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# Reinforced earth retaining walls

# Murs de soutènement en terre armée

Cette communication décrit l'utilisation de terre armée pour le dimensionnement et la construction de murs de soutènement sur l'autoroute Inter Etats I70, dans le Colorado.
Le problème qui se posait, était de tracer et de construire une route à quatre voies avec un minimum d'impact sur l'environnement et de résoudre les problèmes de stabilité des talus aussi bien en hiver qu'en été. En conséquence la solution retenue a largement utilisée les structures préfabriquées qui comprennent un grand nombre de murs de soutènement. Le soucis esthétique n'a pas été absent lors du dimensionnement.
Cette communication présente une comparaison entre les structures en terre armée et les murs de soutènement initialement prévus pour l'autoroute I70 dans le défilé de Vail Pass ; elle donne des indications sur les économies dues au choix de la terre armée et sur le délai d'exécution.
Le choix des écailles courbes (murs en gradins) ou droites (murs de soutènement) est également discuté.

*Introduction*

The purpose of this paper is to briefly describe the involvement of the Reinforced Earth Company of the United States in the massive construction of Interstate Highway 70 on the west side of Vail Pass in the State of Colorado.

The interstate highway construction program was begun in the 1950's to link all major cities of the United States with four-lane divided highway systems of limited access. Some of these were continuous routes across the country in either north-south or east-west general directions. In the west central United States, Colorado is traversed by three of these major routes: I-70 and I-76 run east-west and I-25 runs north-south. I-70 is the principal route that ultimately connects Baltimore, Maryland, with central Utah (figure 1). About 98% of the work on Interstate 70 is complete with only a few sections of minor distance to yet be built to interstate standards. These remaining gaps are in the mountainous terrain of the states of Colorado and Utah. Construction through these areas is extremely expensive, involving massive earth work, long and complex earth retaining and bridge structures, and very close attention to environmental concerns to preserve the natural beauty and ecology of the Rocky Mountains. Although short in comparison with the total length of Interstate 70, these remaining gaps represent significant projects yet to be constructed in order to complete this section of the interstate system.

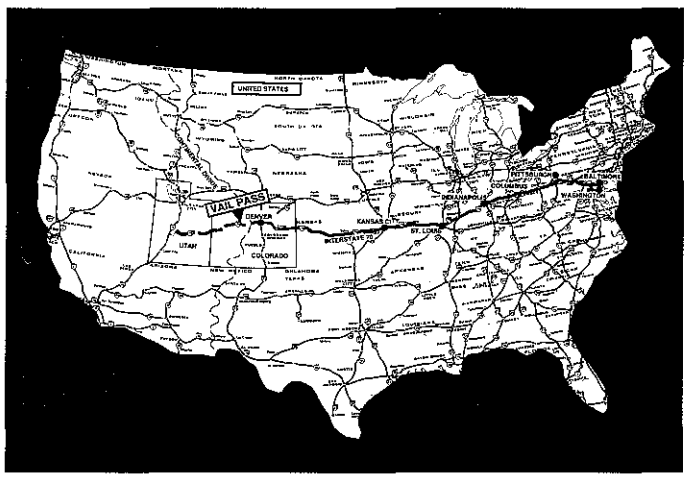



Figure 1.
Location of Interstate Route 70 & Vail Pass

One recently completed section of I-70 traverses Vail Pass in Colorado. At the west foot of the Pass lies the internationally famous ski resort of Vail, and close to the eastern foot of the Pass is a smaller resort community comprised of several ski areas and year-round recreation facilities. The previously existing road through the Pass was a narrow two-lane highway carrying a significant volume of cars and trucks up rather steep grades, often resulting in severe delays to motorists.

Engineering began on the extension of I-70 through Vail Pass in the early 70's and was very

early put to the test of the public hearing process. The Colorado Division of Highways worked cooperatively with many environmental groups to design a roadway that did not detract from the natural beauty of the scenic mountain environment (figure 2) and did not, in any way, harm the delicate ecology of the area. Very unusual design solutions were arrived at whereby cut and fill slopes were either completely eliminated or very carefully done so that revegetation could be established almost immediately. To place a four-lane highway through such rugged mountain terrain within these environmental constraints presented a very challenging problem; and the solution involved some very unique structures, including bridges (some of the first segmental bridges built in the United States) and retaining walls.

In this mountain region the construction season is very limited, and the structures had to be designed so that they could be prefabricated, trucked to the site, and erected in either summer or winter. The precast concrete for these structures also had to be fabricated with a color which would blend into the natural surroundings. For this, a reddish-brown coloration was selected which was close to the color of the natural sandstone outcroppings along the Gore Creek Canyon.

In the retaining wall projects, The Reinforced Earth Company became significantly involved and constructed 14 of these structures, some of which were very extensive in terms of height and length.

This paper touches upon the comparison between Reinforced Earth® structures and the retaining wall system that was initially designed for use on interstate 70 through the Pass, on the economies that resulted from the inclusion of Reinforced Earth structures in the contract bidding process, and on the time frame of construction. The design of the Reinforced Earth walls, both for the unique curved panel, tiered walls and for the straight panel, vertically faced walls will be discussed.

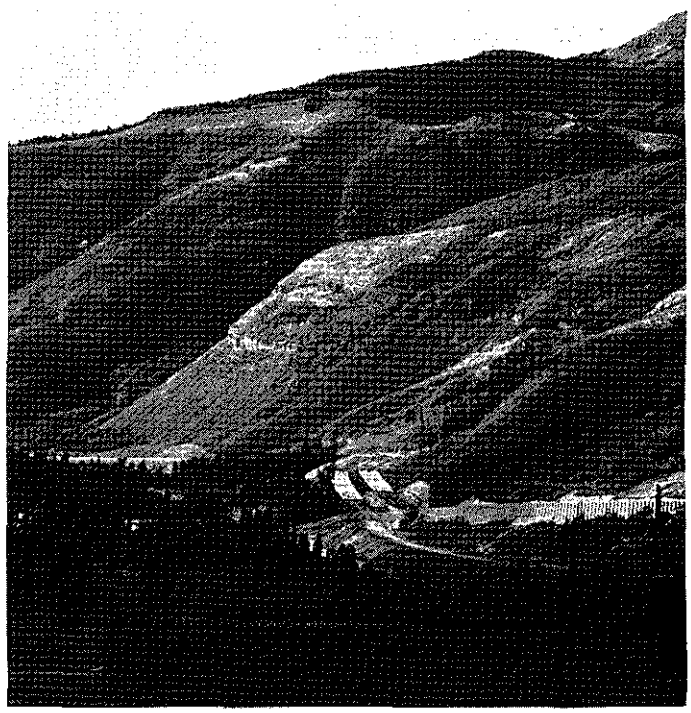


Figure 2. Scenic Environment of Vail Pass.

**Table 1**

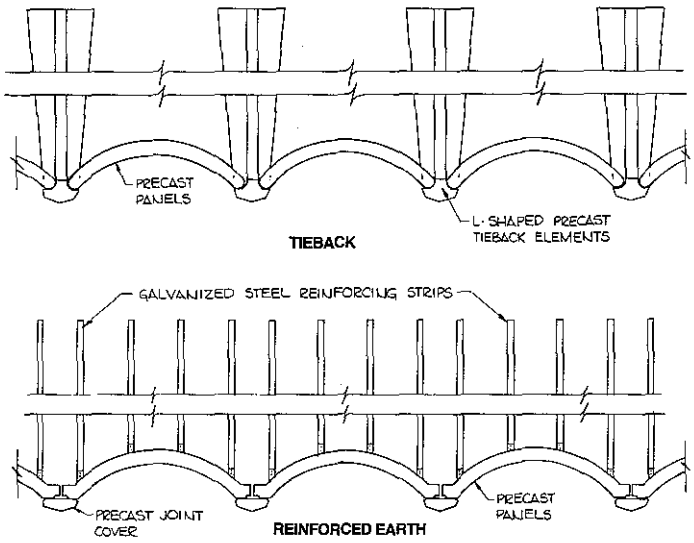
**PROJECT SUMMARY–I-70 RETAINING WALLS, VAIL PASS**

| Project # | | Letting Date | Surface Area | | | | | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | Curved Panel Walls | | | | Vertical RE Walls | | |
| | | | Tie-Back | | Reinforced Earth | | | | |
| CDOH # | RE # | | Sq. Ft. | $M_2$ | Sq. Ft. | $M_2$ | Sq. Ft. | $M_2$ | |
| I-70-2(53)192 | | Jan' 75 | 29,772 | 2,766 | | | | | Sta 450-500, Median walls plus 6-tier wall. |
| I-70-2(49)191 | 157 | Mar' 75 | | | 65,245 | 6,061 | 8,010 | 744 | Sta 390-450. Median plus 2 major fill ret. walls (7-tier wall and "399" wall). |
| I-70-2(48)189 | 158 | Mar' 75 | | | 83,866 | 7,791 | | | Sta 95-390. Predominantly median walls. |
| I-70-2(50)192 | 195 | Oct' 75 | | | | | 30,521 | 2,835 | Sta 547-566. Ret. wall to catch fill at Miller Cr.–ancient slide. |
| I-70-2(65)191 | 223 | Apr' 76 | | | | | 13,179 | 1,224 | Sta 408-413. Ret. wall, cast approach 2nd Black Gore Cr. Bridge. |
| I-70-2(61)192 | 227 | June 76 | | | | | 6,129 | 569 | Sta 562-565. Ret. wall at east approach Polk Cr. Bridge. |
| I-70-2(50)192 | 257 | Sept' 76 | | | | | 6,652 | 569 | Sta 562-565. Ret. wall east approach, Polk Cr. Bridge |
| I-70-2(51)193 | 233 | June 76 | 31,463 | 2,923 | | | | | Sta 575-687. Low median walls including Jersey barrier sections. |
| TOTALS | | | 16,235 | 5,689 | 149,111 | 13,852 | 64,491 | 5,990 | |

The paper reviews the construction of the walls, the unique solutions incorporated on some of the projects, and out of the ordinary construction events which were encountered.

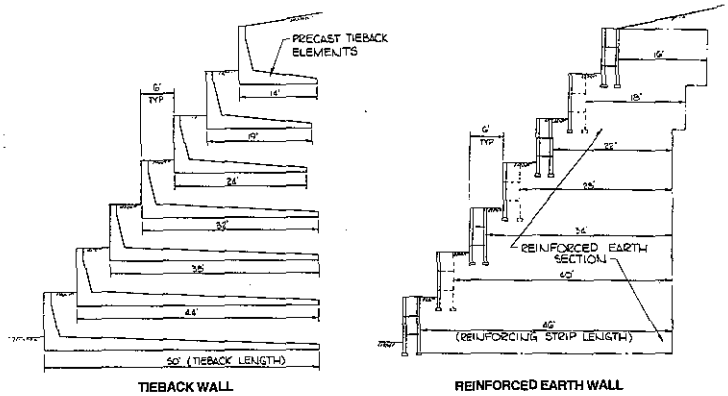
*Background*

Several months prior to the active design of the retaining structures at Vail Pass, a system of "tie-back" retaining walls was developed by the state of Colorado in conjunction with the Federal Highway Administration and the International Engineering Company, acting as a consultant. This system involved variable length L-shaped legs that were placed in an excavation and backfilled. Active earth pressures were to bear on eliptically curved facing elements that butted into the vertical legs of the L-shaped tie-backs or counterforts. The length of the horizontal legs of the counterfort was designed based on the amount of frictional resistance necessary to anchor the facing system and to resist the pressures at the face. This concept is illustrated in figures 3 and 4.




**Comparison of Reinforced Earth Design with Tieback Design**

Figure 3.




**Section at Sta 441+00**
**Alternate Designs**

Figure 4.

The tie-back wall was specified on the first Vail Pass retaining wall project to go to bid in January, 1975. This was designated project #1-70-2(53)192 (table 1, and figure 5). There were several walls involved, the largest being a structure six tiers in height comprising an approximate surface area of 30,000 sq.ft. (2,790 $m^2$). Until this job was let, The Reinforced Earth Company was not aware of the requirements for retaining walls on this project and had not been asked for any opinions or preliminary designs by either the Colorado Division of Highways or their consultants. At the time this project was bid, there was no time available to prepare an alternate design or to "value engineer" a solution in Reinforced Earth. It became quite apparent to those in the Company who examined the project and the results of the bidding that an alternate using Reinforced Earth could be very competitive. The Company's engineering staff had not previously designed a facing system similar to that being specified but felt that such a facing for Reinforced Earth could be easily developed.

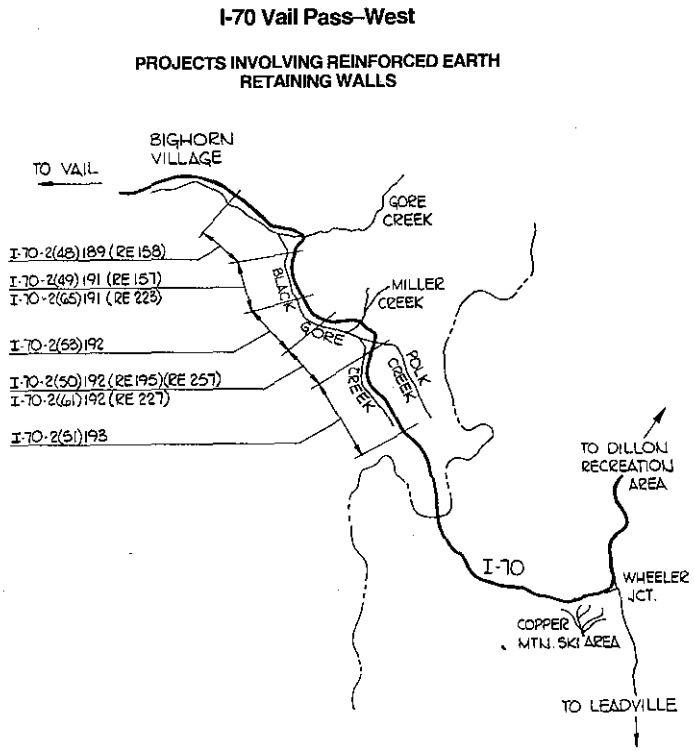



Figure 5. Specific Retaining Wall Project Locations on Vail Pass.

Also at the time of the Company's first acquaintance with this project, another Vail project having a number of retaining walls was taking its final engineering form. This was I-70-2(49) which involved over 65,000 sq. ft. (6,000 $m^2$) of retaining walls of the curved panel, tie-back design. The Company was successful in being allowed to submit an alternate design for this

work in Reinforced Earth which incorporated a curved panel tiered arrangement similar in most outward respects to the tie-back wall (figures 3 & 4). This was bid in March, 1975, and the difference in bid price between the Reinforced Earth system and the tie-back wall was significant -- on the order of $5.00/sq.ft. Subsequently, several more projects were brought to the bidding table with Reinforced Earth specified either as an alternate or as the primary system of construction (in vertical walls). In all, a total of 275,000 sq.ft. (25,600 $m^2$) of retaining wall were constructed of which 210,000 sq.ft. (19,509 $m^2$) were of the curved panel type and 65,000 sq.ft. (6,000 $m^2$) of straight verticle. Of this amount of curved panel wall, The Reinforced Earth Company was awarded contracts on 149,000 sq.ft. (13,500 $m^2$) or 71% of those walls (figure 6). Of course, Reinforced Earth was selected for construction of all the vertical walls (figure 7). It is estimated that the savings by using Reinforced Earth in the curved panel walls was on the order of $750,000. This figure is derived from the bid tabulations comparing prices bid for Reinforced Earth with those actually bid on the alternate system.

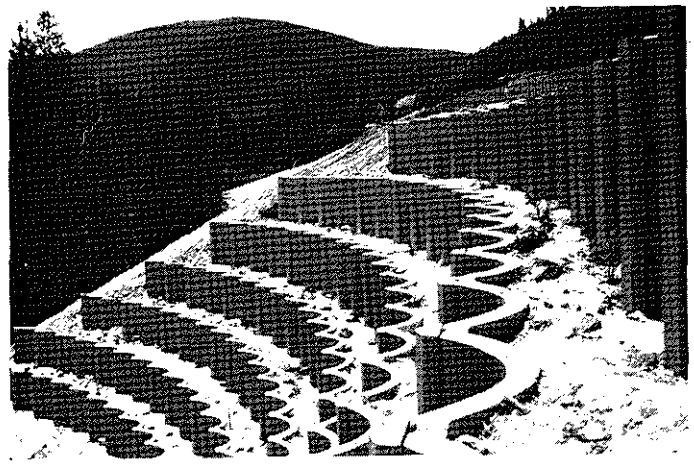


Figure 6. Seven-tiered curved panel Reinforced Earth Wall on project I-70-2 (49) 191 (RE #157).

*The Design*

In general, the engineering of a Reinforced Earth wall involves the calculation of horizontal stresses within a wide mass of granular material outwardly conforming to the shape of the retaining wall being designed. Through computations of these stresses, a sufficient density of steel reinforcing strips can to be incorporated in the mass to carry in tension these horizontal stresses which are transferred by friction between the granular backfill material and the strips. The curved panel tiered wall, althouqh somewhat of a departure from the standard cross-section of a Reinforced Earth wall and a definite innovation in the geometry of the facing system, is basically the same as any other Reinforced Earth wall. The largest of the curved panel retaining walls designed for Vail Pass incorporated seven tiers of 8 feet (2.44 m) effective height per tier, for a maximum height of 56 feet (17.07 m). Each tier was stepped back 6 feet (1.83 m) so that effectively a retaining wall with a slope of 3/4:1 was designed. Total tier height was 10 feet (3.05 m); however, 2 feet (0.61 m) of embedment per tier was incorporated. A comparison of the design of the tie-back wall with that of the cross-section of the Reinforced Earth wall is shown in figure 4. Basically, the Reinforced Earth cross-sectional design was then a trapezoid much as that of the tie-back wall; however, technically the two systems are completely dissimilar. Differences in the facing systems can be seen in figure 3 as previously discussed.

The vertical walls were designed in a conventional manner having a constant rectangular section. Some unique geotechnical considerations were involved in the retaining wall at Miller Creek, (I-70-2(50)192). This is a 30,500 sq.ft. (2,835 $m^2$) wall which was designed to span a geotechnically unstable side hill which had been the site of an ancient slide. It was feared that excessive excavation at this location would trigger a new movement of this slide by unloading the material at the toe which provided the present stability. In order to minimize

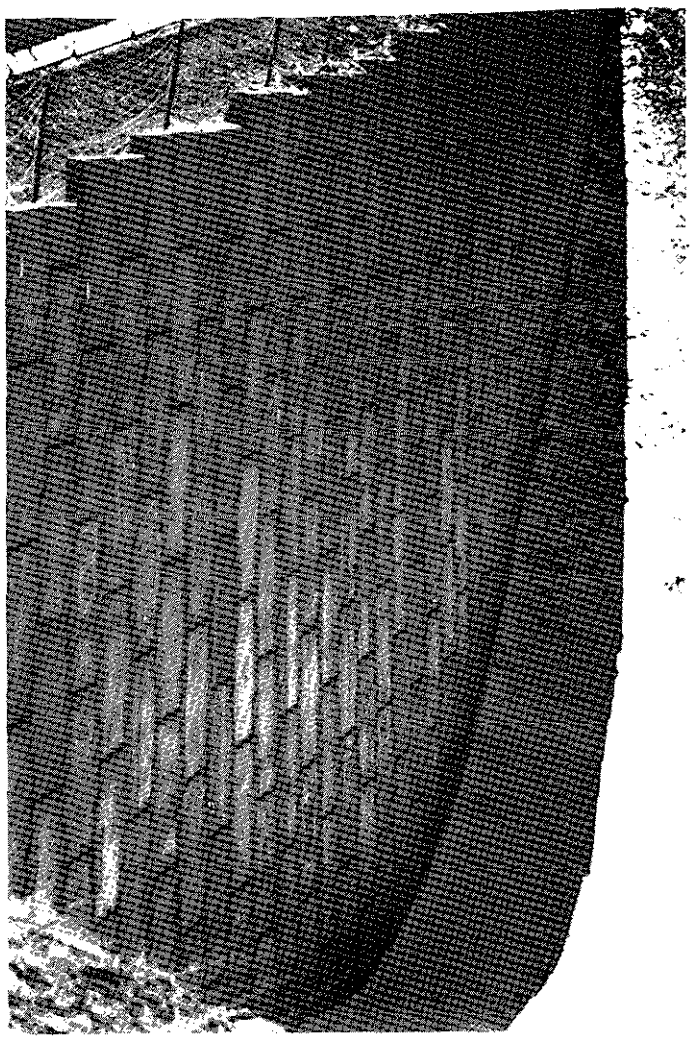


Figure 7
Vertical Reinforced Earth Wall on same project.

this danger, a design was called for which would allow only short increments of the excavation to be opened at any one time and for a retaining wall to be staged across the landslide in discrete sections. The lower level to this wall was to be constructed during the fall and winter months when the water table is low and most amenable to this type of construction (figure 8). I became apparent that the only system of retaining wall construction feasible for staging of this nature was Reinforced Earth.

Probably the most noteworthy feature of the Reinforced Earth design for Vail Pass was the response time that was exhibited in preparing final designs for construction. Since the entry of The Reinforced Earth Company was somewhat belated in the design sequence, its first project I-70-2(49)191 (RE #157) had to be turned around in final form in three weeks. During this three week span, the curved panel facing system had to be completely designed and a large surface area of wall (65,245 sq.ft.) (6,061 $m^2$) had to be computed, designed, and detailed. In subsequent jobs, precious little additional time was available to The Reinforced Earth Company over which to spread the design; the Washington D.C. based design staff was required to work extrememly long hours with essentially no time off. The second project, which involved the preparation of final design for some 83,866 sq.ft. (7,791 $m^2$) of wall surface, was also completed and submitted in three weeks.

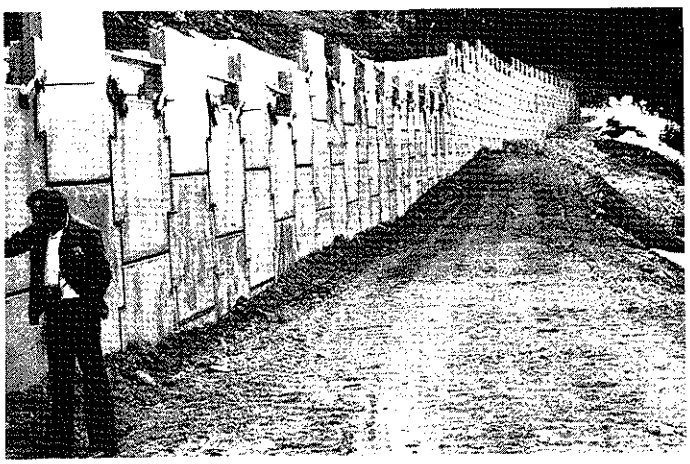


Figure 8.
Miller Creek Wall (RE #195) at 1/3 height.

*Construction*

As previously stated, the Vail Pass retaining wall projects were let in eight separate contracts of which six incorporated Reinforced Earth as the chosen alternate. These were awarded as follows:

1) To H.E. Loudermilk Company, general contractor, with J.M. Kenny as subcontractor for wall erection 83,866 sq. ft. (7,791 $m^2$) curved panel and 43,302 sq.ft. (4,023 $m^2$) of straight wall.

2) To Green Construction (Colorado Constructors), general contractors, with Peter Kiewit & Sons, Inc., as subcontractor for wall erection 65,245 sq. ft. (6,061 $m^2$) of curved panel and 21,189 sq.ft. (1,968 $m^2$) of straight wall.

These contractors utilized equipment and experience gained over many years of high mountain construction and their ability to move earth in that environment, particularly in winter construction, was impressive. Much of the work on projects RE #157 and #195 was accomplished in winter, in particular the Miller Creek wall (RE #195) on which one-third of the structure was staged and built during the winter of 1975 (figure 8). Because Reinforced Earth lends itself to staged construction, this wall could be built in a construction sequence which involved quickly excavating 20 ft. (6.1 m) segments and replacing the removed material with short sections of Reinforced Earth wall. The type of backfill specified for this wall was to be taken from a source of dredge rock located near Breckenridge some 45 miles (72.4 km) east over the Pass. It was an excellent rocky material, insensitive to snow and freezing as it was placed in the embankment. The wall was staged in short segments as described and built to one-third of its final height during the winter of 1975. Completion of the remaining two thirds was achieved in the late spring and early summer of 1976 (figure 9).

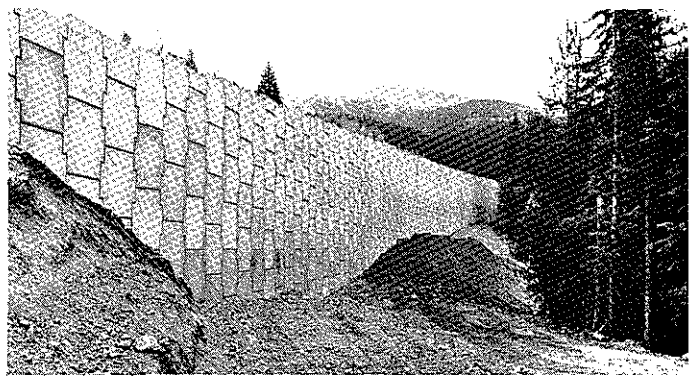


Figure 9. Miller Creek Wall Completed.

For the most part, the erection of the 275,000 sq.ft. (25,000 $m^2$) of Reinforced Earth went smoothly; however, there were three events which were out of the ordinary and worthy of note.

The first unusual event occurred on the RE# 158 project where some cracking on the face of a few of the concrete panels was noted. The problem was analyzed as a correctible flaw and not related to the structural integrity of the wall. The panels were repaired and the problem did not reoccur on the project.

The second was encountered during construction of the vertical retaining wall (RE #157) at Station 399+00. This vertical structure was 56 ft (17.1 $^2$) high at its center. The problem involved the verticality tolerances achieved by the contractor. In one portion of the wall, a bulge in the facing system of approximately 6 inches (15 cm) was found. In this case, the problem of exceeding wall tolerances caused only a surface effect not

related to the strength or service life of the structure. Several panels appear to be out-of-line on the face of the wall. This problem was probably caused by excessive compactive effort. For example, the contractor compacted one lift of the backfill for over seven hours with heavy vibratory equipment. It should be noted that on occasion, the responsibilities of the various parties involved tend to become confused or ambiguous. The Reinforced Earth Company provides education to the contractors, inspection personnel, and the resident project personnel. Its role is to assist the state or owner in the proper interpretation of the project's specifications and to assist the contractor in the proper selection of labor force, construction equipment and tools, etc., so that he can build the structures according to the specifications. However, the enforcement of the specifications lies with the owner.

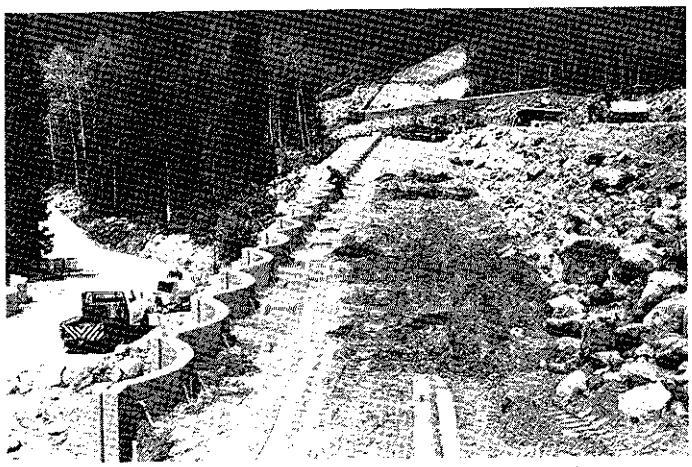


Figure 10. Moisture contents well above optimum contributed to tolerance problems at this median wall.

The most annoying of these unusual construction events occurred on contract I-70-2(49)191 (RE #157) on a section of the curved panel, median height retaining walls (figure 10). Here, the contractor was attempting to complete the wall's construction before winter weather forced him to shut down. There were occasions when the backfill was becoming excessively wet due to snowfall. During the embankment placement operations, the face of a 300 ft. (91.4 m) long section wall moved out of alignment. Reinforced Earth representatives came to the site immediately and identified the problem as one of excessive moisture in the backfill. Under those conditions, the construction loads due to compaction equipment were far in excess of the design in-service loads. Because of the excessive moisture, the panels moved under the loads. Subsequent tests showed that the gradation of the backfill was within the design criteria and would have been adequate given proper moisture control.

The Colorado Department of Highways conducted a thorough inhouse investigation including sheer tests and compaction tests, and concluded that "the problem with the wall was caused by a combination of factors:

1. Material considerably over optimim moisture.
2. Material with high (18-24) passing #200 sieve.
3. Material compacted with a vibratory roller.
4. Wet, cold weather which did not allow drying of materials, coupled with relatively rapid construction".

The State concluded "that the elimination of any one of these factors could have resulted in no movement of the wall during construction". The Reinforced Earth Company was found to be in no way responsible for this failure. There was no question of long term stability.

With regard to the question of backfill specifications, the structural backfill specification for Reinforced Earth structures used by the State of Colorado was adequate. It was similar in all respects to a backfill specification that had been used for structures in other western states including California and Nevada.

It must be noted that these three unusual events involved approximately 3,000 sq.ft. (279 $m^2$) of the Reinforced Earth walls or 1.4% of the total constructed.

*Summation*

The Reinforced Earth Company is very proud of its participation and contribution to the Interstate 70 project over Vail Pass. We were greatly impressed with capabilities of the State of Colorado Department of Highways and their consultants, and we appreciate their cooperation. We were equally impressed with the high quality of the contractors who work in these mountains; these people make difficult problems seem ordinary.

At the Vail Pass, Reinforced Earth was selected because it could respond to the difficult technical requirements, provide construction efficiencies, and offer a significant overall cost savings. In total, approximately 214,000 sq.ft. (19,900 $m^2$) of Reinforced Earth walls were constructed; and in spite of minor and unusual construction events, this amount of experience and involvement stands clearly as a unique demonstration of the design flexibility and cost effectiveness of Reinforced Earth structures.

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