

Vail Pass area. Careful selection and treatment of materials—e.g., the use of self-weathering steel box girders and the use of color in the concrete—were undertaken to blend the bridges into the natural color scheme of their surroundings.

Without these concerns for environmental protection, it is likely that the cantilever construction of segmental concrete box girders would not have been attempted. The experience gained in this popular European construction technique on the Vail Pass project, and on other projects more recently initiated in this country, will help to promote its more widespread use in future U.S. bridge projects. The alternative bidding technique used on the Vail Pass bridges indicates that, in the matter of cost, the segmental concrete structures can compete quite favorably with the more conventional types of structures.

Where retaining walls were applicable, environmental and aesthetic concerns also resulted in extraordinary measures to minimize damage to the natural terrain. A unique precast concrete retaining-wall unit was developed that was aesthetically acceptable and easy to cast and erect. As an alternative, panels of the patented reinforced-earth type of wall were redesigned to be practically identical to the precast units. An attempt was made to evaluate the comparative costs of the two wall systems, but the results were inconclusive. The cost of the precast concrete tieback walls can be significantly reduced if they are designed on the battered-wall concept.

The various structures at Vail Pass as they appear today provide evidence that major highway structures can indeed be constructed without serious damage to

the environment. The Vail Pass bridges and retaining walls will stand for many years as testimony to the sincere efforts of various government agencies and designers involved in the project to preserve the aesthetic appeal of the area.

ACKNOWLEDGMENT

We would like to acknowledge the following firms and individuals who were involved in the various aspects of the Vail Pass project discussed in this paper: Frank Lloyd Wright Foundation, H. J. Meehen Engineering Company, James R. Libby and Associates, F. Dwayne Nielson of International Engineering Company, and Ralph B. Peck, geotechnical consultant.

REFERENCES

1. Design Considerations for I-70 Bridges at Vail Pass. International Engineering Co., Denver, April 1973.
2. Vail Pass Alignment Studies and Design Concepts. International Engineering Co., Denver, April 26, 1972.
3. Design and Field Test of a Precast Concrete Retaining Structure. International Engineering Co., Denver, Aug. 1974.
4. Test and Evaluation of Concrete Tieback Retaining Wall, Station 498, Vail Pass. International Engineering Co., Denver, July 1976.

**A.B. Milhollin was with the Denver office of International Engineering Company when this research was performed.*

Cast-in-Place Segmental Bridges in the Vail Pass Project

Man-Chung Tang and Khaled M. Shawwaf, DRC Consultants, Inc.,
New York
Juergen L. Plaehn, Dyckerhoff and Widmann, Inc., San Diego

The design and construction of four cast-in-place segmental bridges that carry the Vail Pass section of I-70 over Miller and Black Gore Creeks are discussed. The free-cantilever method of construction is detailed. Measures dictated by special environmental and time restrictions on construction are also examined.

This paper describes the design and construction of four bridges that carry the Vail Pass segment of I-70, located about 11 km (7 miles) southeast of Vail. Two of these structures span Miller Creek and the other two Black Gore Creek.

The configurations and cross sections of the bridges are shown in Figures 1 and 2. The spans are relatively short, but the strict environmental constraints specified in the contract documents limited possible construction techniques.

The owner prepared two completely different designs for bidding purposes—one with a steel superstructure and the other with a prestressed concrete superstructure. Although the concrete design was based on precast segmental construction, the cast-in-place method was allowed if the contractor preferred. To blend the

structures with their surroundings, a light pink concrete color was specified to match the large natural rock outcroppings in the area.

Final construction was based on the cast-in-place segmental method, and the construction sequence was slightly different from that suggested in the original design. The piers, which varied in height from 6 to 21 m (20 to 70 ft), were cast-in-place hollow sections prestressed vertically. The substructure was constructed according to the original contract plans.

Construction of the superstructure of the Miller Creek bridges started in May 1977 and was completed in the first week of September. In August, construction of segments on falsework was started on the Black Gore Creek bridges; the cantilever segments of these bridges were started after the form travelers had been removed from the Miller Creek bridges. Construction of the Black Gore Creek bridges was completed in the second week of November 1977.

Figure 1. Elevations and typical section of Miller Creek bridges.

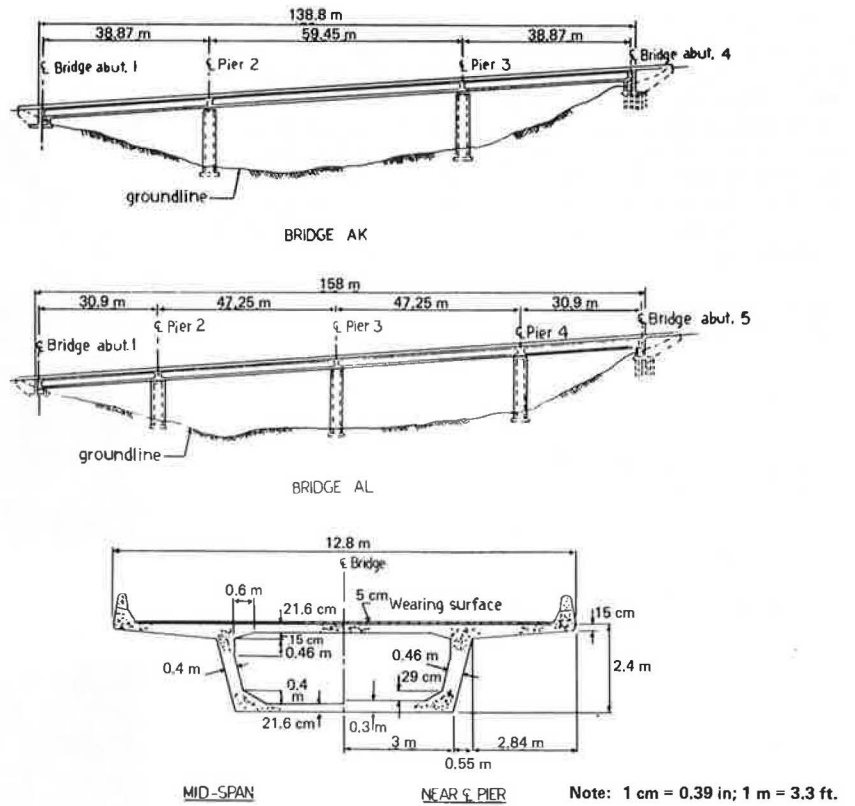
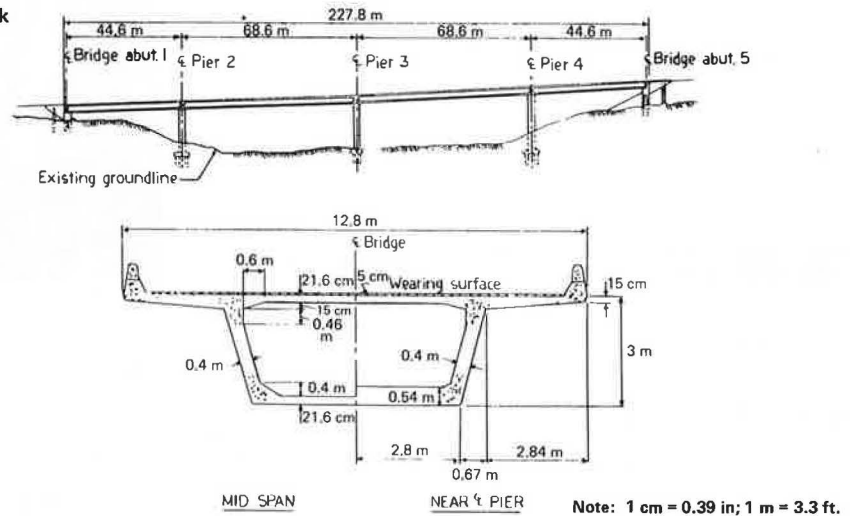


Figure 2. Typical elevation and typical section of Black Gore Creek bridges.



CONSTRUCTION METHOD

Because of the relatively cold climate in the Vail Pass area, the available time for construction was very limited. To meet the requirement that all four bridges be finished within one year, a very tight schedule had to be maintained. Because of the requirement that the environment should not be disturbed during construction, falsework construction was not permitted for most parts of the bridges.

Figures 3 and 4 show the construction schemes developed to overcome these restrictions. Figures 5-10 show various aspects of the structures themselves during construction operations.

Three types of construction schemes were devised: one for the two Miller Creek bridges and one each for

the Black Gore Creek bridges. Both bridges across Miller Creek (structures AK and AL) were built by the cantilever method on temporary supports, as shown in Figure 5. For each bridge, two form travelers were assembled on top of 9-m (30-ft) segments of the superstructure at both abutments. The side spans were supported at every second segment by a temporary bent. For bridge AL, temporary bents were also used in the interior spans.

Construction started from the abutments and proceeded toward the center of the bridge, where one of the form travelers was dismantled and the closure pour, at midspan for bridge AK and at the center pier for bridge AL, was made by the remaining form traveler. This method was selected because the spans in these two bridges were too short for the classical free-

cantilever method (balanced cantilever), which would have required assembling two form travelers at each pier and dismantling and transferring them to other piers after only a few segments had been cast. The method used here required that the form travelers be assembled and dismantled only once for each bridge. Another important advantage of this method was that construction material and personnel could be transported over the finished part of the bridge to the segment under construction.

Figure 3. Construction schemes for Miller Creek bridges: (a) bridge AK and (b) bridge AL.

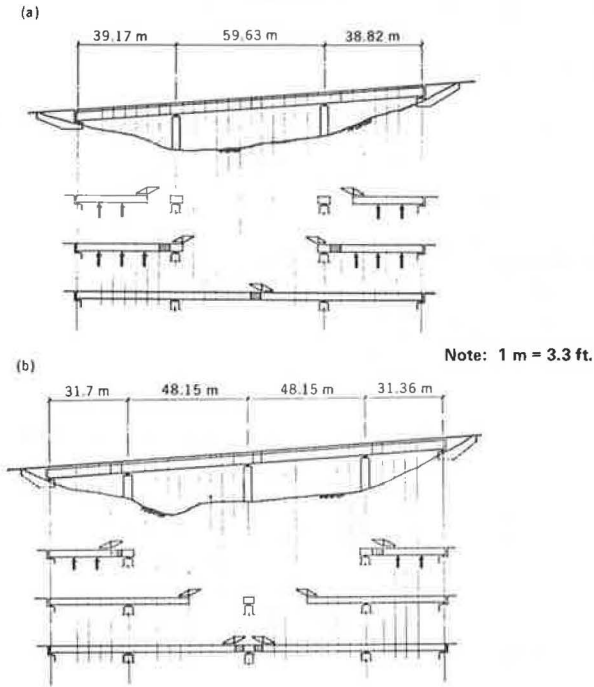


Figure 4. Construction schemes for Black Gore Creek bridges: (a) bridge AM and (b) bridge AN.

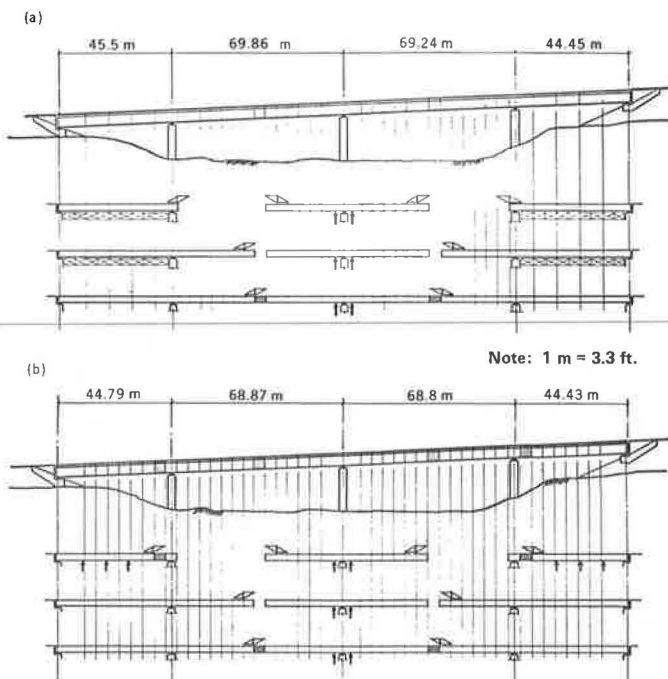


Figure 5. Side-span cantilever construction: bridge AL.



Figure 6. Free cantilevering from center pier: bridge AM.



Figure 7. Bottom view of free-cantilevered span: bridge AM.



Figure 8. Closure pour after removal of form travelers from other side of bridge: bridge AM.



Figure 9. Form traveler.



Figure 10. View of pier segment showing typical tendon arrangement: bridge AK.



The temporary bents consisted of two 30-cm (12-in) steel columns, wide flange and braced as required, to transfer vertical and horizontal loads. It is essential that the footing for these bents be carefully designed to minimize problems caused by excessive or differential settlement.

The bridges over Black Gore Creek (structures AM and AN) have slightly longer spans. Two different construction schemes were used for these bridges, mainly

because of scheduling requirements (Figure 4). Since only six form travelers were available for the whole project, it was not possible to construct all four bridges simultaneously. To gain construction time, both end spans of bridge AM and one end span of bridge AN were built on falsework. Fortunately, this was possible because the clearance under the end spans was low and the falsework would not adversely disturb the environment. After these end spans were finished, the form travelers from the Miller Creek bridges were transferred to the segment over the side piers so that the rest of the construction could be carried out by the free-cantilever method.

The segment over the center pier on bridge AM was stabilized during construction by using steel columns supported on the pier footing, which rested on large concrete caissons (see Figures 6 and 7). During cantilevering, it was apparent that, as a result of overestimation of the allowable bearing capacity, the footing could not resist the specified construction forces without excessive rotations. This resulted in the pier being 15 cm (6 in) out of plumb and the ends of the cantilever deviating from the theoretical elevations by about 0.3 m (1 ft). Before closure, however, the cantilevers were rotated to the correct elevation. Later, remedial measures were taken to reinforce the pier footing. Figure 8 shows the closure pour on bridge AM after removal of the form travelers from the other side of the structure.

Free-cantilever construction was developed in the early 1950s by Finsterwalder of Dyckerhoff and Widmann and has been used since in the construction of many bridges. Until very recent times, this had been the only method of construction for long-span concrete bridges when falsework was not permitted or was uneconomical.

Figure 9 shows a typical form traveler. It is mostly hydraulically operated and can be adapted to various geometric layouts. Horizontal curvature, steep profiles, and cross slopes (such as those of the Vail Pass bridges) can be easily accommodated. The segments are usually between 3.6 and 5 m (12 and 16.5 ft) long. In the Vail Pass bridges all the cantilever segments are 4.5 m (15 ft) long. The use of a constant segment length simplifies construction, form setting, rebar cutting, and installation.

Normal cantilever construction is done in four-day cycles, which means constructing one segment at one form traveler every four days. The most critical item is the curing time of the concrete. Vail Pass specifications required a 24-MPa (3500-lbf/in²) concrete strength at the time of post-tensioning and 38 MPa (5500 lbf/in²) at 28 days.

In order to finish all four bridges within the specified period, a three-day construction cycle had to be achieved. Because the time required for placing rebars and tendons is quite constant, the construction cycle could be shortened by decreasing the curing time. For this purpose, a special water reducer was used to obtain a concrete strength of 24 MPa within 18 h. Toward the end of construction, the time required for each segment was reduced even further—to 2.5 days. Some honeycombing in the concrete did occur in the early stages of construction, probably because of the lack of experience in the use of the water reducer.

The superstructure was prestressed in the longitudinal direction only. Although transverse prestressing would have been suitable for the box-girder dimensions used in the Vail Pass bridges, the top slab was reinforced concrete as given in contract plans.

All post-tensioning consisted of 3-cm (1.25-in) diameter, 10.3-MPa (1500-lbf/in²) threadbars. These

bars were mostly two segments long [$2 \times 4.5 = 9$ m ($2 \times 15 = 30$ 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/in²) 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

William N. Johnson, U.S. Forest Service, South Lake Tahoe, California
R. Scott Fifer, U.S. Forest Service, Glenwood Springs, Colorado

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 pro-