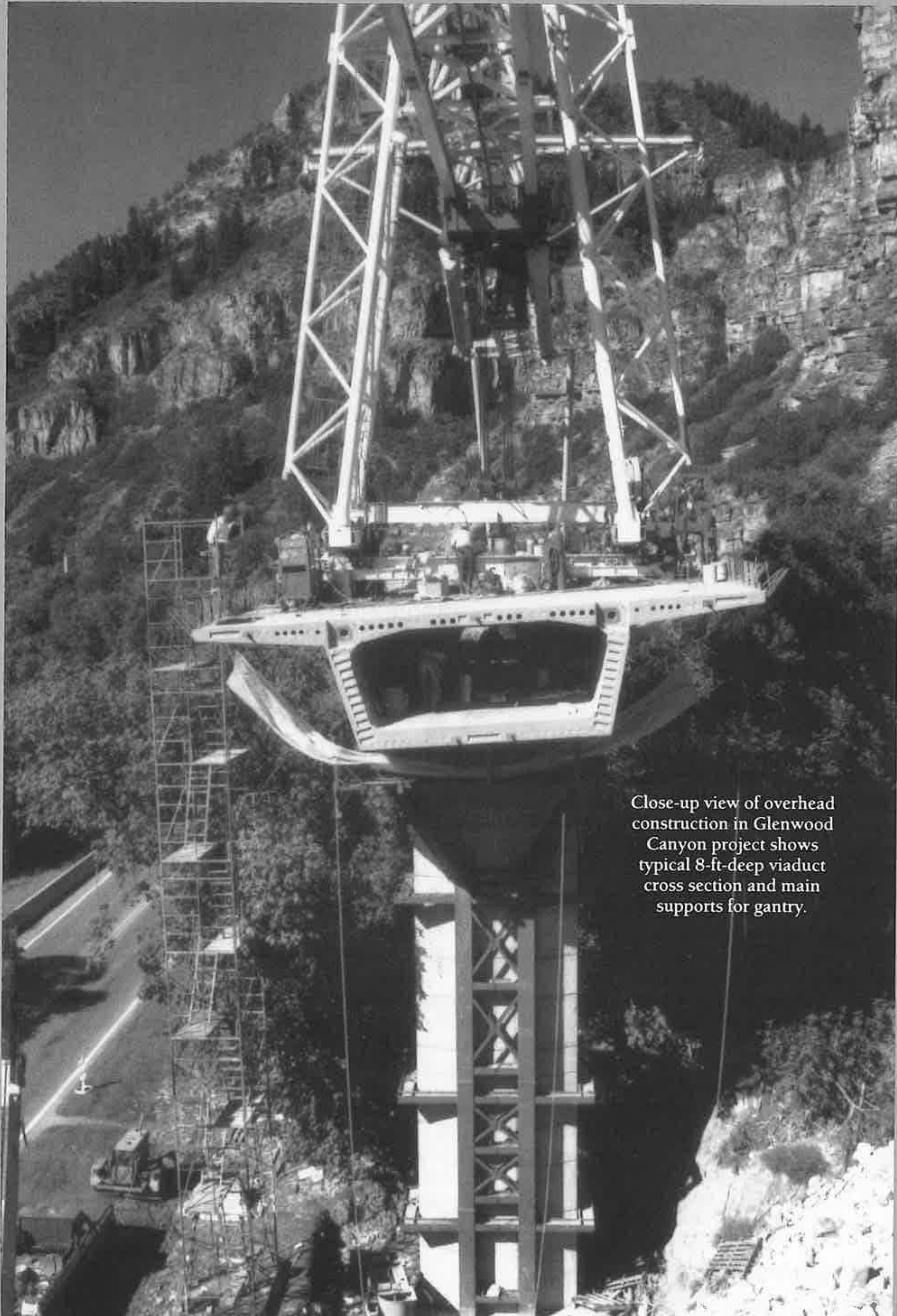
Blending the Wonders of ENGINEERING *and* *Nature*

HERMANN GUENTHER

Colorado Canyon Provides Engineering Challenge in Interstate 70 Construction



Close-up view of overhead construction in Glenwood Canyon project shows typical 8-ft-deep viaduct cross section and main supports for gantry.

"The interests of the people of this state will be best served by a highway so designed that . . . the wonder of human engineering will be tastefully blended with the wonders of nature."

This statement, in a joint resolution passed by the Colorado state legislature in 1968, presented a formidable challenge to the Colorado Department of Highways (CDOH), considering the physical and administrative obstacles facing the managers and designers assigned to accomplish this goal.

The highway cited in the resolution is a 13-mile segment of Interstate 70 through Glenwood Canyon in western Colorado. After years of study this scenic gorge, carved by the flow of the Colorado River, was selected as the most viable route for construction of the last major section of I-70 in Colorado. For more than 100 years the corridor has served as a transportation route. A mainline railroad track along the south wall of the canyon was constructed in 1887, followed shortly thereafter by primitive cart tracks along the north side, which by the early 1930s became the first narrow two-lane highway to traverse this seemingly impassible route.

Was the task set before CDOH by the legislature an unfair and insurmountable one? Not in the opinion of the author, considering that when final design began in 1980, CDOH had already established its credibility with the recently completed Vail Pass section of I-70. What differentiated the Glenwood Canyon route from other environmentally sensitive highway projects was the technical challenge of constructing a safe and efficient four-lane highway that would be fully compatible with nontransportation-related concerns. Certain variances from Interstate highway design standards that were granted in the 1976 Federal-Aid Highway Act allowed I-70 to better fit in the available space in the canyon. Many special construction features, not normally eligible for federal highway funding, were permitted by a subsequent Federal-Aid Highway Act in 1981. Without these features, the project might never have proceeded beyond the planning stage, despite earlier route location approvals.

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Undertaking the Challenge

Building a highway along the meandering route through the White River Plateau has challenged the minds of some of the nation's most talented highway professionals for years. Anticipating a long and difficult project in Glenwood Canyon, CDOH assembled a design team that included key individuals from its own staff and the staffs of several consulting firms, and two uniquely talented individuals who served as the project's "inspired" designers.

The design team's responsibilities, under the leadership of Ralph Trapani, the state's project manager, were to identify the project constraints, formulate methods for mitigation of adverse environmental impacts, develop plans for implementation, and supervise the construction to meet all commitments. To afford architectural consistency and visual continuity, the firm DeLeuw, Cather & Company was selected to serve as supervising architect. The firm Daniel, Mann, Johnson, & Mendenhall (DMJM) was selected as the management consultant.

During the preliminary planning and design phases, Colorado highway officials recognized that individuals and special interest groups would be affected by, and have an impact on, the project. Accordingly, they authorized the formation of a technical review group and a citizens' advisory committee, whose members would represent the views of the public.

Bringing these opposing forces together and maintaining progress on the project with a semblance of harmony was a problem that faced the design team in the early years of the project. Designers Joseph Passonneau and the late Edgardo Contini addressed the problem through their ability to communicate difficult technical concepts to the public in lay terms and at the same time incorporate community input in technical solutions. The success of the project was contingent largely on their ability to win the confidence of those opposed to construction in the canyon.

The final approval to construct I-70 through Glenwood Canyon was encumbered by numerous public commitments and legal stipulations that resulted from years of study, deliberation, and court action. The design team, therefore, had to develop designs that would overcome physical and administrative obstacles in order to meet those commitments, which mandated that the new highway must, among other conditions,

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- Cause no damage to the natural canyon environment,
- Accommodate and enhance recreation,
- Afford aesthetic appeal compatible with the grandeur of the canyon, and
- Maintain the safe flow of traffic during construction.

These conditions resulted in the identification and formulation of several project elements to mitigate the concerns brought before the design team. A description of the function, design, and construction of the principal project elements is essential for a complete understanding of

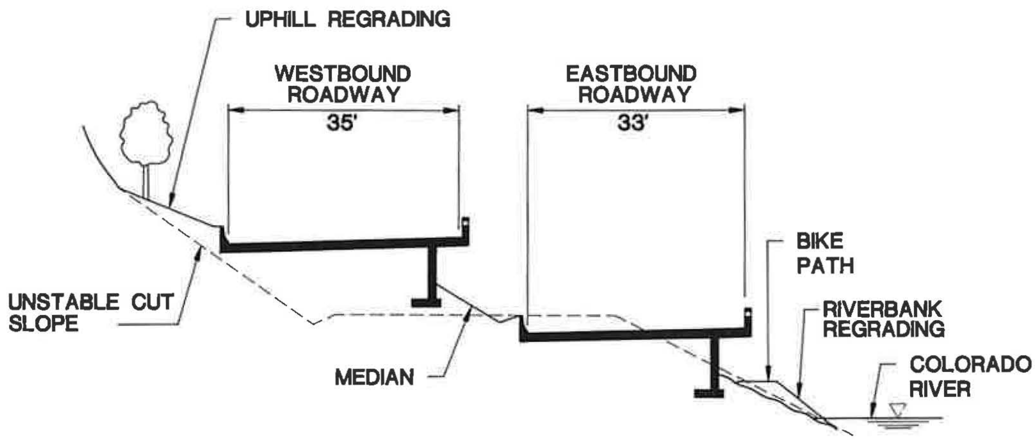


FIGURE 1 Terraced system of retaining walls with posttensioned concrete pavements permits optimum use of existing terrain.

what makes the Glenwood Canyon project unique.

Project Elements

A Tight Squeeze

The extremely narrow space available in which to build a new four-lane highway, in the exact location of the existing two-lane road, presented an immediate and obvious dilemma. One solution was a terraced system of retaining walls with posttensioned concrete pavements that would cantilever 6 feet beyond the face of the walls. As shown in Figure 1, this configuration allows optimum use of the existing terrain. The proximity of the lower eastbound roadway to the westbound, as well as the relative heights of the walls, was dictated by the steepness of the slopes above and below the old highway. It was not unusual for some of the wall heights to approach 40 feet in critical locations.

A typical construction sequence was to build the lower roadway first. This, obviously, had to be accomplished while maintaining the flow of traffic, which was accomplished by squeezing the travel lanes against, and even into, the rocky, uphill slopes. Under these conditions, contractors had a narrow strip available for their operations, which began with excavation for and construction of a continuously reinforced concrete footing. The walls were designed as twin-tee sections, prefabricated, and hauled to the site as needed. The sections were fastened to the footing by posttensioning, using vertical steel rods anchored in the footing and threaded through ducts in the stems of the tees. After backfilling was completed, the 9-inch-thick slab was placed, posttensioned, and fitted with the parapet and safety rail. Once the slab was overlaid with asphalt pavement, traffic was shifted to the new roadway, and the process was

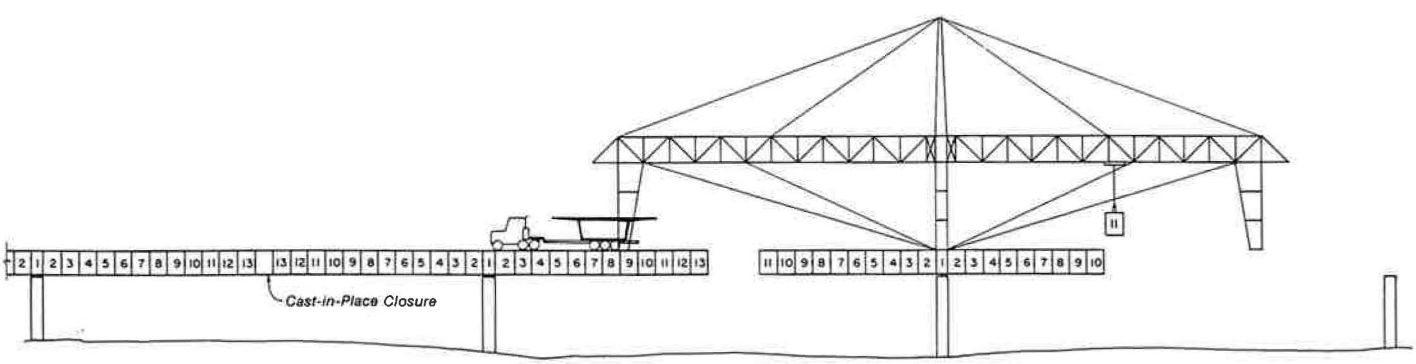


FIGURE 2 Traveling gantry construction sequence.

repeated for the westbound section. Most of the 20 miles of retaining walls in the canyon were constructed this way.

Preservation and Enhancement

Aside from the physical benefits of this system, there are aesthetic enhancements to be realized. Construction of the old highway in the 1930s left considerable scars in the landscape, which in some cases have been a cause of excessive erosion and rockfall, not to mention their lack of visual appeal. The damage will be repaired or virtually eliminated from sight by a complete program of regrading and landscaping.

It was mandated early in the process that the landform, as well as the landscape, must be preserved in its natural condition to the maximum extent possible. This meant that excavation of the majestic rock formations must be minimized and that vegetation must not be disturbed unless absolutely essential to construction. Any necessary blasting of cliff faces had to be conducted in a manner that left no evidence of man's intervention, accomplished in some cases by staining the exposed rock surfaces with a color that matched the naturally weathered rock. Preservation of vegetation was ensured by establishing "environmental limits" on which contractors could not encroach. To help enforce the limits, construction contracts contained stringent specifications regarding protection of the landscape, which, if violated, could result in significant financial penalty to the offending contractor.

Canyon Links

Among the project elements designed to mitigate adverse environmental and visual impacts, bridges and viaducts are some of the most visible. Thirty-nine such structures, with a combined length of 6.5 miles, are being built in the canyon. Although a few are for traditional purposes such as river crossings or grade separations, most were designed for environmental protection and reclamation. It would have been aesthetically and environmentally unacceptable to place the roadway on the large fills or high retaining walls that otherwise would have been required to traverse the draws, sidehills, and other geologic features of the canyon. Geometric constraints forced the alignment into locations that would have suffered irreparable damage under normal highway construction processes.

Before final design was begun, a detailed bridge concept study was completed that identified preferred bridge types at all locations on the basis of evaluations of environmental, architectural, structural, and economic criteria. The preferred types were cast-in-place box girder, precast segmental concrete box girder, steel plate girder, and steel box girder superstructures. Although they are all fairly standard bridge types, their construction, in most cases, was not so straightforward.

With the exception of cast-in-place box girder bridges, which were built only in locations in which there was adequate space, no traffic, and minimal environmental impact, most bridges presented major construction logistics problems. Limited access for the large equipment required to erect the bridges was compounded by the lack of maneuvering room. Because some of the bridges were to be erected using traditional crane lifting methods, constructibility studies were prepared to ensure that the methods would work. The ability of each crane to lift and reach among such obstacles as cliff faces, trees, overhead power lines, and other cranes was analyzed.

Construction from Above

One of the bridge erection methods being used in the Glenwood Canyon project has been used extensively in the Alps and involves the use of an erection gantry. The 350-foot-long truss permits the construction of the superstructure entirely from above (after the piers and abutments have been placed), and thus the natural features of the canyon that would otherwise hamper or even preclude traditional erection methods are avoided and preserved. The gantry, which was imported from Europe, was used in the successful completion of the 4,000-foot-long French Creek Viaduct and is now being used in the construction of the largest bridge project in the canyon, the 7,000-foot-long Hanging Lake Viaduct.

The method used for placing the precast segments is known as the balanced cantilever method. For this simplified description of how the method works, it is best to refer to Figure 2. The gantry is a horizontal truss that spans from pier to pier. Segments are delivered along the completed portion of the bridge, transported by trolley along the gantry to the next pier, and attached and tensioned to previously installed segments. The seg-

PADE/TOM PADE PRODUCTIONS

Aerial view of French Creek Viaduct illustrates lack of available space for highway construction.

ments are placed on alternating sides of the pier, with a maximum imbalance of one segment allowed, until the trailing cantilever from one pier meets the previously completed leading cantilever from the earlier pier. Where the two cantilevers meet, a closure segment is poured in place. At this point, the gantry, which has four pairs of "legs," is "walked" to the next pier, where the process is repeated.

Logistic and Environmental Benefits

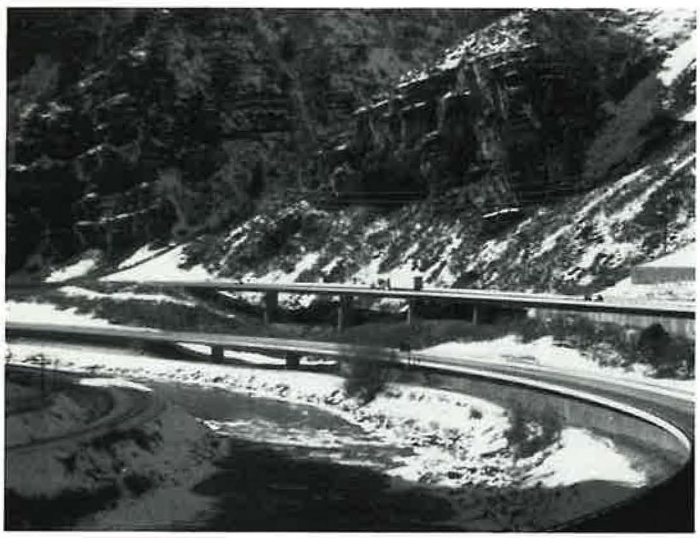
The benefits of using this method are extensive. For those responsible for managing traffic through the construction, the procedure has afforded considerable relief because most work can be accomplished adjacent to, or above, moving traffic. The environmental benefits are especially apparent when one walks underneath the French Creek Viaduct and looks up at a bridge that appears to be floating above the trees. The few areas that had to be disturbed for pier construction have already been replanted, and evidence to date indicates a complete recovery, with the visual impression that, somehow, the entire structure was airlifted into place. In a sense, the major portion of it was.

Standardized Details

To preserve the architectural integrity of a project with so many structural elements, numerous details, which became known as common element design directives, were standardized. The result was that the opportunity to be creative—at least in the visual sense—was taken away from the detail designer. From the technical standpoint, on the other hand, designers were sometimes challenged to the very edge of the art to develop structural systems that would satisfy both the aesthetic visions of the concept designers as well as the formidable constructibility obstacles confronting the contractors. All this notwithstanding, meeting numerous safety and performance codes was further complicated by poor foundation conditions, lack of space to stage construction operations, and the need to meet federal mandates to consider alternative structure types in steel and concrete.

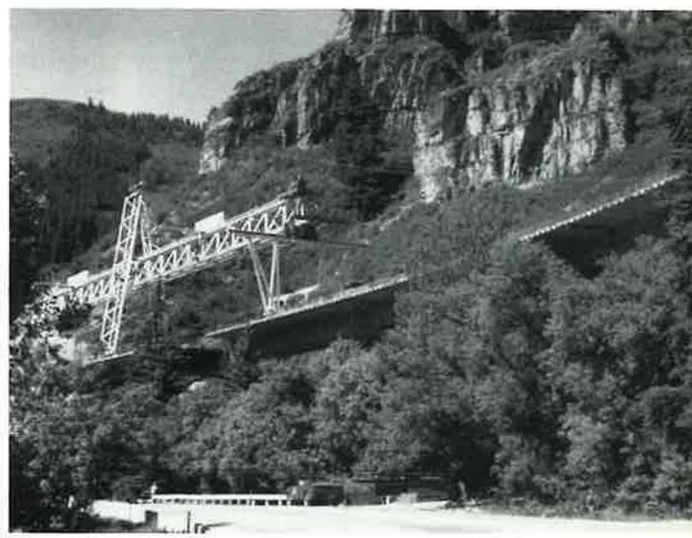
Tunnels Preserve Popular Trail

The trail to Hanging Lake, the most popular hiking trail in Colorado, begins right in the middle of Glenwood Canyon, in one of its most scenic spots. It is not surprising, therefore, that construction of a four-lane highway through this area met with considerable resistance from groups and individuals concerned with recreation and



ECHOLS/DMJM

View of completed section at west end of canyon shows aesthetic use of bridges to preserve natural landform.



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Erection gantry allows construction of French Creek Viaduct without disturbing the landscape.

"...designers were sometimes challenged to the very edge of the art..."

the environment. Consequently, more design alternatives were studied for this location than for any other in the canyon. The one that emerged as the most acceptable consisted of a pair of tunnels bored through the cliffs on the opposite side of the Colorado River, which would allow the entire area around the trailhead to become a traffic-free zone. The only access will be by means of a narrow trail from an interchange some distance away.

As highway engineers know, tunnels are complex structures. The Hanging Lake Tunnels, which will be 4,000 feet long when completed, are no exception, and their design was not made any easier by the fact that the four portals will also act as bridge abutments so that highway construction can be continued on the north side of the river. It should not be hard to imagine the difficult interface coordination that was required between the tunnel and bridge designers and contractors.

The tunnel construction process uses a support system unique in the United States. Because of favorable ground conditions, the firm that designed the tunnel, Parsons Brinckerhoff, was able to propose a system that uses rock reinforcement as the permanent tunnel support.

Successful implementation of this type of construction requires a close working relationship among designer, owner, and tunneling contractor. A drill-and-blast technique, beginning with the excavation of a center top heading followed by two side slashes, is being used. After each round, rock bolts, in combination with shotcrete if necessary, are installed. Damage to adjacent rock resulting from blasting must be minimized. Once the crown of the tunnel is stabilized, the bottom bench can be excavated under safe working conditions. This system does not require any active structural steel or concrete support system. The tunnel interior will consist of a nonstructural concrete lining finished with ceramic tiles.

Tunnel Control Complex

Because of their length and somewhat isolated location, these tunnels will be provided with a fully staffed control complex, complete with instrumentation and monitoring equipment. The facility, to be located near the midpoint, where the tunnels traverse under a side valley, will be a four-story building that also will house ventilation equipment. Construction of this complex (including short sections of the tunnels) is being conducted in an open excavation. After completion of this work, the floor of the side valley will be restored to its original condition, and the entire complex will be buried and almost completely hidden from view.

The ventilation system will be of the semi-transverse type and will consist of sets of fans that will provide fresh air when needed through vent openings in the tunnel ceiling. (Natural airflow is expected to be adequate most of the time.) In the event of a fire or other emergency, the fans can be reversed to operate in an exhaust mode, and fresh air can be pulled in from the portals and exhausted through the ceiling vents, minimizing the spread of smoke and facilitating access to the fire for emergency response crews.

Ice Detection

Roadway icing at tunnel portals is a common maintenance problem in Colorado. The problem will be exacerbated in this case because the roadway sections into and out of the Hanging Lake Tunnels are on bridges. These bridges, along with several others in the canyon, are not exposed directly to the sun for several months in the winter. To help resolve this problem, an ice detection system will be installed on the tunnel approach structures, as well as on the other long bridges. Bridge deck sensors connected to remote processing units will feed information back to a central computer in the control center. Information on temperature, moisture, local weather conditions, and ice formation will allow maintenance crews to respond before icing becomes a problem. Closed circuit television monitors will allow visual confirmation.

Recreation Enhancement

Early project commitments ensured that recreation in Glenwood Canyon will not only be preserved, but enhanced, as part of the overall construction program. One feature of the project will be a 10-foot-wide bike path the entire length of the canyon between the highway and the river. In places where the canyon is particularly narrow, the bike path will be cantilevered from the faces of retaining walls, to minimize the effects on (and from) river hydraulics.

Before construction started, numerous areas along the highway were available to motorists for picnicking, fishing, hiking, photography, sightseeing, and other activities. These areas have all been eliminated by the construction. To compensate for the loss, four specially designed rest areas in the canyon will provide trail access, picnic grounds, special facilities for launching river rafts, access to the bike path, parking areas, and rest room facilities.

Because construction has begun on only one of the rest areas, their popularity has yet to be determined. If use of the bike path is any indication of public appreciation, the rest areas may well become destinations in their own right. To date, about one-half the length of the path is open, and usage is exceeding expectations.

One of the commitments to be met during construction was maintaining access to the Colorado River, ensured through public forums at which ideas, concerns, and needs of all parties were discussed openly. Although certain critical construction operations precluded river access for safety and efficiency reasons, no major confrontations or encounters occurred during the forums.

Management Obstacles

It is one thing to design such a magnificent highway and to make it all fit, at least in concept, into the canyon. It is another matter entirely to prepare detailed plans that take into account schedules, funding, constructibility, and traffic. However, with the human resources available in its design management structure, CDOH was able to overcome these and many other obstacles, although sometimes with considerable difficulty. The problem was that none of the main considerations could be addressed individually. They were interrelated and so dependent on outside influences over which CDOH had no control that they could only be treated as one large management headache, which has still not fully abated.

It was known, of course, even before final design started, that these issues could affect the progress of the project. The design team, therefore, had to continually prepare for changing conditions, which sometimes made the task seem impossible.

Funding

Perhaps the most significant unknown was the availability of federal highway funds for the project. This, of course, would determine the overall project schedule, which could not be changed without considering constructibility impacts, as well as the manner in which traffic could be safely conducted through construction zones. These potential problems were recognized before final design began. At that time, the master project schedule contained 28 construction packages. The contracts were examined to ensure logical construction sequencing that would afford uninterrupted mobility for contractors as well as for the traveling public. The project has since grown to about 40 contracts because of the emergence of unforeseen site conditions (mostly geotechnical) and technical or administrative roadblocks.

Traffic Control

One of the most burning questions was whether this complex project could be built under continuous traffic conditions—sometimes involving the passage of more than 15,000 vehicles per day. Because of the lack of suitable alternative routes to this major interstate ground transportation link, it was unthinkable that the canyon be closed to traffic for more than short periods of time. Although the potential for massive traffic congestion was anticipated early in the design phase, no definitive steps had been taken to address the certain gridlock.

After four years of progressively intense construction using traditional traffic control methods, the inevitable happened. Traffic became so entangled that neither the traveling public nor the construction contractors were able to move. A one-way trip through the canyon sometimes took up to two hours because the contractors, whose work zones frequently overlapped, were individually controlling and indiscriminately stopping traffic. By late 1984 and early 1985, the situation became so intolerable that CDOH was compelled to try a new approach, one that would combine all traffic control functions under its authority.

This concept, recommended by CDOH's management consultant (DMJM), included a coordinated process that essentially began to control traffic even before it entered the outermost construction zone. With the aid of a sophisticated radio communications network and the use of pilot cars, traffic was metered through the entire construction area—frequently one direction at a time in a single lane because there was no room to run two lanes of traffic concurrently with construction operations. Contractors were not permitted to stop or otherwise interfere with traffic as it moved through their work zones.

Although this program was initially implemented on an experimental basis, its success was apparent within the first few hours. It soon evolved into an efficient operation that gained statewide and national recognition. Those traffic control devices and functions that traditionally had been provided by the construction contractors were now combined under a single traffic control support contract. In this manner, efficiency and authority could be optimized without eliminating the opportunity for competitive bidding for these services. The overall traffic control management responsibility, along with the related public information and communication efforts, were assigned to DMJM.

The success of this traffic control program manifested itself in greater efficiencies for construction contractors, reduced delay for travelers, and improved safety. In 1986, the program received the Transportation Achievement Award for Operations from the Institute of Transportation Engineers.

Outlook for Completion

Although most of the principal elements that make up the Glenwood Canyon project are not new to highway construction, the manner in which they have been combined into a single functional unit is rather remarkable. The fact that construction is proceeding as well as it is, despite the enormous potential for interference, demonstrates the benefits of a sound management structure. Some of the most difficult work has been completed with minimal interference among contractors and between construction activity and traffic. The critical scheduling interface specified for the complex central canyon projects (which include the tunnels and the large river-crossing bridges at both ends) is a product of a design review and claims avoidance program that has noticeably minimized contract disputes.

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Pier shapes and bridge rail are two components specifically developed for and standardized throughout the project.

At the time of this writing, the project is about 75 percent complete. Of the total project cost of $450 million, the contracts currently under way account for almost half that amount. They are for the most expensive elements: tunnels and complex bridges. Substantial completion of I-70 in Glenwood Canyon is expected in late 1993, at which time the entire 13-mile stretch will be opened to four lanes of divided highway.

One of the "inspired" designers predicted several years ago that "this will be one of the great highways in the world." If the construction completed to date is any indication, Passonneau's forecast may come true.