intruded by granites and pegmatite dikes. These are overlain by a sequence of younger sedimentary rocks which range in age from Cambrian to Mississippian. These consist of thick hard beds of quartzite, dolomite and limestone which range to several hundred feet in thickness and are separated by occasional thin beds of softer shale. Rapid weathering of the shales undercuts the harder overlying beds and results in rockfalls which cause the outcrops to recede. This produces the "shouldered" appearance which characterizes the canyon walls. Aggregate thickness of the sedimentary rocks is over 1000 feet in the vicinity of the canyon.

DESCRIPTION OF RECENT DEPOSITS

The youngest deposits in the canyon are Pleistocene to Recent in age and include river terraces and alluvium, talus slopes and, unexpectedly, a thick sequence of fine-grained lake deposits which underlie the river bed throughout the eastern half of the canyon. The most significant geotechnical problems encountered in the design and construction of the highway have been associated with these materials.

River Terraces

River terraces are present from a few feet to about 200 feet above the river but older stream-laid deposits are reported as high as 2700 feet above the floor of the canyon. The terrace materials consist of dense, mostly well-rounded gravels, cobbles and boulders of the harder rock types present in the Colorado River drainage, mixed with lesser amounts of sand. In many places, the terraces are covered by talus up to 50 feet thick.

Talus Slopes

Talus deposits are found throughout the canyon but show considerable variation in both size and composition. Where the source is nearby, the deposits cover smaller areas and may be as much as 50 feet thick at the toe. In general, these slopes are partially vegetated. The rock fragments are angular and usually smaller than those in the larger talus slopes, and test borings have encountered pockets of silty material in a few locations.

The larger talus deposits may slope as steeply as 40 degrees in their upper reaches but many are flatter near their bases than the smaller deposits. These flatter, more stable, portions support heavy growths of oak brush and smaller plants, while the steeper portions often have patches of unvegetated rock debris, indicating recent origin and probable current activity. Because of their long vertical reach, many of these slopes pass through much of the stratigraphic column and the talus contains a variety of lithologies. These deposits contain a higher percentage of large rocks with some of the fragments ranging to several feet in diameter. Test drilling disclosed the presence of unfilled voids ranging to six or eight inches across in several of these in the western part of the canyon. These larger deposits may exceed 60 feet in depth.

Lacustrine Deposits

At the end of the Pleistocene a large rockfall occurred near the middle of the canyon. Remnants of it are still visible a few hundred yards west of the Shoshone power dam. The rocks formed a dam at least 200 feet high which blocked the canyon and impounded a lake approximately ten miles long. Because this occurred when millions of tons of finely-ground rock debris were being washed out of the mountains by the melting glacial ice, as much as 80 feet of thinly interbedded gray clay, silt and sand were deposited in the lake. This material has been referred to in Glenwood Canyon geotechnical reports as the "gray layer". The prehistoric lake in which it was deposited is referred to as "Lake Glenwood". Radiocarbon dating performed on organic material recovered from the top and bottom of the deposit shows ages of 8200 and 9500 plus or minus 120 years, respecitvely. As would be expected, the average grain size in the lake sediments decreases downstream, with high percentages of sand and silt near the east end of the canyon and predominantly clayey material near the dam.

Floodplain Deposits

At the time of the rockfall, the canyon east of and above the dam was at least 140 feet deeper than it is today. During the approximately 8000 years following the Lake Glenwood deposition, the gray layer has been covered with floodplain deposits of sand, gravel, cobbles, and boulders which range from a few feet to more than 40 feet in thickness. Overlying the granular material at many locations are extensive lenses of extremely soft, saturated coarse silt and fine sand. Where present, the silt and sand average only a few feet in thickness but in a few locations may reach thicknesses of 20 feet.

ENVIRONMENTAL CONSTRAINTS

The Glenwood Canyon design and construction activities are largely controlled by environmental considerations which have been laboriously developed, debated, and redefined over a 25-30 year period. The process began in 1958 and still continues. Between 1958 and 1966 many route alternatives were considered and it was concluded that Interstate-70 should generally follow existing U.S. Highway 6.

The route location phase lasted ten years (1966-1976). Many groups participated, including a seven-person Citizen's Advisory Committee, several environmental consultants, affected government agencies, a ten-person advisory committee to Governor Vanderhoof, three concept design consultants, the general public, and the Colorado Department of Highways. Many routes were considered, including alternatives to Glenwood Canyon, the status-quo ("no-build") alternative, and various schemes for improvements within the Canyon. In 1971, a draft Environmental Impact Statement (EIS) was issued which recommended a four-lane Interstate be built in the Canyon. Following this draft EIS, it was obvious that the roadway must be sensitively designed to meet the high standards of Interstate construction and the Canyon environment. In September, 1973, three independent consultants were asked to prepare conceptual designs for such a roadway. Different ideas from each of these studies were incorporated into a single concept in 1974 and submitted as part of a Final EIS. Approval of this Final EIS was granted in February, 1976.

The preliminary design process began immediately. It involved an open planning process. Initially, a period of concept evaluation was undertaken with extensive public involvement and public hearings. The seven-member Citizen's Advisory Committee and a Technical Review Group participated in community workshops and interacted with the design team. Recommendations were developed on many matters including environmental considerations, recreational potential, accessibility, and highway width and design speeds.

A period of design development followed. This resulted in dividing the canyon, from No Name on the west to Dotsero on the east, into 12 sections. A series of preliminary design documents were produced. DeLeuw, Cather and Company acted as supervising architect, while the alignments were chosen by two engineering design groups, one for the east half and one for the west half of the canyon. Figure 3 shows a typical set of alignment alternatives generated for one section at this time. In March, 1978, an extensive public hearing sequence was held in Glenwood Springs. A ten-day pre-hearing display of models and design concept documents was viewed by over 800 people, and the public hearing involved over 300 participants.

Following 1978, refinement of the design, construction bidding, and actual work began. Currently, the work is expected to involve 28 major phases, cost $318 million, and be completed in 1991.

The extensive open planning process frequently resembled a New England town meeting. Illustrations of many types were used extensively. Many critical design concepts became accepted at this relatively early stage. These included methods of cantilevering and terracing the roadway and the extensive use of bridges and tiedback retaining walls, so as to minimize the highway's disturbance (see Figures 4-7). Many details concerning the style and type of architectural elements were also chosen at this time, without any concern as to their impact on the actual construction in the geological setting within the canyon. Other environmental consider-ations included several new rest areas, often with extensive recreational activities, and construction of a separate bikeway paralleling the highway (see Figures 8 and 9).

GEOTECHNICAL ENGINEERING RESPONSES

In Glenwood Canyon, design and construction personnel must not only build a safe and economical facility, they must also satisfy the environmental and aesthetic commitments made to the public, while constructing a new facility mostly on top of the existing facility, often in very confined quarters, with minimal disruption to heavy traffic flow. The geologic conditions were not fully investigated prior to the design hearings. The need to construct on talus slopes in the western parts of the Canyon, and the presence of com pressible sediments in the eastern parts of the Canyon have combined with the constraints to require the use of new, innovative construction methods.

Use of prefabricated structural elements, careful sequencing of operations and contracts, and tight supervision are part of the solution. Compaction grouting of loose talus allows use of spread footings for walls and bridge piers. Flexible wall systems that can withstand extreme settlement have been developed. Retention of unstable cut slopes is being accomplished by use of wall panels held in place by soil anchors.

ROCK MECHANICS CONSIDERATIONS

Bedrock affects the construction far less than might normally be expected, because of the decision to minimize rock excavation. Some rock cuts are required, however. Each is evaluated as excavation progresses and natural fractures are utilized to "terrace" the cut and make it appear as natural as possible, while also considering safety and economics. In the sedimentary rocks the bedding is nearly horizontal and experience to date with such cuts has been favorable. Jointing in the igneous and metamorphic rocks is less regular and some possible wedge failures have been identified. So far, all such cuts have been completed satisfactorily.

At Hanging Lake, the road will pass through 3500-foot-long twin-bore tunnels on the south side of the canyon. This will include a 500-foot cut-and-cover section near the midpoint, where a narrow tributary canyon is crossed. Ventilation control structures will be placed here. The balance of the tunnels are in hard Precambrian rocks. However, because of a nearby shear zone, they are more fractured than usual. A ten-foot diameter test bore has been completed and the information gained suggests that steel sets will be required throughout the traffic bores.

A shorter (580-foot long) single-bore tunnel will be required to carry the westbound lanes at the Reverse Curve (see Section 6, Figure 2). This will be driven in Sawatch Quartzite. No major problems are expected, although protection from minor rockfall at the portals is believed necessary.

Rockfall is an ubiquitous hazard throughout the Canyon. In February 1984, a rockfall sent several large rocks through two retaining wall structures, severely damaging them. Although the roadway was not open to traffic, the incident served to emphasize the hazard potential. Review of past accident statistics has revealed several sites of higher rockfall incidence. Further studies by the Colorado Geological Survey and the CDoH are underway to further quantify the hazard and suggest appropriate mitigation measures. Studies near the Shoshone Power Plant suggest scaling of the slopes should be undertaken there.

DESIGN OF RETAINING WALLS

Virtually all of the roadway which is not on bridge or in tunnel is on embankment supported by retaining walls. When completed, approximately 30 separate construction contracts for retaining walls and slabs will have been awarded. It is estimated that over 1.0 million square feet of precast wall panels and over 2.0 million square feet of roadway slab will be constructed.

Five major types of retaining walls have been designed:

(1) Cantilever post-tensioned walls using precast double-tee sections on cast-in-place concrete footings. Standard nominal panel width is 10 feet with heights varying from five to 33 feet (see Figure 10).

(2) Tiedback walls using precast concrete panels and soil anchors. Standard nominal panel width is 10 feet, with heights varying from eight to 20 feet (see Figure 12).

(3) Tiedback walls for temporary support of excavations using precast concrete panels and soil anchors. Standard panel size is eight by seven feet (see Figure 13).

(4) Two stage reinforced earthfill systems have been built in areas of very compressible subsoil in the eastern parts of the Canyon where consolidation of the foundation material is expected to occur during the first two to three years after application of a fill surcharge. The final facing, consisting of precast panels, will be constructed after most of the settlement has taken place (see Figure 14).

(5) Fabric-reinforced walls using geotextiles as earth-reinforcing medium and shotcrete facing have been designed for temporary detour roads (see Figure 15).

CANTILEVER POST-TENSIONED WALLS

The new four-lane facility will often be constructed over the location of the existing two lane facility. A terraced concept (see Figure 5) evolved to mitigate the impact of side-hill cuts and fills. A sophisticated system of retaining walls and cantilevered concrete pavement slabs, where both the eastbound and westbound pavements overhang the face of the retaining wall by six feet, yields a significant overall width reduction. The overhang results in a visual mitigation because it casts a shadow on the wall resulting in an apparent reduction of the wall height.

The construction of this system consists of pre-cast double-tee retaining wall segments, ten feet wide, placed onto a continuous reinforced footing. After the segments are leveled and bolted in place, they are post-tensioned to the footing by means of threaded rods, previously cast into the footing, and inserted through ducts cast into the stems of the tees.

The pavement slab in constructed in 200-foot lengths with diagonal joints (see Figure 11). Ducts containing post-tensioning strands or rods are then placed parallel and perpendicular to the joints in a criss-crossing pattern. In this manner, two-way post-tensioning can be accomplished with all the stressing taking place along one edge of the slab. This allows an adjacent slab to be poured prior to post-tensioning of the previous one.

Except for some minor problems that were easily resolved, this daring concept has passed all tests to date, in that traffic has been running on a completed section for several years now. In addition to its outstanding performance, the cantilever slab/retaining wall system has been widely acclaimed for its aesthetic appeal.

TIEDBACK WALLS

Another space-saving innovation is the retaining walls for excavation support. These occur mainly in areas where, despite the system described above, some excavation is still required on the uphill side(Figure 5). They are also being used for temporary support such as when traffic detours require cutting into the hillside (see Figures 11 and 12). These walls consist of concrete panels held in place by soil anchors which are embedded in the same material that they are meant to hold back. Several of these have already been constructed and were heavily instrumented to monitor movement, especially as related to anchor pullout. So far, results have been encouraging and more widespread use of these systems is anticipated.

FLEXIBLE RETAINING WALLS

When the Lake Glenwood sediments were discovered during exploratory drilling, laboratory tests were performed which indicated potential settlements ranging from 8 to 18 inches. As a result, the preliminary design for conventional concrete retaining walls was revised to a flexible wall design. To test the settlement estimates and evaluate the effects of the movement on flexible structures, two flexible retaining walls were constructed.

The first, consisting of 300 feet of gunite-faced fabric wall with an adjoining 50-foot section of Hilfiker Welded Wire Wall, was built outside the Interstate alignment at the east entrance to the canyon (see Figure 14). The second, a 1300-foot section consisting of 650 feet of Reinforced Earth and 650 feet of VSL Retained Earth, both faced with 20 foot full-height concrete panels, was constructed at Book Cliffs, approximately one mile inside the east end of the canyon. Both installations were heavily instrumented.

Total settlement to date on the fabric wall ranges from 14 to 26 inches, while total settlement on the Book Cliffs wall currently ranges from zero, at one location where bedrock is close to the surface and the gray layer is absent, to 16 inches. In spite of the amount of differential settlement, the concrete panels show surprisingly little structural damage.

Immediately to the west of the Book Cliffs, a new two-stage method of wall construction is being evaluated. In this case, the wall is constructed using a temporary flexible facing and soil reinforcement. Permanent panels will be installed after primary settlement is complete (see Figure 13). To date this technique appears very successful.

In the area of Bair Ranch, saturated floodplain silts were encountered with blow counts as low as one per foot. Consolidation tests indicated settlements of 0.5 inches per foot of deposit thickness could be expected, but that such settlements would be rapid, achieving 95% completion in only a few weeks. Some panel walls have been built on segmented footings in this area and surcharges have been applied. Settlement has occurred as predicted and shear failures in the silt have been avoided. Some additional two-stage wall construction is slated for this area.

COMPACTION GROUTING OF BRIDGE FOUNDATIONS

Preliminary studies have proposed that 39 bridges be constructed in Glenwood Canyon, varying in length from less than 100 feet to over 7000 feet. Some of these bridges are located in environmentally sensitive areas that require special construction techniques which will allow them to be built without disturbing the landform or vegetation except at pier locations. For these situations, independent construction access reports are prepared which illustrate to prospective contractors the access limitations, as well as restrictions on crane locations. Selection of the architectural style was based on constructability, cost, and visual impact. Several larger bridges will be designed as steel and concrete alternates by mandate of the Federal Highway Administration.

Construction of bridge piers and abutments on loose talus became a major concern. The potential settlement here would not be gradual as is characteristic of consolidation; it was predicted that the collapse of void spaces would occur as soon as the superstructure load is transferred to the foundation, with the possible result of overstressed zones in the superstructure.

Since deep foundations such as caissons or piles were ruled out due to prohibitive costs and adverse environmental effects, a method of stabilizing the talus to the point that spread footings could be used had to be devised. Compaction grouting of the talus at the bridge foundation locations was recommended. This involved the injection, at high pressure, of a cement grout mixture into the talus, allowing it to fill all voids and then set up. This should create a large homogeneous mass that will be stable enough to withstand any loads resulting from bridge structures.

The effectiveness of this method was recently demonstrated at a location where this type of settlement had not been anticipated. Settlement of an abutment of a cast-in-place box girder bridge occurred soon after the falsework was removed and the superstructure loads were transferred to the abutment. This settlement continued to the point where the superstructure had to be jacked in order to relieve supercritical stresses. It was decided to immediately initiate compaction grouting operations in order to stop the subsidence. After completion of the grouting, all settlement ceased, and the structures were stabliized.

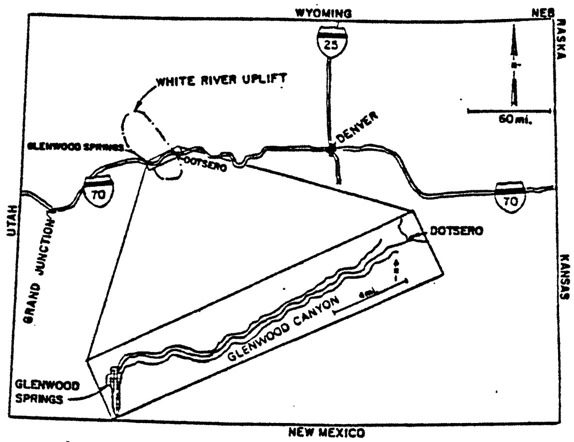

Figure 1. Glenwood Canyon location map.

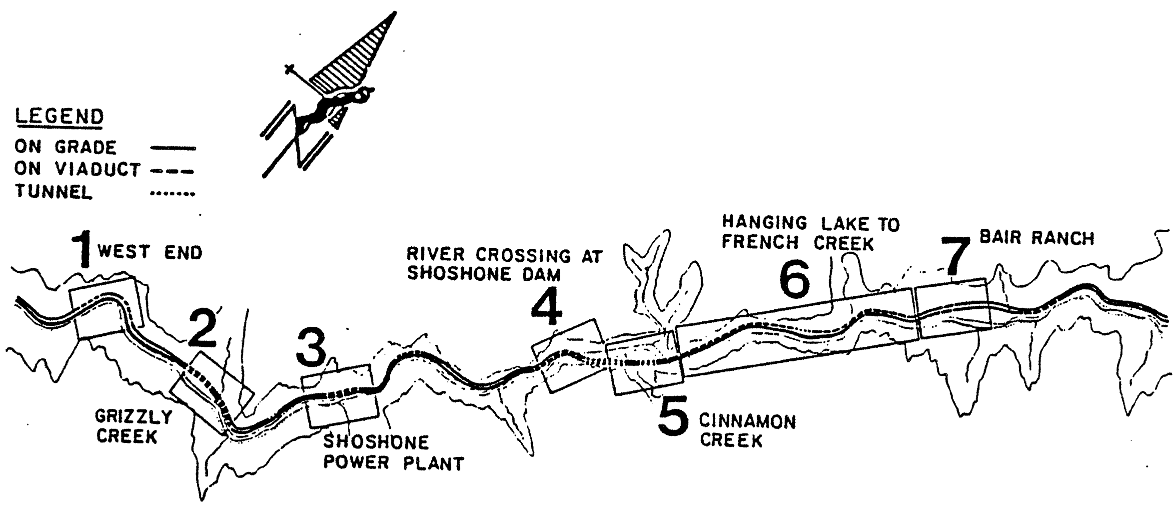

Figure 2. Principal Features in Glenwood Canyon.

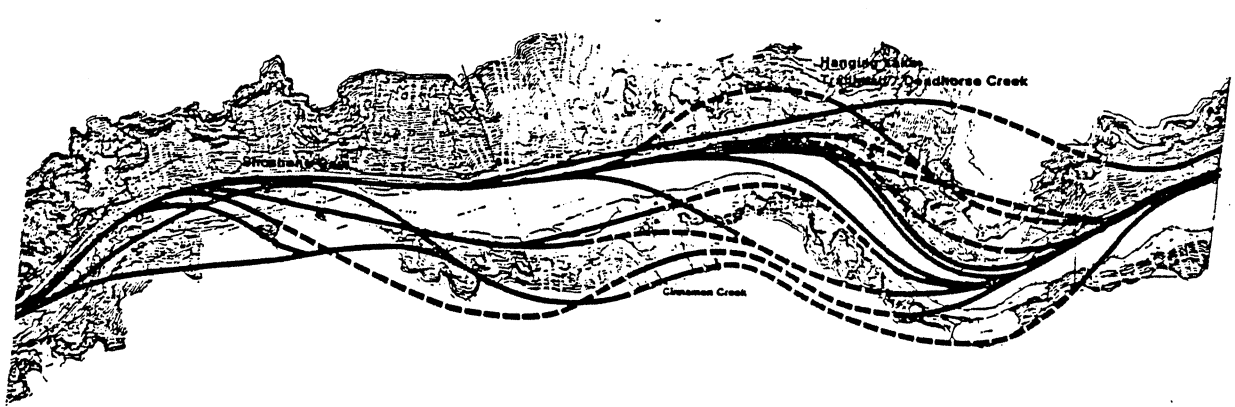

Figure 3. An example of preliminary design alternatives; areas 4 and 5 of Figure 2 are shown.

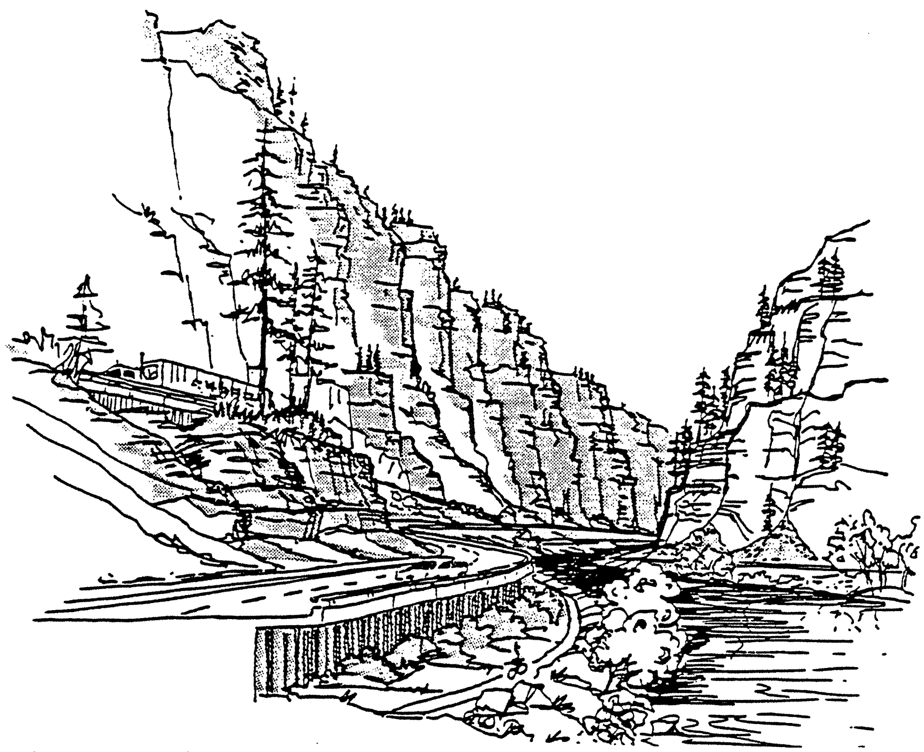

Figure 4. Architectural sketch of terraced roadways.

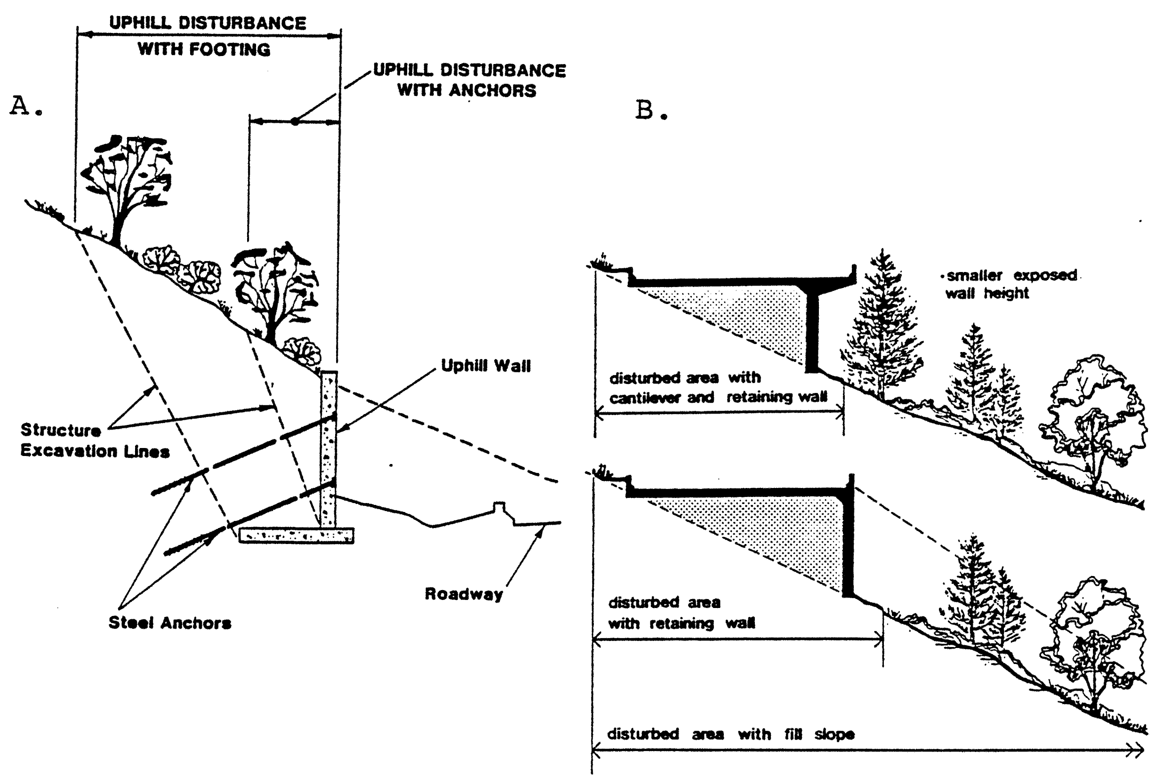

Figure 5. Methods of reducing the area of disturbance on cut (A) and fill (B) slopes.

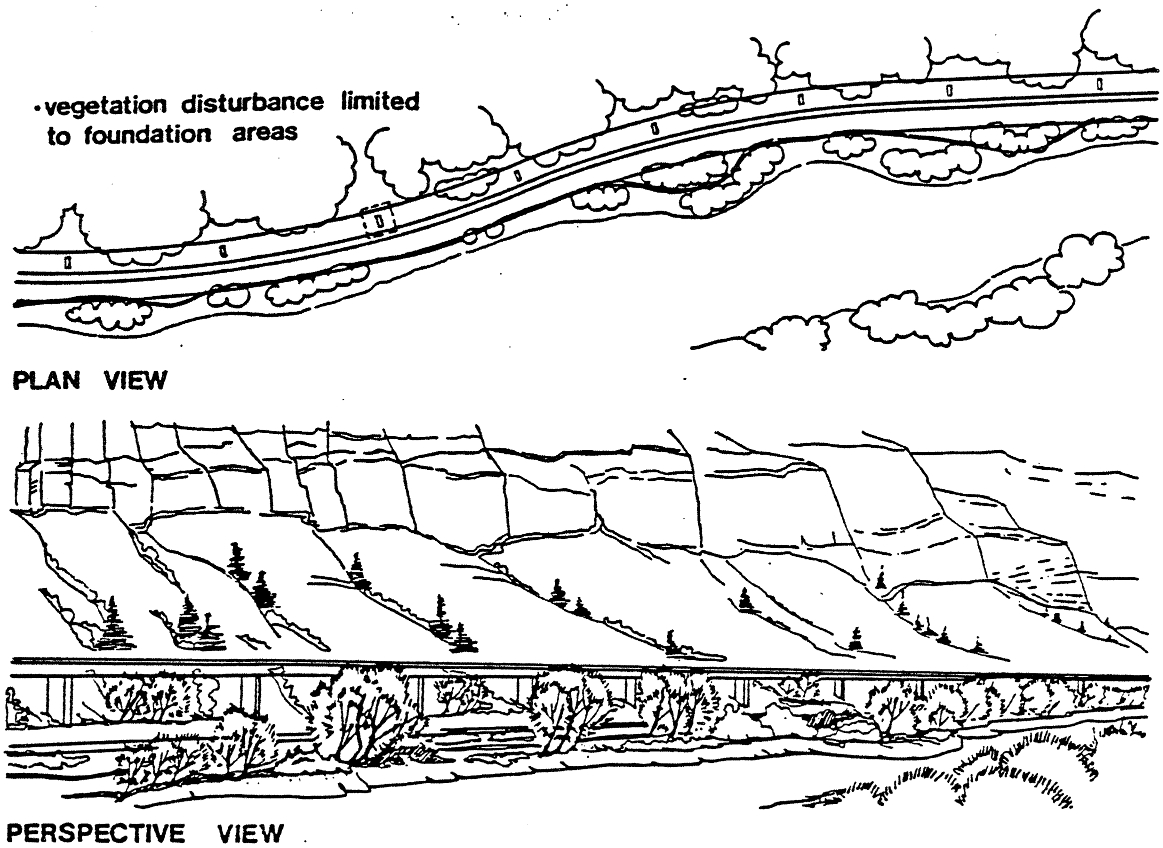

Figure 6. Sketch of side-hill viaduct section.

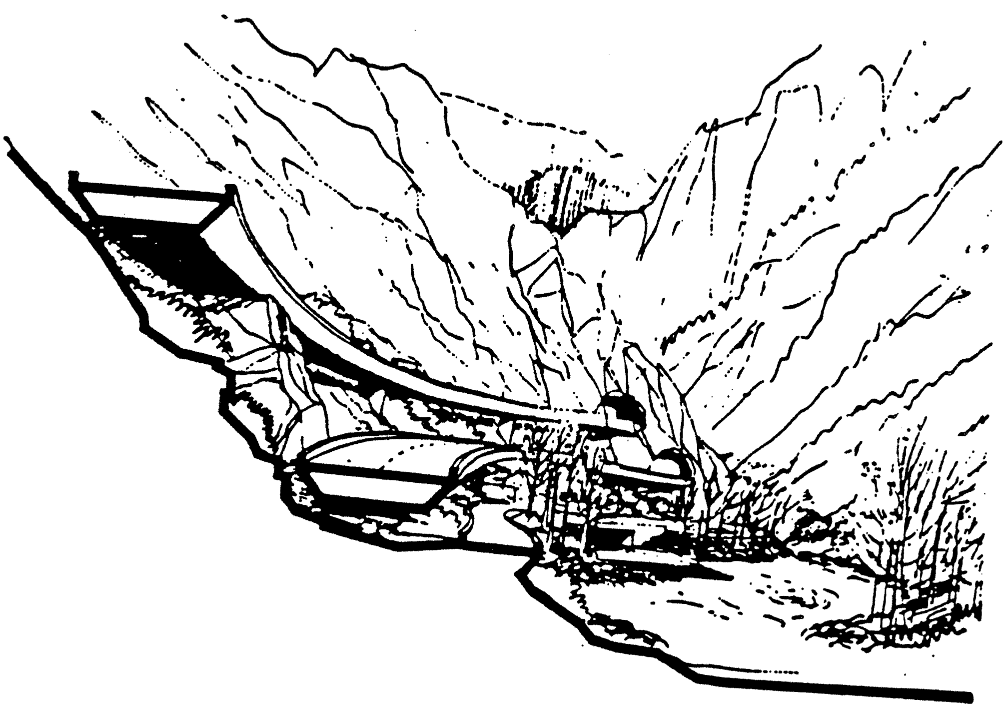

Figure 7. Artist's concept of bridges near Shoshone power plant.

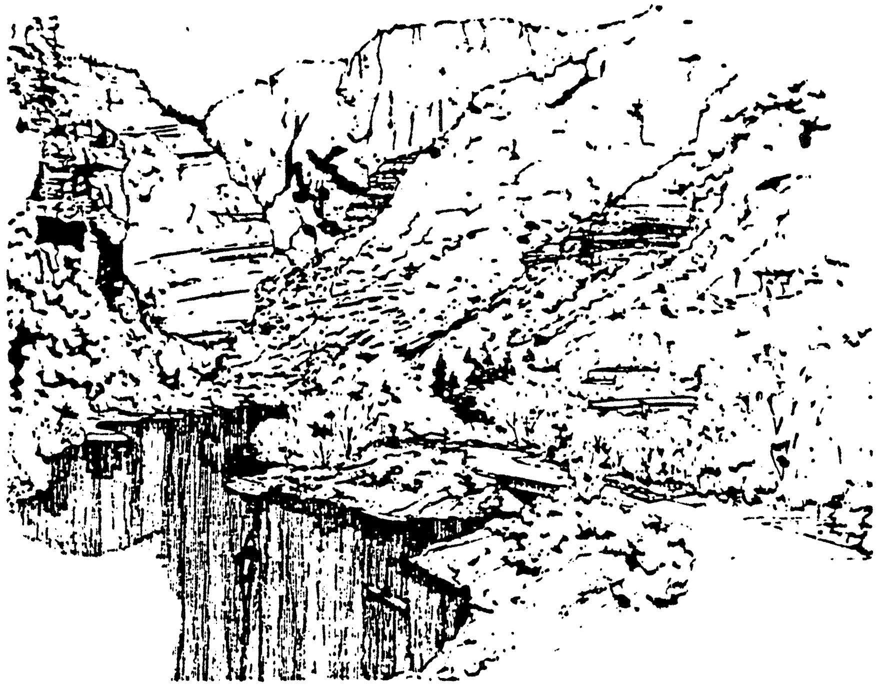

Figure 8. Environmental conceptual sketch; the Grizzly Creek rest area.

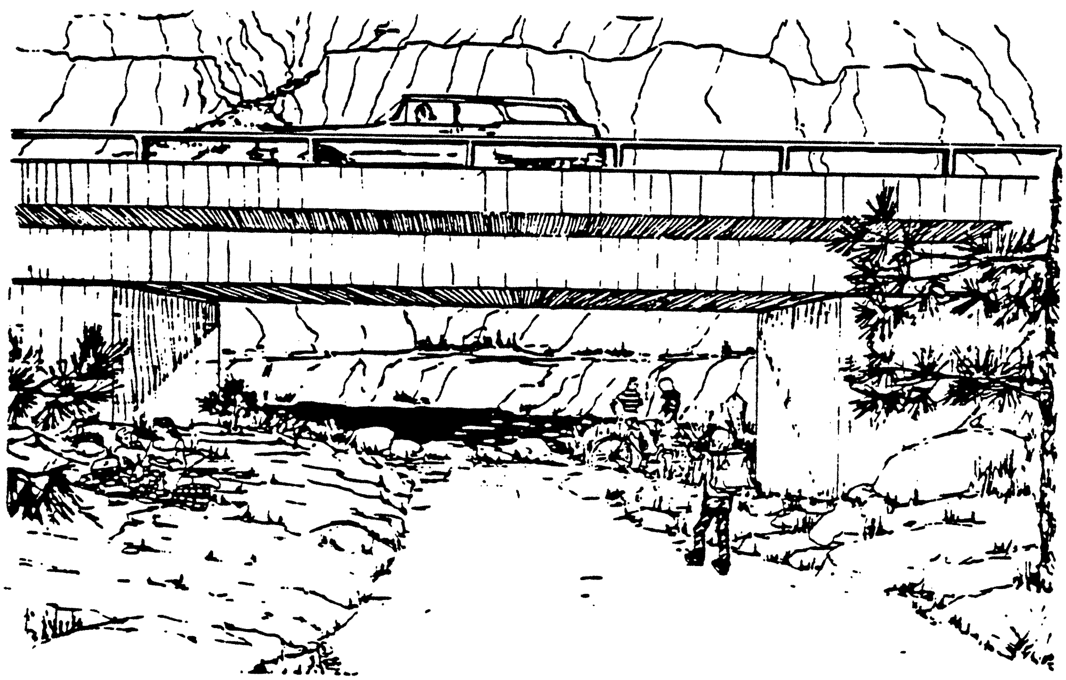

Figure 9. The bikepath and typical pedestrian underpass.

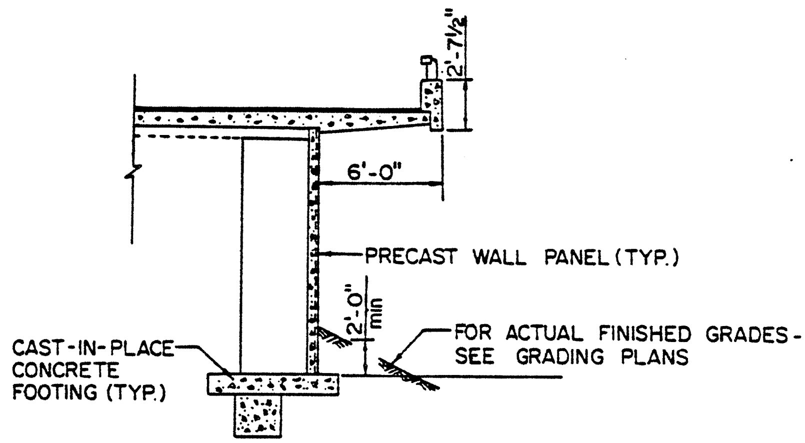

Figure 10. Precast wall with cast-in-place post-tensioned slab.

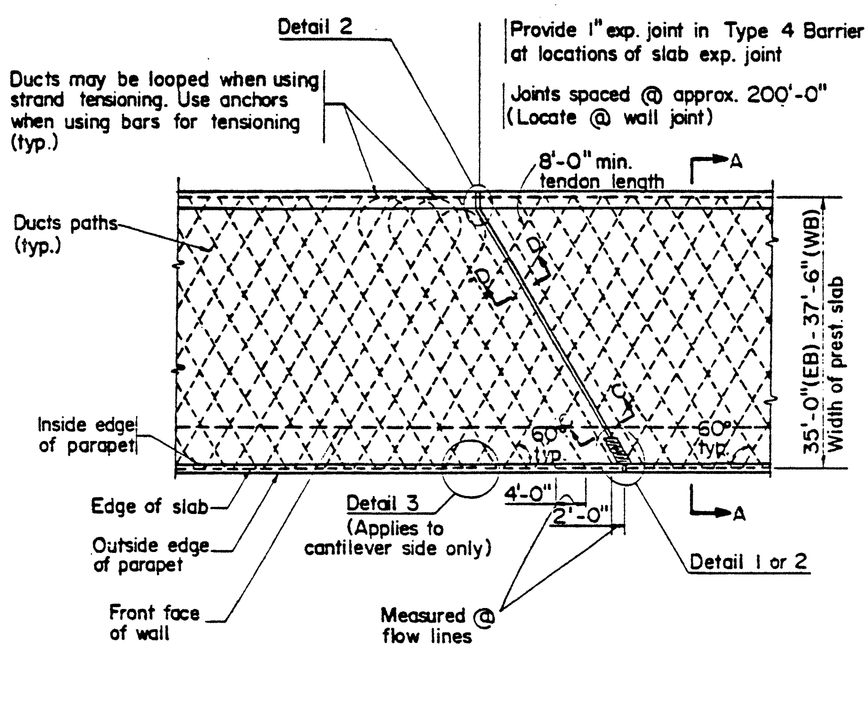

Figure 11. Plan of roadway slab showing location of post-tensioning tendons.

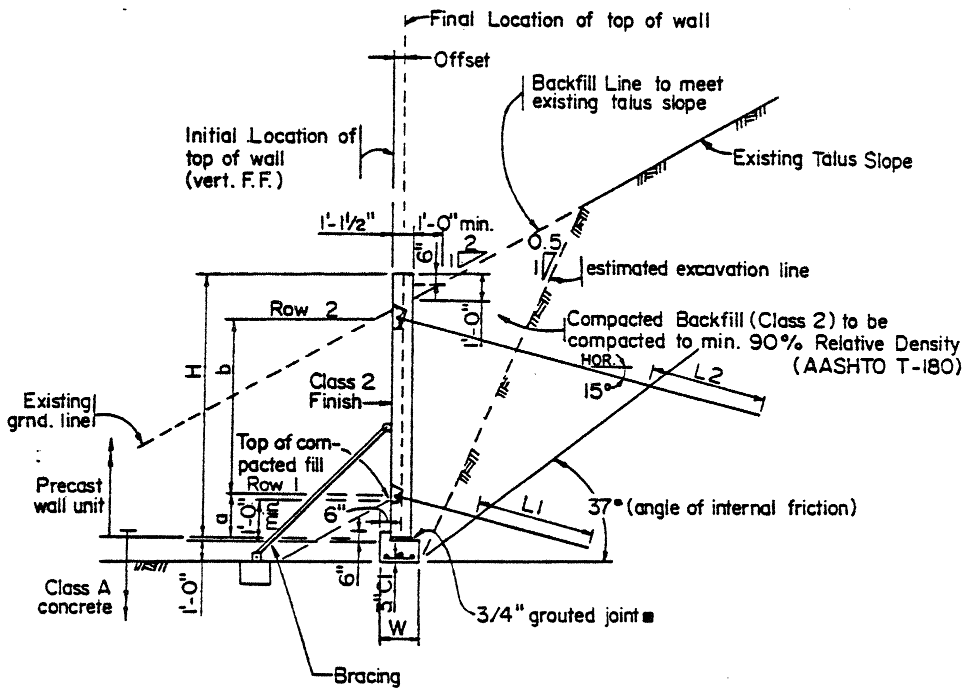

Figure 12. Tiedback wall using precast panel for permanent installations.

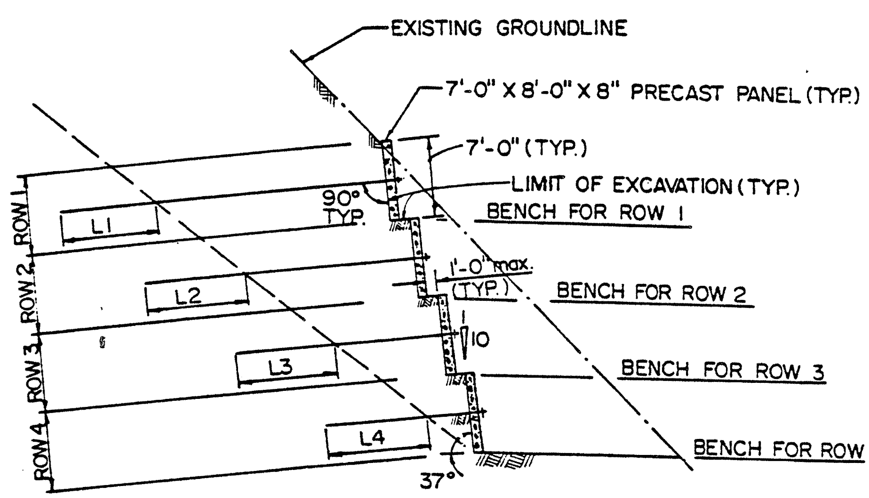

Figure 13. Temporary tiedback walls with precast panels.

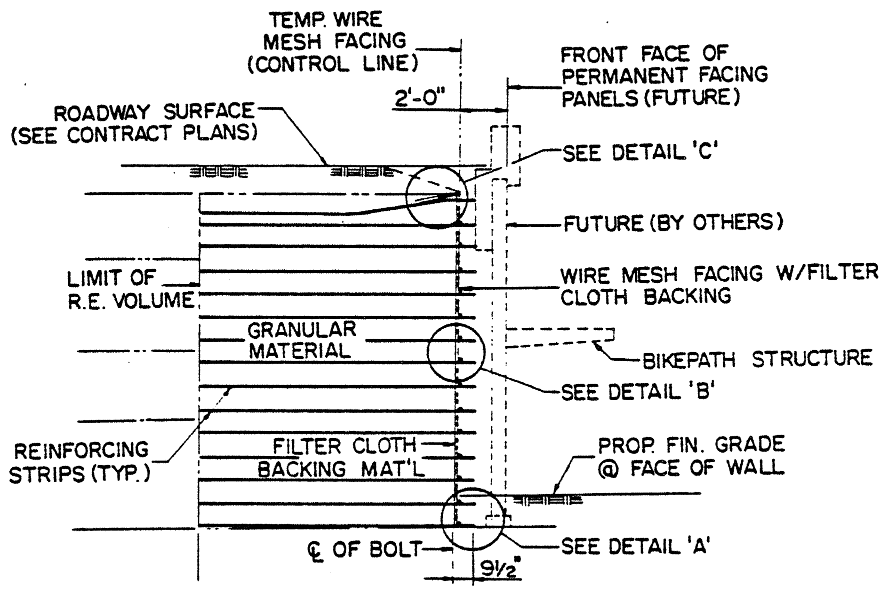

Figure 14. Two-stage wall system for use over very compressible soils.

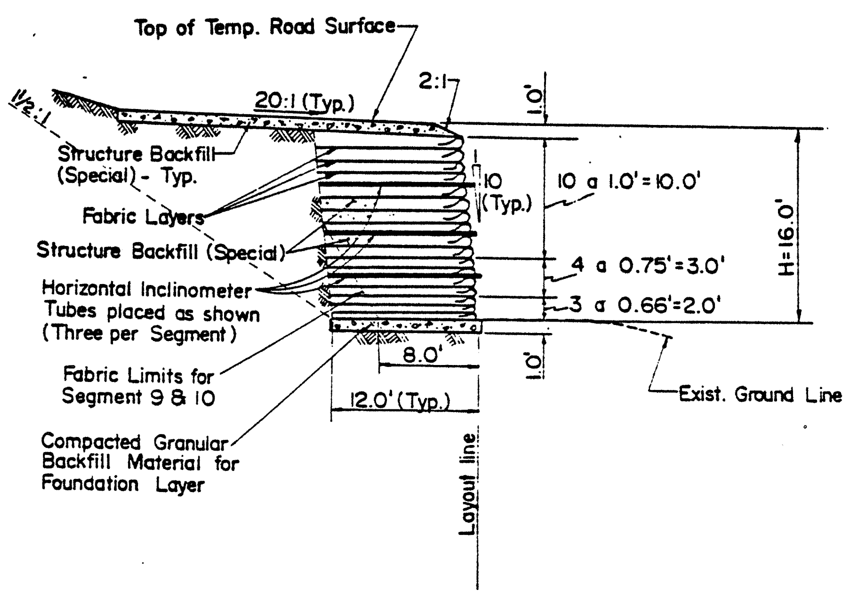

Figure 15. Temporary flexible retaining wall using geotextile fabrics.