to keep water originating above the work areas from running through work areas and carrying loose earth into streams below by placing plastic-lined ditches or temporary pipes across the project area. We learned that water that originated in the work area could either be channeled into settling ponds and processed before going into streams or sprinkled onto nearby hillsides. We also learned how to more efficiently include landscaping, topsoiling, seeding, mulching, and the construction of pollution-control structures in the cycle of normal earthwork operations. And we learned that, through careful channel changes, we could even improve waters for trout fishing.

In the words of a spokesman from the Rocky Mountain Center on Environment, which recently bestowed an award for the work done at Vail Pass, "The project demonstrated that a highway of significant magnitude can be constructed in an area of delicate environment without inflicting permanent environmental damage." Yet much remains to be learned, not only from the standpoint of developing techniques for working within the laws but also from the standpoint of making the laws themselves more workable. Perhaps this can be a starting point.

Abridgment

The Vail Pass Project: View of the Colorado Department of Highways

Jack Kinstlinger, Colorado Department of Highways, Denver

I-70 was constructed over Vail Pass as part of the Colorado segment of the Interstate highway system. Many safeguards had to be designed and constructed so that the project would be consistent with the goals of the Colorado Department of Highways to improve travel efficiency and safety while preserving the environment of the state. An Interstate highway can cause great damage to the mountain environment, and the cost of minimizing these impacts is necessarily great.

Prior to 1973, Vail Pass was crossed by way of a two-lane highway that wound along the valley bottoms. Motorists had to take care to avoid on-coming automobiles, trucks, and campers while viewing the scenery. In those days roadside maintenance was extensive. Traffic was often delayed by stalled vehicles. Winter accidents multiplied as the skiing industry grew.

Today, Vail Pass is safely traversed on a four-lane Interstate facility. Stalled vehicles do not hold up traffic, and roadside maintenance is minimal. The roadway was designed and constructed to fit the land, and the end result allows the motorist many splendid views of the mountain landscape.

For a while it was thought that Vail Pass would go down in history for other reasons. Lawsuits were pending from local communities, the Bureau of Land Management and the U.S. Forest Service conducted critical on-site inspections daily, major geologic problems threatened the integrity of the facility, and local controversy over the project prompted daily newspaper editorials. Traffic delays caused by construction further fueled the controversy.

From this shaky beginning grew a form of interagency cooperation that has spread to other projects. To solve the mounting construction-related concerns, the department pulled together an interdisciplinary team composed of representatives from the U.S. Forest Service, local environmental organizations and citizens, staff geologists, engineers, hydrologists, and landscape architects as well as consultants and contractors to review project plans for potential impacts. Once the impacts were identified, techniques for mitigating them were developed and designed into the project. A project team was set up at the site to ensure that unforeseen problems were quickly solved.

The Vail Pass experience has produced a number of benefits not evident on the pass itself:

1. Credibility of the Colorado Department of Highways with the citizens and agencies of Colorado has been improved. All parties involved in the Vail Pass project now have an improved understanding of the department's capabilities, intentions, and limitations. In subsequent projects, both large and small, a smoother working relationship between the department and other agencies and a better understanding of each other's concerns have been demonstrated. This results in faster project turnover and savings in project costs.
2. The department's environmental impact statements are now more than just paperwork. Environmental design techniques tested at Vail Pass can now be outlined and specified to minimize potential impact areas. This makes the environmental impact statement a design document that directs rather than limits the future design and construction of a project.
3. The interdisciplinary approach has been strengthened and improved by the willingness of agencies and individuals to participate with the department on future projects. This is essential to the environmental impact statement process.
4. A valuable data base has been established on which the Colorado Department of Highways can draw for future projects. Construction techniques tested and used at Vail Pass can now be used with confidence and cost savings on other Colorado highway projects. Engineering and geotechnical applications and new materials and environmental design techniques are part of this data base. The department is now looking at projects constructed prior to Vail Pass to see if they are possible candidates for reclamation actions.

SUMMARY

Vail Pass has provided the Colorado Department of Highways a training ground for a wide range of design and construction techniques. The lessons gained on the Vail Pass project have produced a more costeffective construction program and will continue to do so in the future.

Vail Pass is a milestone in Colorado highway construction history by which all past and future highway projects will be measured.

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Final Geotechnical Investigations on the Vail Pass Project

Robert K. Barrett, District 3, Colorado Department of Highways, Grand Junction

An overview of final geotechnical investigations on the 22.5-km (14-mile) Vail Pass I-70 alignment is presented. The geotechnical studies involved personnel of the Division of Highways, Colorado Department of Highways, and consultants from four engineering firms. The Interstate corridor traversed several areas where geologic conditions posed extreme difficulties. Unique and innovative designs were required to provide a stable, attractive, and environmentally compatible highway. Examples of the geologic problems encountered and the techniques used to surmount them are described. Approximately 30 person years of geotechnical expertise and 10 drill-crew years were required on the project. The geotechnical studies are estimated to have cost $2 million.

Final geotechnical investigations on the 22.5-km (14-mile) Vail Pass I-70 project began in 1971 after completion of preliminary investigations by a consultant in engineering geology. The preliminary and intermediate phases included four years of investigation by engineering geologists of the Division of Highways, Colorado Department of Highways; consulting engineering geologists; soils engineers; and rock-mechanics engineers.

Preliminary and intermediate investigations identified many kilometers of potentially unstable areas where the routing of a four-lane Interstate highway could be adversely affected by rock, soil, and snow slides. It was recognized at the end of these early studies that the final alignment would have to be selected in conjunction with a final, comprehensive geologic investigation.

From 1971 to 1977, geologists and soils engineers worked closely with both consulting design engineers and Colorado Department of Highways design and construction engineers in selecting the optimum location for the roadway. This report describes some of the investigations conducted during that period and explains, from a geologist's viewpoint, how and why various alignment and alignment-related features were finally selected. The geologic symbols used in the figures are explained in Figure 1.

GENERAL GEOLOGY

The final geotechnical investigations added the third dimension to the geologic maps assembled by Charles S. Robinson and Associates and R. V. Lord and Associates and provided soil and rock engineering properties and groundwater data. Aided by geologic maps; black-and-white, color, and infrared photography; and seismographs and drills, it was possible to create a complete picture of the recent geologic history of the Vail Pass corridor and to predict the impacts and consequences of various alignment alternatives.

It was discovered that a glacier had caused deposition of extensive silt, sand, and organic horizons high on the mountainside just east of Bighorn Creek at the west foot of Vail Pass (see Figure 2). It was probably this same glacier, originating from main Gore Creek, that dammed Black Gore Creek and caused widespread fine-grained lake sediments to be deposited on the hillsides for a distance of 1.6 km (1 mile) up Black Gore Valley.

Many of the bedrock failures were drilled, and much was learned about the failure machanisms. It was concluded that the failures originated on extremely weak, thin, fine-grained, silty, micaceous shale lenses within the predominately sandstone and siltstone bedrock. Bedrock failures on slopes as flat as 4° were observed. In the areas between stations 615 and 680 (Figure 2), both valley walls of Black Gore Creek have failed from near their crests to below the level of the creek—a vertical distance of more than 610 m (2000 ft).

Soils were sampled and tested for strength and permeability. The predominant soils at Vail Pass, classified AASHTO A-2-4 and A-4, were deceptively poor for highway purposes. These soils were highly micaceous and relatively impermeable. Although visually the soils all appeared to be similar, R-values determined by using the Hveem stabilometer varied from 5 to 82 (the stabilometer test is a measure of the relative stability of soils on a scale of 1-100), and triaxial tests indicated a wide variation in strength parameters.

SELECTED GEOLOGIC PROBLEMS AND SOLUTIONS

Stations 310-340

The consultant's preliminary studies concluded that the hillside in the vicinity of stations 310-340 probably contained deep deposits of unconsolidated materials. Concern was expressed about the extensive side-hill cuts proposed for that area (see Figure 3).

In 1972, drilling was initiated in the area. The soils initially selected for drilling consisted of granite boulders as large as 0.9 m (3 ft) in diameter in a matrix of sand, gravel, and cobbles. Since these materials could not be penetrated by the standard rotary drilling equipment owned by the Colorado Department of Highways, they were drilled by a private firm using a percussion drill.

The drilling program verified that deep, uncon-