investigations were virtually continuous. It is estimated that 30 person years of geotechnical expertise and 10 drill-crew years were involved. Approximately 6100 m (20 000 ft) of vertical drilling and 2400 m (8000 ft) of horizontal drilling were completed. Several hundred standard split spoon samples and about 50 thin-walled tubes were obtained. Over a hundred meters of penetrometer holes were also accomplished.

The instrumentation used consisted of 32 inclinometers, 11 borehole extensometers, 12 piezometers, 40 gloetzl soil pressure cells, 63 electrical strain gauges, and 2 shear strips. Geophysical studies were conducted by the Colorado School of Mines and by the Colorado Department of Highways with single and multichannel seismographs.

The total expenditure for geologic investigation on the Vail Pass project is estimated to be $2 million. According to the study by the Robinson and Lord firms, approximately 11.2 of the 22.5 km (7 of 14 miles) traversed by I-70 was unstable to marginally stable terrain. Only one unanticipated failure larger than 153 m^3 (200 yd^3) occurred as a result of construction. This occurred during the spring of 1978 and cost about $75 000 to repair.

SLOPE DESIGN

Angles of cut-and-fill slopes across Vail Pass were based on geotechnical data and on experience in similar materials in similar climatic conditions. Many areas of Vail Pass required cuts and fills that approached critical heights.

At the highest cut, a 91-m (300-ft) high bedrock cut between stations 605 and 614, the highway department retained a specialist in rock mechanics to evaluate the slope design and to design and interpret an instrumentation system. In fact, all significant cuts and fills were reviewed by at least two geotechnical specialists in an effort to minimize stability problems during construction.

The final slope configuration, especially the molding and sculpturing effect now visible to the motorist, is the result of intensive joint efforts by landscape architects and construction and geotechnical personnel. Individual grading projects were staffed with landscape specialists who prepared conceptual plans for the final appearance of cuts and fills and other related features. These plans were reviewed by geotechnical personnel to ensure compatibility with on-site geologic conditions and with construction personnel to ensure that construction was practicable.

Slope design was thus yet another product of cooperation among practitioners of several disciplines.

CONCLUSIONS

Geologic conditions at Vail Pass were generally unfavorable for the construction and maintenance of a four-lane highway facility. Severe constraints and limitations were placed on designers by extensive areas of soil and bedrock failures, steep topography, and a cold and wet climate.

Successful completion of a project of this magnitude can result only from the combined efforts and cooperation of several disciplines under strong and enlightened leadership. These elements were present throughout the Vail Pass project. Geologic constraints were given appropriate consideration at every level and during each phase of project development. All of the geotechnicians involved appreciated the opportunity to participate in so challenging an undertaking, in a cooperative atmosphere.

The substantial amount of money expended for geotechnical aspects of the project was justified by the project's successful and timely completion. From a geotechnical point of view, this project stands as a model for future major engineering efforts in difficult geologic conditions.

ACKNOWLEDGMENT

Major contributors to the final Vail Pass geotechnical studies include J. B. Gilmore, R. P. Moston, and A. C. Ruckman of the Colorado Department of Highways; Charles S. Robinson and M. D. Cochran of Charles S. Robinson and Associates; Dwayne Nielson of International Engineering Company; Mike Bokovansky of Dames and Moore; and Horst Ueblacker of Ueblacker and Associates.

The figures presented in this paper are based on those in a Robinson-Lord joint-venture report and were modified by Jim Lance of the Colorado Department of Highways.

Abridgment

Landscape Treatments on the Vail Pass Project: Slope-Design Procedures

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During the construction of I-70 over Vail Pass, many landscape techniques were used to stabilize highway slopes and to achieve visual compatibility with the surrounding forested mountainsides. Although slope beautification was an initial objective, successful landscape treatments were soon found to be those that imitated existing landscape elements. Methods of erosion control, slope stabilization, and revegetation eventually merged into a format that has proved to be successful in preserving scenic quality.

Stable highway slopes were always the basic consideration in any treatment. At no time could landscape treatments take precedence over the engineered stability factors necessary for an Interstate highway.

Highway safety was also an important consideration. Treatments were designed to ensure the safety of the

motorist. Median landscaping with large boulders and trees at the ditch line was used sparingly and only in areas where it was deemed safe for the motoring public. Shoulder landform treatments were kept within engineering requirements. Snow-removal operations also limited the extent of shoulder treatments to modified berms and minor plantings. Larger trees were only planted near the top of cut slopes and the toe of fill slopes to minimize snowplow damage and allow ample snow storage.

A landscape plan was developed for this project and was integrated into the construction plans. The intensity of the treatments varied according to the amount of landscape manipulation and the visibility of the area. The most visible areas received the greatest attention. On these sites, plantings, slope molding, and other treatments were used to the fullest extent possible. Slope molding and rock-cut sculpturing treatments were worked into construction operations before clearing began by modifying the placement of slope stakes.

To achieve the necessary blending, landscape work was generally concentrated near the base of fills and the top of cut slopes. This standard was used over most of the pass to satisfy requirements related to safety, snow removal, and visual quality.

The techniques used at Vail Pass developed from a design approach established early in the construction history of the project. It was recognized that a motorist traveling at 88 km/h (50 mph) would not be able to recognize detailed landscape patterns but mostly only landscape forms and linear qualities. Changes in colors and textures were minimal and often only seasonal.

In pedestrian areas or areas of slower traffic movement, landscape treatment concentrated on details that would properly relate the features of the landscape to the motorist. In areas of high traffic flow, landscape treatment reflected and extended existing landforms, vegetation patterns, and landscape features. Because of the lack of visual detail required in these areas, plant groupings often lacked the diversity of species typical of urban plantings. Plant groupings of one or two tree species were used without attention to understory shrubs and forbs.

The landscaping approach on the project was to completely eliminate visible transition points by modifying vegetation clearing lines and cut-slope lines and even median-ditch location. All treatments were adjusted to blend with existing or planted features and to simulate natural forms.

SLOPE MOLDING

In the past, cut-and-fill slopes were designed only to satisfy stability requirements and balance the quantities of materials. As a greater awareness of aesthetics and the final appearance of projects developed, it was realized that these maximum slopes were imposed on the landscape and limited the motorist's appreciation of the terrain. Slopes were designed with profile and cross sections, but little attempt was made to modify these typical sections in the field.

At Vail Pass, slope-molding techniques were incorporated into contract documents. Although many large cut-and-fill slopes were proposed, provisions were added to test new techniques. Standard slopes were established as a minimum slope treatment. In areas where minimum cut-slope treatments could be modified, the additional materials generated were used to mold and flatten fill slopes. Cross sections were studied to determine areas of possible slope molding. Slope stakes were then adjusted by the landscape architect and the survey crew to accomplish slope-treatment objectives inexpensively.

The types of slope treatments used are briefly described below.

Lay-Back Treatment

Where natural draws were encountered, the cut slope was laid back, or flattened, to match the grade of the draw (see Figure 1). This treatment resulted in cut slopes that had a natural appearance and added greatly to the overall success of the project.

Typically, cut slopes were designed to a minimum 2:1 slope. At natural draws, this standard slope was flattened to 4:1 or flatter to match as closely as possible the natural grade of the draw. This technique generated additional material that had to be hauled away. Alterations in the forest clearing line also had to be made.

The lay-back treatment was accomplished in several ways, depending on the phase of the project. On-site treatments were used in areas that were not designed or slope-staked for that treatment. Special project accounts were set up to accommodate this extra on-site dozer work. The contractor was directed to provide equipment hours to perform the special grading, and the landscape architect was available to direct the equipment operator to achieve the desired slope treatment at each location.

Most areas that required the lay-back treatment were identified at the slope-staking stage. Where cut slopes crossed natural draws, the positions of slope stakes were recalculated for flatter slopes. Changes made at this stage were generally more successful and less expensive. Topsoil and revegetation were done after final grading. Once the corrected slope staking was accomplished, the contractor's operation ran more smoothly.

Design-stage manipulation of ground forms was limited to matching grade contours. In the design of lay-back treatments, cut-slope lines were designed to parallel contour lines as much as possible in draw areas.

Accented Ridges

Where natural ridges were encountered, they were accented by steepening and rounding to a convex form. This is only successful over short distances. Where long ridge cuts were encountered, additional slope treatments were necessary. Although this treatment proved only moderately successful, it did smooth the natural to standard transition edge along the roadway. Again, slope stability was an important factor. Accented ridges were never constructed above stable limits. Normally, accented ridge slopes did not exceed a 2:1 ratio.

The treatment proved successful when it was used in combination with the lay-back technique described above.

The accenting of ridges was accomplished mostly by adjusting slope stakes. Slope ratios were reset at obvious ridge areas to produce a steeper slope. Ridge accents were staked so as not to run more than 30 m (100 ft).

Adjustments to steepen slope ratios are difficult to make once construction begins. Decisions to accent ridges were seldom made after a slope was opened up. A method of flattening nearby slopes and accenting the steeper ridge slope was used with some success (see Figure 2).

This treatment, like the lay-back treatment, is designed so that the staked cut-slope lines parallel existing contour lines.

Figure 1. Lay-back treatment.

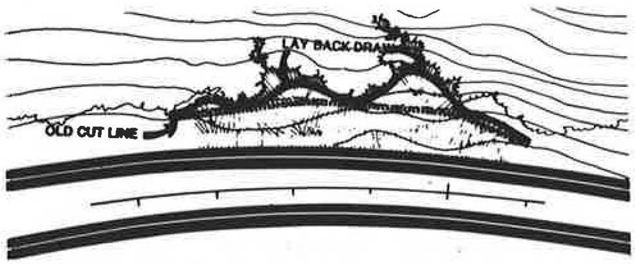


Figure 2. Accented ridges.

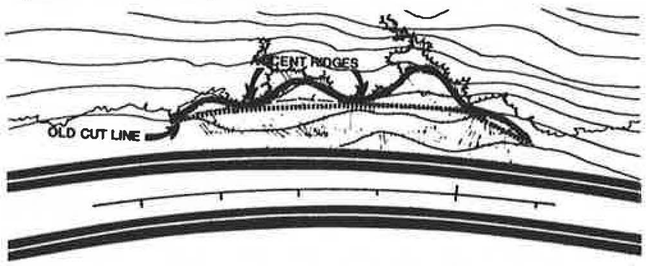
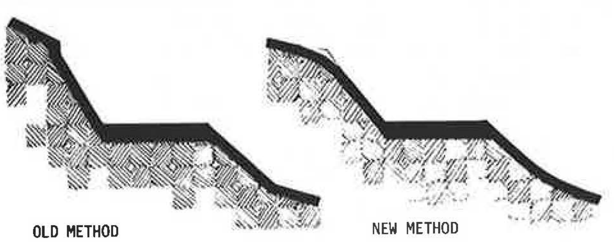


Figure 3. Created landform diversity.

Figure 4. Slope rounding.



Created Landform Diversity

On some large slopes, it was impossible to modify slope characteristics by just laying back draws and accenting ridges. On these slopes, diversity was created by modifying slope ratios and developing false draws and ridges along the slope. Large slopes were rarely left at their 2:1 ratio but were often flattened and rolled to reflect the natural character of the terrain.

This treatment was used in areas of extensive disturbance. Long-running ridge cuts were molded to create landform diversity and minimize the apparent size of the cut slope. Fill slopes and large borrow pits were also molded in this way (see Figure 3).

The methods used are similar to those used in flattening draws. Excess material generated on other project activities can be used to mold the fill slopes to match existing terrain. In larger work areas, such as borrow pits, contractor excavation operations can be coordinated to accomplish the desired effect.

It is essential to design for landform diversity. Detailed perspectives, grading plans, and typical sections are necessary. At Vail Pass, perspective sketches were found to be especially useful in that they could be posted in construction trailers and even carried by equipment operators. Once the end product was visualized by all parties concerned, the landform grading became an easier task.

Rounding

All cut slopes were rounded at the top to present a softer transition line between constructed and existing slopes (see Figure 4). This treatment was relatively easy, and results were significant. Additional right-of-way was needed and more vegetation was often disturbed, but the recovery time of the slopes was considerably shorter and visual scars healed faster.

Rounding was also effective at the toe of fill slopes. Again, the treatment was intended to blend the fill slope with existing terrain. Standard specifications that directed the contractor to round all slopes were set up.

REVEGETATION

The slope treatments used on the Vail Pass project were often designed for visual effects, but it was soon found that those completed slopes were more stable and promoted native plant growth. Although the revegetation techniques used promoted native plant species, slope treatments are felt to have assisted the revegetation process. Hence, the environmental stability of the Vail Pass roadsides is ensured by the establishment of natural plant communities on slopes of natural configuration.

CONCLUSIONS

In the execution of slope-design treatments at Vail Pass, no single feature of roadway design was compromised. Engineering, safety, geologic, environmental, and aesthetic requirements were all met, and to this is due the credit for the long-term success of the project. Slope-molding treatments provided natural form to the Vail Pass roadsides and ensured proper growing conditions for native plants.