bars were mostly two segments long [2 × 4.5 = 9 m (2 × 15 = 30 ft)]. They were extended by means of couplers to the required length and were terminated as required by the bending moments. Typically, four to six tendons were stressed and terminated at each segment so that sufficient post-tensioning was provided for the construction-stage loading. No temporary post-tensioning was required.

A typical tendon layout is shown in Figure 10. The amount of post-tensioning provided closely matches the force requirement so that the quantity of tendons is optimum.

STRUCTURAL DESIGN

In the tender document, only the precast segmental scheme was given. After the bid, a revised design was carried out for the cast-in-place cantilever construction and the modified construction sequence. This redesign took into consideration all the construction stages and the redistribution of stresses caused by creep, shrinkage of concrete, and relaxation of steel. However, instead of using analytical methods to account for the redistribution of moment caused by creep, the owner specified that a 1724-kPa (250-lbf/in^2) residual compression stress should exist at the end of construction in the bottom slab in areas of positive moment. The specification also stipulated that no tensile stresses were allowed under both construction and service loads.

To ensure tight elevation control at the jobsite, camber values and curves were provided for each loading stage. In general, two camber curves are required for the construction of each cantilever segment, one for the stage before the placing of concrete and one after the placing of concrete and post-tensioning. Deviations between the site-observed values and the calculated values are corrected during the construction of subsequent segments. The form travelers are equipped with hydraulic jacks for very fine adjustments in both elevations and horizontal alignment.

ACKNOWLEDGMENT

The I-70 project of which the Vail Pass bridges are a part was a federal-aid project managed by the Colorado Department of Transportation. The consulting engineer was the International Engineering Company in Denver. The general contractor was Peter Kiewit and Sons. The redesign and construction engineering were carried out by Dyckerhoff and Widmann. A computer program especially developed for segmental construction was used for the stress and camber analysis.

The completion of all four bridges in so short a construction period was made possible by the contributions and close cooperation of all the parties involved.

Water-Quality Considerations for Highway Planning and Construction of the Vail Pass Project

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Soil erosion and sediment control have long been concerns associated with road-construction activities. Several manuals that have been written on the subject provide excellent guidelines for estimating costs and implementing control measures. The construction of the four-lane segment of I-70 at Vail Pass has provided the opportunity to implement many of these control measures in a sensitive mountain environment. This report evaluates the performance of the structures used at Vail Pass for erosion and sediment control. The results are considered to be representative of what might be expected in other steeply dissected, mountainous terrain. The measures used are applicable to other land-disturbing activities, including timber sales, mining operations, ski areas, and all construction sites.

Construction of the four-lane segment of I-70 over Vail Pass began in 1973 and was scheduled for completion in 1979. Vail Pass is located in the central Rocky Mountains southeast of Vail, Colorado. Elevations range from 2526 m (8400 ft) near Vail to 3203 m (10 500 ft) at the summit. Precipitation totals 89-114 cm (35-45 in) annually, and 80 percent of it is in the form of snow. Climate conditions are typical of high-elevation areas that have a wide seasonal and daily temperature variation. Average monthly temperatures vary from -10°C (14°F) in January to 12.7°C (55°F) in July. The growing season is short, less than 60 days near the summit.

I-70 parallels West Tenmile Creek on the east side of the pass and Gore Creek on the west. Both creeks are municipal water supplies and are important for recreation, fisheries, and aesthetic and agricultural uses. Soil erosion and protection of water quality were key considerations in the design and construction of the highway.

Because the alignment of the 28.3-km (17.6-mile) stretch of road was limited by the steep mountainous topography, it was necessary to construct through highly erodible soils and isolated areas of active landslides. Soon after construction began and despite conventional control efforts, several soil-erosion and water-quality problems were encountered. As a result, many new and innovative erosion-control measures were implemented on the project. This report examines those methods and discusses their effectiveness in a sensitive mountain environment.

EVOLUTION OF THE PROJECT

Because of the sensitive subalpine environment at Vail Pass, water-quality stipulations were necessary to protect soil and water resources during highway construction. Stipulations were formulated and agreed on by the Colorado Division of Highways and the U.S. Forest Service. These stipulations, which applied to fish habitat, stream crossings, disposal of waste materials, and limitations on construction machinery in or near stream courses, became requirements and conditions to be met by the state of Colorado in order to obtain an easement deed from the federal government along the highway right-of-way.

To meet the constraints set forth in the stipulations, the U.S. Forest Service developed guidelines that would maintain water quality during and after highway construction. These guidelines were published as part of the Landscape and Erosion Control Manual prepared by International Engineering Company for the Colorado Department of Highways (1). The manual, which served as a guide for the design and construction of the highway projects at Vail Pass, discussed various techniques for landscape design, erosion control, revegetation, and control of water runoff.

Water-Quality Monitoring Program

To determine the effectiveness of the guidelines, a water-sampling program was established. Its goals were to gather baseline chemical and sediment data prior to construction at the three principal drainages—West Tenmile, Gore, and Black Gore Creeks—and to continue collection of these data throughout the entire construction project. This was done to determine the overall impact of the construction of the highway on water quality and the effectiveness of the water-quality constraints. This information is still being collected. After completion of the highway, an evaluation report will be prepared.

Water-Quality Plan

Even with the monitoring program and the erosion-control guidelines set forth in the Landscape and Erosion Control Manual, many water-quality problems arose during the initial construction season. Surface flows from the spring snowmelt and summer thunderstorms created many erosion problems on the newly exposed soil surface. As these problems became apparent, solutions were developed and corrective action was taken. But the solution often came too late to prevent much of the erosion and the subsequent degradation of water quality. The contractor was simply not aware of or prepared to handle the numerous soil-erosion problems encountered in such an extreme environment. It became obvious that, before much more construction was done, additional project control would be needed.

To alleviate these problems the U.S. Forest Service developed a water-quality plan, outlining additional guidelines necessary to protect soil and water resources. In March 1974, a draft of this plan was presented to the Colorado Division of Highways. After months of negotiations, the guidelines were adopted by the division, to be implemented the following construction season. They took the form of special provisions to the standard specifications for road construction in Colorado and became part of the requirements and conditions on which contractors bid for the construction projects.

The new plan continued the ongoing monitoring program and use of the erosion-control guidelines but added the requirement that each project would be monitored individually and, if at any time a water-quality problem occurred, the project engineer and the Forest Service liaison officer would be notified immediately to ensure that corrective action was taken. In addition, the water-quality plan required the contractor to do the following:

1. Prepare a contingency plan for erosion control and water quality and submit the plan for approval before beginning construction. The plan must address potential water-quality problems and outline methods for correcting them. The contents of the contingency plan vary depending on the location of the site. Projects located in steep terrain, adjacent to streams, require a more comprehensive plan than projects on flat terrain, away from stream courses. A contingency plan might include (a) methods of handling groundwater seepage into the construction site, snowmelt and rainfall runoff, and small creeks flowing through the project limits; (b) the control of haul-road or access-road drainage and locations of temporary culvert installations; and (c) locations of proposed features for water-pollution control, such as sediment ponds, collection ditches, pumping stations, and temporary diversion ditches.
2. Appoint an erosion-control and water-quality supervisor who is responsible for implementing control measures. Problems with soil erosion often go unattended simply because no one knows whose job it is to correct them. Erosion-control problems receive more attention when one individual is held accountable.
3. List the materials, machinery, and personnel available for erosion control. Because so many erosion problems occur spontaneously, the materials needed to control them must be on hand at the construction site. Erosion-control materials might include hay bales, culverts, irrigation pipe, sandbags, gravel, plastic, and flexible downdrains.
4. Agree to give erosion-control work priority over all other aspects of the construction projects. When a problem is encountered, the required personnel and materials will be released to correct it.

The Colorado Division of Highways also appointed a full-time specialist in erosion control and water quality to oversee the water-quality plan on all Vail Pass construction projects. His responsibilities were to review and approve the water-quality contingency plans submitted by the contractor, to monitor the water quality above and below each construction project, and when necessary to develop and implement measures to mitigate water-quality problems.

EROSION-CONTROL PLANNING

Many erosion and sedimentation problems can be avoided during road construction if they are anticipated and prepared for in advance. Planning ahead for these problems begins with the initial road design and continues through the actual construction period. During the Vail highway project, various erosion-control methods were implemented and evaluated so that their relative merit in controlling erosion and sediment problems in a sensitive mountain environment could be determined. The following sections discuss the permanent and temporary methods in detail and report the findings.

Permanent Erosion Control

The design of a road is very important, for it contains the permanent features of erosion and sediment control. The topography, geology, soils, and drainage patterns of the terrain must be evaluated in order to select a road alignment that is most favorable to road construction. At Vail Pass this was particularly challenging because the steep mountainous terrain and the risk of landslides limited location options.

Because the majority of the Interstate had to be located on highly erodible soils, special design considerations were included in the construction plans to overcome erosion and sediment problems. Some of these considerations included retaining walls, protected drainageways, subsurface drains, contour cut-and-fill slopes to dissipate runoff, energy dissipators below concentrated runoff points, and extensive buttressing below unstable land masses.

Revegetation

It is generally accepted that the best way to ensure permanent erosion control on disturbed sites is through a successful revegetation program. The materials and techniques used to accomplish this are well documented (2-9). The methods selected depend on the location of the project and the specific objectives established for revegetation.

At Vail Pass, an ambitious revegetation effort was undertaken to fulfill the objectives of erosion control and retention of natural scenic beauty. The specific techniques used were agreed on by the Forest Service and the Colorado Division of Highways. They consisted of one or a combination of the following activities: seeding with grass, fertilizing, mulching, applying protective matting, and planting or transplanting native trees and shrubs.

Revegetation began immediately after slope disturbance to take advantage of available soil moisture. As cut slopes were made, revegetation closely followed the earth-moving process. Only 9.1 m (30 ft) of exposed slope was allowed at one time. Application of the seed, fertilizer, mulch, and netting was completed immediately rather than being drawn out over a long period of time.

Revegetation was extremely successful at Vail Pass. The cost of the program was approximately $20 000/hm^2$ ($8000/acre).

Topsoil

Because of the coarse texture of the Vail Pass soils and their low nutrient content and water-holding capacities, topsoil was imported to cover all cut-and-fill slopes. The majority of the topsoil was collected from bogs and meadows and stockpiled on deposition areas along the right-of-way. Topsoil stockpiles must be in areas that can be protected from erosion. Some erosion problems occurred when topsoil was stockpiled too close to a live drainage.

Analysis of the topsoil was necessary to determine if the material had suitable texture, organic matter, and nutrient content.

The topsoil was spread 10-15 cm (4-6 in) deep over the cut-and-fill slopes by use of a drag line. Depths in excess of 15 cm (6 in) were subject to slumping or sliding as the soil became saturated during the spring runoff period.

Seeding

Two seed mixtures were used in the project because of differences in elevation and exposure. The Forest Service developed the seed mixtures from the best available research data and from its work on ski areas adjacent to the project. Seed species were selected that provided immediate and long-term erosion control. Many of the species commonly occurred in the immediate vicinity of Vail Pass. The seed was initially applied at a rate of 22.7 kg/hm^2 (20 lb/acre) by broadcast and 11.3 kg/hm^2 (10 lb/acre) by drilling. This rate turned out to be somewhat low and was increased to approximately 45.4 kg/hm^2 (40 lb/acre) by broadcast seeding.

In areas such as Vail Pass, which have frequent summer rainfall, the seeding operation can take place almost anytime during the summer as long as the stand of grass can be firmly established to avoid winterkill of the young, lush grass.

Fertilizer

Fertilizer is necessary for all high-elevation plantings (10). Low nutrient levels, coupled with a short growing season, slow processes of soil formation, and low decomposition rates, result in extremely harsh conditions for plant growth. In studies on adjacent high-elevation ski areas, it was found that 283.5 kg/hm^2 (250 lb/acre) of 16-20-0 ammonium phosphate-sulfate should be applied with grass seeding (11). A follow-up fertilization of 226.8 kg/hm^2 (200 lb/acre) of 16-20-0 can be used at the beginning of the second growing season for maintenance. It is appropriate, however, to regulate the amount of fertilizer applied according to the texture, organic matter, ion-exchange capacity, and depth of the soil at the project site. Generally, the application rate for soils at Vail Pass was 34-57 kg/hm^2 (30-50 lb/acre) of available nitrogen in the form of ammonium sulfate or urea and at least 113 kg/hm^2 (100 lb/acre) of P_2O_5.

Maintenance fertilization with nitrogen was necessary to ensure an adequate stand of grass. A light green or yellowing color in the grass and slow growth or thinning of the stand are good indicators that fertilization is necessary.

Mulch

Some form of mulch is essential to aid in germination of grass seed. The mulch helps to maintain soil moisture and reduces rapid fluctuations in soil temperature. The mulch also aids in temporarily stabilizing the disturbed soil while vegetation is being established. The most effective mulch used at Vail Pass was straw, applied by a straw blower or by hand at a rate of 3.4-4.5 Mg/hm^2 (1.5-2 tons/acre).

In the mountain environment, it was essential that the mulch be anchored to the ground to prevent its removal by wind, gravity, and water. Methods of anchoring the straw included use of a straw crimper or modified sheep's foot on the flatter slopes and plastic or jute netting on the steeper slopes.

Jute Netting

Because of the highly sensitive nature of Vail Pass soils, netting was used to hold the mulch in place on all slopes that exceeded 3:1. The primary netting used was a jute matting composed of heavy hemp material. The jute came in a roll 1.2 m (4 ft) wide by 68.6 m (225 ft) at a cost of approximately $35/roll. The netting proved extremely effective in providing immediate erosion protection for the sensitive soils of Vail Pass.

Some problems developed when the jute netting was not overlapped properly. During installation there should be a 10.2-cm (4-in) overlap on the matting to allow for shrinkage. The jute must be securely stapled to the ground and tucked into the slope at the upper end to prevent wind damage and surface erosion. It is also important that no concentrated surface runoff be allowed to flow over the slope. In several locations, the jute matting failed because flows crossing the slope were not confined in a natural drainage or rock-lined ditch.

Irrigation

Irrigation was used to a limited extent. Summer rainfall in the Rockies provides much of the water for stand establishment, and so there is much less need for irrigation than there is in other areas such as the Sierra Nevada. In some cases, however, it is still essential to carry new stands of grass through dry periods. Watering is particularly important for recently planted shrubs and trees.

One irrigation technique that was used at Vail Pass was a large water truck with spray nozzles. There were also opportunities to irrigate while pumping water from sediment ponds.

Shrubs and Trees

Many shrubs and trees were transplanted from areas in the project right-of-way for landscaping and long-term erosion control. It was found that shrubs and trees from higher elevations could be transplanted to lower elevations. The reverse, however, did not hold true: Results were very poor when plants were taken from lower to higher elevations. It is essential in transplanting to maintain the integrity of the root ball by means of a large mass of soil and to keep stored trees damp and in the shade.

Highway Maintenance

The success of a revegetation program depends on highway maintenance. After construction, care must be taken not to dump spoiled material over a vegetated slope. This is especially true in the spring when the drainage ditches are being cleared of sanding material and other debris. Designated dumping areas are necessary and should be identified in the water-quality plan. Educating maintenance crews to this idea is a necessity.

Permanent Drainage

To ensure long-term erosion control on cut-and-fill slopes, permanent protection from concentrated surface runoff is necessary. Surface-runoff patterns were evaluated during the initial highway planning phase, and culverts or protected drainages were planned where high runoff volumes and velocities were expected. On flat gradients, rock-lined ditches underlaid by a porous filter blanket proved effective for transporting water. On steeper slopes, shallow gabions underlaid by a filter blanket were more effective. When culverts were used, the outlets were placed in a location where discharge from them could be easily routed to a natural drainage or where it could be effectively dissipated and spread over undisturbed ground. When this was not done, severe erosion resulted.

Energy dissipators constructed from gabions were used to dissipate water runoff below steep, permanent slope drains. These structures were installed in areas where high runoff volume and velocities were expected. When properly placed and constructed, the gabions were very effective in checking high flows. But some problems were encountered when they were not properly placed or keyed into the slope. Soil erosion and eventual undercutting of the structure resulted from inadequate protection between the drainage outlet and the gabion structure.

Retaining Walls

It was found that, because of the close proximity of highway construction to live drainages, fills flattened out at 2:1 would often encroach on streams. To protect the integrity of the drainages and maintain good water quality, several types of retaining walls were used. Treated wood-crib retaining walls were used on small cut slopes, but the larger retaining walls were primarily precast concrete, dyed to match the color of the native rock and soil of the area. The retaining walls were very effective in reducing the encroachment of fill slopes on live drainages.

Temporary Erosion Control

In addition to the permanent erosion-control features incorporated in the roadway design, control measures must be anticipated and used during the actual construction period. These measures are temporary in nature and are designed to be removed once the construction is complete. They are extremely critical since the potential for water-quality and erosion problems is greatest during and immediately after construction. Temporary methods include sediment basins, sediment traps, and clear-water diversions.

Sediment Basins

A sediment basin is a natural or man-made depression used to detain runoff of turbid construction water. Water entering the basin is slowed to allow particulates to settle out before the water passes to downstream areas. The cleaner surface water is drained from the top of the basin, usually through a culvert or a rigid hose. Spillways are provided to protect the basin in the event their capacities are exceeded during storm periods. The size and the amount of particulates retained in a basin are a function of the volume of inflow water with respect to the size of the basin. Generally, given a steady inflow, the larger the basin is, the more sediment will be trapped.

Sediment basins are constructed by building a low head dam, excavating a depression, using a natural depression, or any combination of the three. All of these methods were used, with varying degrees of success, on the Vail Pass project. The effectiveness of the basins depended largely on the selected design, overflow drainage, and maintenance of the structures.

Design and Placement

Sediment basins were difficult to construct and maintain in the steep terrain of Vail Pass. The capacities of the basins were often below the design water inflow because of terrain restrictions. However, the basins were effective in retaining sand- and silt-sized particulates.

The excavated and natural basins were located in relatively flat terrain near the valley bottoms or on natural terraces. Construction runoff water was directed to the structures by temporary conveyances such as berms, culverts, flexible down drains, and plastic sheets. Overflow from the basins was discharged from a spillway to the undisturbed land or natural drainageways below the structures.

Dam-type basins were located in small natural drainages and usually in steeper terrain than excavated basins. The drainage bottoms were rounded out, and the excavated material was used to build a low head dam. Overflow from the basins was discharged, through a culvert drain, to the natural drainage below the structure. Spillways made of rock or plastic were placed on the dam face for overflow protection during storm periods.

Basins constructed by excavating depressions or using natural depressions (see Figure 1) proved superior to ones built with low head dams. Because these basins were located in flatter terrain, access for their con-

Figure 1. Excavated sediment basin.

struction and maintenance was generally easier. Their simple design did not require the construction and upkeep of a steep dam face. In contrast, the dam-type basins were located in narrow drainages that restricted the movements of construction equipment. Since it was often difficult to achieve adequate compaction, the fill material was allowed to become saturated during the spring runoff and summer rains. Consequently, dam faces would occasionally fail and send large amounts of sediment to downstream areas.

Overflow Drainage

Excavated and natural sediment basins drained the cleaner surface water over spillways provided at the low end of the structure. The spillways were protected from erosion by a covering of rock or plastic. The rock size varied, depending on the source, but was usually 10.2-15.2 cm (4-6 in) in diameter. Plastic coverings were 0.15-0.35 mm (6-10 mils) thick.

Both coverings proved effective, although rock was more durable if the basin was designed for more than one season. Plastic-lined spillways were reliable, but after a year of use the plastic tended to become brittle and suffered tear damage. Maintenance usually involved making sure that the plastic was anchored into the soil and/or properly weighted with rock. Rock-lined spillways required very little maintenance.

Dam-type sediment basins drain by drawing surface water through a metal culvert or flexible hose. The drains are connected to a culvert at the bottom of the basin, where the water is discharged to downstream areas. Variations of these drainage devices tried at Vail Pass included rigid hose, soft hose, culvert, and culvert with slits.

Flexible hose drains are buoyed to the basin surface by a float device, usually an airtight plastic bottle or a piece of wood. Continual problems arose in using these drains to provide unrestricted drainage. The soft flexible hosing would sometimes collapse or become twisted from the movement of the float device on the surface of the basin. In addition, the rigid hosing occasionally failed to provide good drainage: The hose was too buoyant and prevented water from entering the drain.

Culverts proved to be more effective outlet drains than flexible hosing. The 46- to 61-cm (18- to 24-in) diameter culverts generally required less maintenance and were more durable than the smaller 15.2- to 20.3-cm (6- to 8-in) diameter hose drains. Some culverts were constructed with slits in the upper foot to provide drainage before the basin capacities (at the top of the culvert) were reached. The Colorado Division of Highways discontinued use of this design because the slits became plugged with sticks and other debris.

Maintenance

The effectiveness of sediment basins depends largely on maintenance. The basins at Vail Pass were drained after a runoff event, to prepare for the next storm, by syphoning or pumping the collected clear surface water from the basin. Sediment basins were also periodically cleaned to retain their design trapping efficiency.

Disposal sites and the equipment necessary to clean the ponds should be planned in advance. A flat or depressed area, where the sediment can be spread and revegetated, serves as a good disposal site. Some types of recovered material can be dried and used as fill material on the construction job. Placing the accumulated material adjacent to the basin is not acceptable: The Vail Pass basins are of minimal size, and this served to reduce trapping efficiency because the sediment that had been trapped once washed into the basin a second time.

Sediment basins must be routinely inspected so that accumulated debris around drainage outlets can be removed. Failure to do this resulted in the drains being clogged and created the potential for overflow or washout. Provisions should be included in the water-quality plan to establish a maintenance schedule for the sediment basins and to designate the person who is to be responsible for inspection.

Sediment Traps

Sediment traps are temporary, small detention structures that operate on the same principle as sediment basins. The traps slow the velocity of runoff water, allowing the coarser particulates to settle. The cleaner surface water is passed on to downstream areas. Sediment traps cannot handle runoff volumes as large as those handled by sediment basins, but they are much easier and quicker to construct. They are generally used for one season or less, and the accumulated sediment and the traps are removed after the construction period. The location of the traps is usually determined in the field as the need for them arises. They can be constructed from a variety of materials, including straw bales, plastic, sandbags, filter cloth, and rocks.

Straw bales (see Figure 2) are perhaps the quickest and easiest type of sediment trap to construct. They are readily available and easy to transport and can be formed into a sediment trap just about anywhere. They must be firmly anchored to the ground to prevent failure underneath or between the bales. The standard procedure is to key them 10.2-15.5 cm (4-6 in) into the ground and to drive steel re-bars through the center. Anchoring the bales properly is extremely important in a mountain environment where steep gradients promote high runoff velocities. Most of the unanchored bales at Vail Pass failed after a short time.

Another effective and easily transported sediment trap is constructed by using a fabric filter. The fabric is made from filament fibers with randomly distributed pore openings. Water easily passes through the fabric, but soil is trapped. Figure 3 shows how the fabric is attached to a temporary wire fence. The bottom 15.2 cm (6 in) of the fabric is buried in the ground to prevent water from flowing under the structure. Construction runoff water is directed to the filter trap along berms, dikes, plastic-lined ditches, or culverts. For the best results, the water should be dispersed before it en-

Figure 2. Straw-bale sediment trap.

Figure 3. Filter-fence sediment trap.

counters the filter blanket. Fences in steep, narrow drainage ditches or swales should be avoided. The fabric has little lateral support and cannot withstand a force such as that caused by impounding 0.6-0.9 m (2-3 ft) of water.

Sandbags were also effective in trapping sediment at Vail Pass. They were considerably heavier and harder to transport than straw bales but were more durable and withstood high runoff velocities well. Although sandbags are heavy, they are pliable, which means they can be placed on steep sideslopes and across ground-surface irregularities. Because of their weight, sandbags can withstand a greater force per unit area than straw or fabric. This allows more water to be impounded with less risk of failure.

Small rock dams were occasionally used as sediment traps at Vail Pass. The rock size varied from 5.1-20.3 cm (2-8 in) in diameter. The rock dams worked well and provided a durable structure. They must be located in accessible areas because they are usually constructed, maintained, and removed by heavy equipment. These dams were most often used in areas where rock was abundant.

The key to the success of the sediment trap is, again, proper maintenance. In mountain areas like Vail Pass, the environment can be harsh. High winds, heavy rains, excessive runoff, and extreme temperatures can damage and reduce the effectiveness of the sediment traps. The inspection and maintenance of the structures must be performed regularly by the contractor. This should be part of the water-quality plan to ensure its enforcement.

Diversion of Clear Water

Many erosion and sedimentation problems can be avoided if runoff water is intercepted and conveyed around disturbed construction sites. A successful system of clear-water diversion intercepts the clean water above the project, transports it through the work area, and discharges it below with little or no degradation of water quality. This not only protects the integrity of the runoff water but also avoids on-site erosion and wet, muddy working conditions for the contractor.

Interception

Streams, springs, bogs, and shallow subsurface flows all contribute water to the construction zone. In mountainous terrain, these drainage patterns are complex and require an array of techniques to divert clean runoff water around disturbed construction sites. Some of the methods used at Vail Pass included shallow interception ditches, hay and plastic ditches, and small collection basins with pipe drains. Shallow interception ditches constructed above work areas were effective in routing clean water around the projects. The ditches were constructed on the contour and most often used on northerly slopes where numerous springs and wet subsurface conditions existed. The diverted water was routed to natural drainageways or culverts by which it was conveyed below the work zone. The ditches were either hand dug or trenched by using a small backhoe.

Hand-dug ditches such as the one shown in Figure 4 proved superior to backhoe trenches. The ditches were usually constructed on side slopes during the early construction season when conditions were wet. Backhoes had a difficult time operating in these conditions, often sliding and rutting the area adjacent to the ditch. It was also difficult to operate them in and around obstacles such as rocks and trees. Hand-dug ditches, on the other hand, had only minimal effects on the terrain and could be constructed through tight places such as forested hillsides.

Once constructed, the ditches held up well. Minor slumping and vegetative overgrowth were evident after one year of use. A jute netting or a similar product was often used to line the ditch at gradients of more than 6 percent to guard against erosion. Drainage was most efficient when gradients ranged from 5 to 8 percent; when gradients were less than that, water ponded and drainage was ineffective. Gradients of more than 10 percent that were not lined with a jute netting caused some scour and minor erosion.

Another, less effective method of diverting water along the contour was the use of straw bales lined with plastic. As surface flow came in contact with the hay and plastic, it was diverted laterally to a natural drainage or culvert. Both the straw bales and plastic were keyed 10.2-15.2 cm (4-6 in) into the ground. This system required more time to construct than hand-dug ditches and needed continual maintenance. The plastic and straw were difficult to keep anchored in the ground, and the plastic was subject to tear damage from wind, rocks, and tree limbs. It was also limited to diverting surface flows and did not reach the shallow subsurface water. It is recommended that this system be discouraged in favor of hand-dug ditches.

Collection basins were effective in impounding and diverting water where drainage problems were isolated to a few places such as a spring, a seep, or a small creek. Small basins were dug in the ground or con-

Figure 4. Hand-dug interception ditch above project area.

Figure 5. Failure of plastic-lined ditch.

structed by using sandbags at the water source. The impounded water was diverted into an irrigation pipe, a culvert, or flexible plastic down drains and directed through the work area. The water was then discharged into natural drainage courses below the construction site. Collection basins work well if they are inspected and maintained. The inflow pipe must be kept free of debris to prevent overtopping and subsequent erosion. As in the case of other temporary erosion-control structures, a routine maintenance schedule is imperative for collection basins and should be specified in the water-quality plan.

Transport

Once the clean water is diverted above the construction sites by either ditches or basins, the water has to be directed safely through the construction zone. Many different methods were used at Vail Pass, including metal culverts, flexible plastic down drains, irrigation pipe, and plastic-lined ditches. The method of transport depended on the anticipated water volumes, the duration of use, and the length and steepness of transport.

Metal culverts 46-61 cm (18-24 in) in diameter were the most effective all-around method of transporting water through work areas. They can withstand high runoff velocities and transport water great distances and can be expected to hold up for more than one construction season. Their disadvantage is that metal culvert is more expensive than some of the other diversion materials.

Irrigation pipe also worked well as a means of transporting water, but because of its size [20.3 cm (8 in)] it was restricted to intercepting small quantities of water. In addition, it required more maintenance to remove accumulated debris from the water-intake opening. During operations in late fall and early spring, ice accumulations would sometimes plug pipe inlets and restrict drainage. If the pipe is to remain functional, someone must be on hand to chop and remove the ice. This type of drain should be used only during the summer and should not be counted on to transport spring runoff water.

Flexible down drains and plastic-lined ditches are also reliable transporters of water, provided they do not have to carry heavy runoff volumes over long distances. These structures are more temporary than the metal pipes and require more maintanance. Flexible down drains are excellent on short, steep slopes. Their flexibility conforms to the water flow, maximizing friction and slowing water velocities. The drains were staked to the ground to prevent excessive movement caused by wind or internal water flow. Such movement may cause creases or bends that can fail under the force of the drainage water.

The use of plastic-lined ditches should be limited to diversion projects of short duration. The ditches require constant inspection and maintenance. The plastic is anchored in place by logs, rocks, stakes, or other means. Figure 5 shows how failures occurred at Vail Pass when the plastic slipped beneath its anchor and drainage water spilled on the disturbed soil. The plastic must also be durable so that water flow does not tear it on the irregular channel bottom. The plastic was at least 0.15 mm (6 mils), and preferably 0.35 mm (10 mils), thick.

Discharge

Discharging the intercepted water below the work area is the final stage of a water-interception system. In the steep terrain of Vail Pass, energy dissipators were often required below the drains to slow the runoff water to nonerosive velocities. A complete system carries the water through the project area and discharges it into an energy dissipator. A variety of temporary dissipators, including loose rock riprap, straw bales, and silt fences, were used.

Loose rock riprap or a wire and rock mattress placed below a drainage outlet was effective in checking erosion and undercutting. Loose riprap consisted of graded angular rocks, 10.2-25.4 cm (4-10 in) in diameter. The rock protection should extend to and around the drain outlet. The riprap should be at least 1.2 m (4 ft) wide to prevent drainage from circumventing the structure.

When water discharge is temporary because of construction activities, simple and less expensive energy dissipators are adequate. Straw bales keyed into the ground and lined with plastic were commonly used at Vail Pass. Maintenance was required to see that high velocities did not tear the plastic and break the straw bales. A silt fence (as described earlier) was placed in a semicircle behind the straw bales to retain sediment that was picked up during transport. These dissipators worked well when high runoff volumes were not encountered. The straw and plastic were most often used below 20.3-cm (8-in) irrigation pipe drains but were not used below 46- to 61-cm (18- to 24-in) culverts. Energy dissipators below high-discharge drains were made of rock even if they were temporary.

Temporary Roads

Many temporary roads were required during the early construction phases of the project. Proper location of such roads can eliminate many potential water-quality problems. Where possible, the roads at Vail Pass avoided streamside zones, potential landslide areas, and steep terrain. Adequate drainage in the form of well-spaced water bars, culverts, and temporary bridges effectively reduced water-quality problems while the roads were in use. When their use was completed, the roads were water-barred, seeded, fertilized, mulched, and closed to access. This was followed by field inspection to ensure that the site was properly revegetated and water bars were properly installed.

Temporary Stream Crossing

Because of the steep, dissected terrain of Vail Pass, many temporary stream crossings were required during construction. Temporary bridges, culverts, and low-water crossings were used. The selected design depended on the type of equipment that would cross the stream, the number of crossings required, and the duration of use.

Temporary bridges and culverts were installed in locations where heavy traffic was anticipated over an extended period. The temporary bridges were judged to be the best way to protect water quality. Very little fill material encroached into the stream channel and, once the bridges were in place, log cribbing prevented soil from sloughing into the water. The disadvantage of the temporary bridges was that they were relatively expensive to install and deteriorated somewhat under heavy use.

In contrast, culvert crossings held up well although disturbance of fill material during their installation and removal caused localized stream sedimentation.

Low-water crossings were originally permitted in a few locations where light equipment had to cross a stream only once or twice, but excessive disturbance caused by saturated soils and the absence of rock material adjacent to the streams eventually prompted elimination of this method and the use of small temporary bridges instead.

SUMMARY

Many erosion and sedimentation problems can be avoided during road construction if they are anticipated and prepared for in advance. Planning ahead for these problems begins with the initial road design and continues through the actual construction period. The preparation of a water-quality plan prior to construction activity is essential in protecting soil and water resources. Although the complexity of the plan may vary depending on project location and reclamation objectives, all plans should include provisions to

1. Prepare a site-specific contingency plan that addresses potential water-quality problems and outlines methods to correct them,
2. Establish a maintenance schedule for permanent and temporary erosion-control structures, and
3. Appoint a supervisor for erosion control and water quality who is responsible for implementing control measures.

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