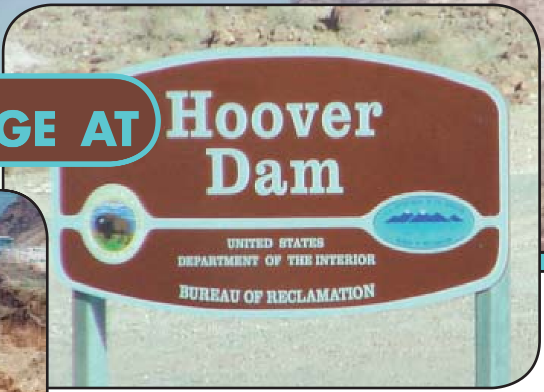
THE NEW COLORADO RIVER BRIDGE AT Hoover Dam

David Goodyear, P.E., S.E.,
Bonnie Klamerus, P.E.,
and Robert Turton, P.E., S.E.



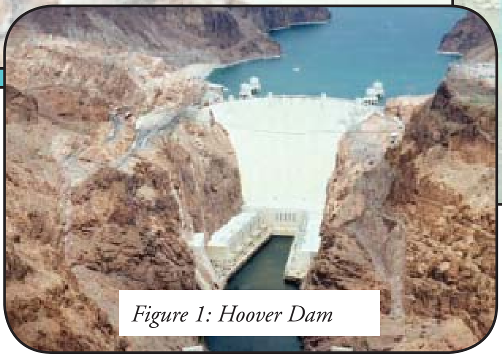


Figure 1: Hoover Dam

A dramatic new concrete arch is joining the setting of the historic Hoover Dam, spanning the Black Canyon between the States of Arizona and Nevada, USA. The 1,060 feet arch will be the 4th longest concrete arch in the world, and the longest in North America. The distinctive design combines steel and concrete components in order to optimize construction and structural performance. This will be the first arch structure of this scale to combine a composite steel deck with a segmental concrete arch and spandrels. The design is also unique in its use of steel Vierendeel struts between twin concrete arch ribs — a feature that both speeds construction and adds ductility to the framing system for extreme lateral loads.

A project team of five US government agencies, led by the Central Federal Lands office of the Federal Highway Administration (CFL) has developed a highway bypass to the existing US93 roadway over Hoover Dam. (*Figure 1*) The existing highway route over the Dam mixes the throng of tourists, for whom the Dam is a destination, with heavy commercial trucking. The blend of these two uses creates hazard and hardship for both. The mix of traffic is an added security burden for the Bureau of Reclamation, which operates Hoover Dam.

Project Development

A consortium of firms working under the moniker of HST (HDR, Sverdrup, and T.Y. Lin International) teamed with specialty sub-consultants and CFL to deliver the final design for approximately 1.5 miles of approach roadway in Arizona, 2.5 miles of approach roadway in Nevada, and a major 2,000 foot long Colorado River crossing 1,500 feet downstream of the historic Hoover Dam.

CFL's formation of both a Design Advisory Panel (DAP) and a Structural Management Group (SMG) as advisory groups for the design resulted in key input during the design process.

Bridge Type Screening Process

By selecting an alignment so close to Hoover Dam, the new bridge will be a prominent feature within the Hoover Dam Historic District, sharing the view-shed with one of the most famous engineering landmarks in the US.

CFL decided to use information developed for prior studies along with new information developed by the design team in an initial Type Screening Process. This Type Screening process was developed to consider policy-level criteria as a first litmus test on bridge types that should proceed to a more formal type study. The alternatives are shown in *Figure 2*. In the end, the deck arch concept was the selected bridge type.

Six deck arch alternatives were developed to the point that general quantities and construction methods could be established for pricing purposes (*Figure 3*), and were then reviewed and rated by both the DAP and the SMG based on architectural and technical criteria, respectively. The DAP expressed a preference for simplicity, and the SMG criteria were similar to those used for the Screening Study — inspection, complexity, vulnerability, construction cost and duration, and serviceability. An integrated ranking was developed to combine the SMG ranking, DAP rating, and cost and schedule estimates. The selection of the composite alternative was made by the Executive Committee, comprised of the operations chiefs from the five leading Agencies; FHWA, Arizona DOT, Nevada DOT, Bureau of Reclamation, and National Park Service.

continued next page

Figure 2: Type Screening Alternatives (see 2d and 2e next page)


Figure 2a: Truss

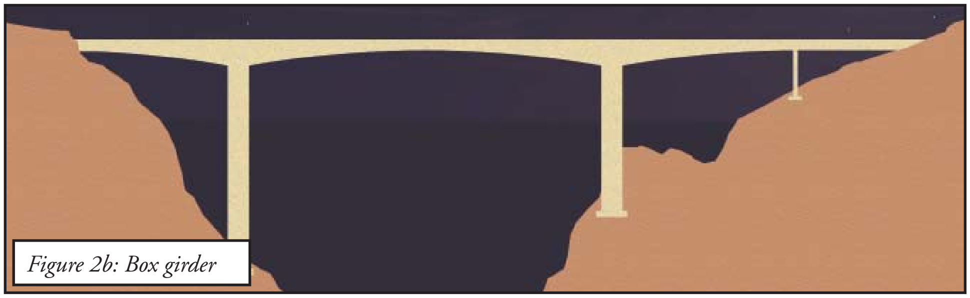


Figure 2b: Box girder


Figure 2c: Cable stayed

Figure 2: Type Screening Alternatives (continued)

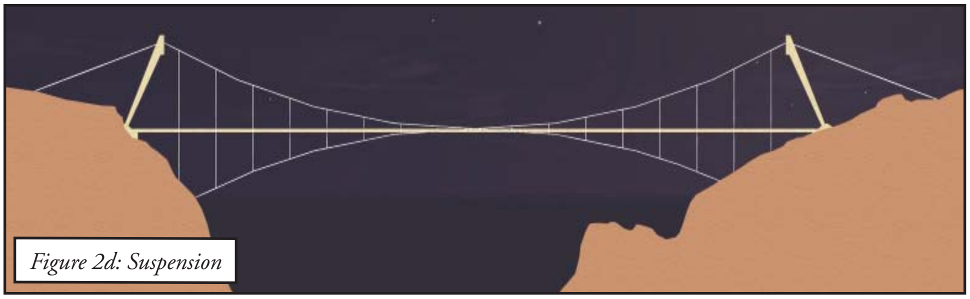


Figure 2d: Suspension

Figure 2e: Deck arch

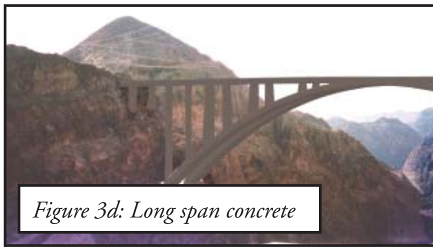


Figure 3d: Long span concrete

Figure 3e: Long span steel Vierendeel

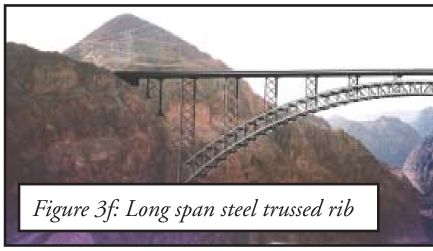


Figure 3f: Long span steel trussed rib

Major Features

The final form of the twin rib framed structure shown in *Figure 4* was dictated by the engineering demands on the structure. It was initially assumed that earthquake would control the lateral design of the bridge, but wind studies resulted in wind dominating the lateral force design.

Arch Framing

The 10,000 psi concrete arch is an efficient element for gravity loads in its final form. Two design aspects favored a twin rib layout for this arch. The first is one of practical construction. A single box would be 65 feet wide, and weigh approximately 10 tons per foot, which would rule out a precast segmental option. The second is the performance under extreme lateral forces. Initial geophysical studies indicated the potential for a very high seismic design basis. A single arch rib left no opportunity for tuning stiffness or providing for frame ductility, whereas twin ribs provide an excellent means of creating ductile Vierendeel links that could otherwise fully protect the gravity system of the arch. Thus a twin rib arch framing system was selected (*Figure 5*).

Figure 3: Type study alternatives

Figure3a: Short span composite

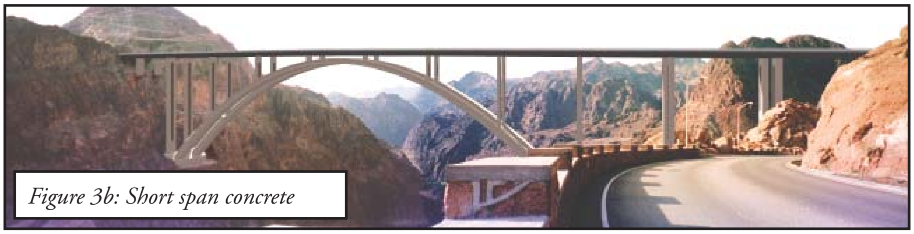


Figure 3b: Short span concrete

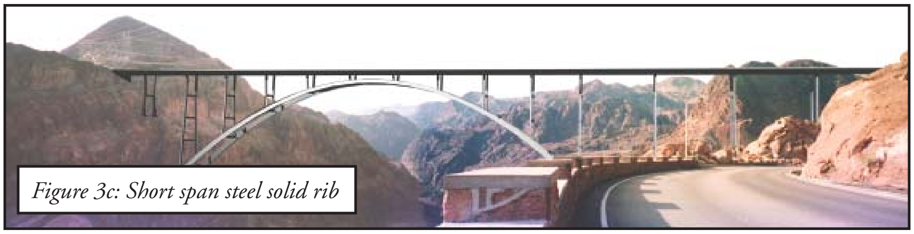


Figure 3c: Short span steel solid rib

Spandrel Framing

The composite superstructure was selected for speed of erection and to reduce the weight. The spandrel spacing was controlled by the concept of erecting the bridge using a highline (tramway) crane system. Above 50 tons, there is a jump in highline cost, so the spans were set to limit the steel box sections to 50 tons, which resulted in a 121-foot span. This span also allows steel girders to be set within the range of most conventional cranes, should an alternative erection system be selected. The statical system includes sliding bearings for the short, stiff piers over the arch crown, which minimized large secondary moments in these piers from creep deflections of the arch and produced a more even distribution of longitudinal seismic forces among the piers.

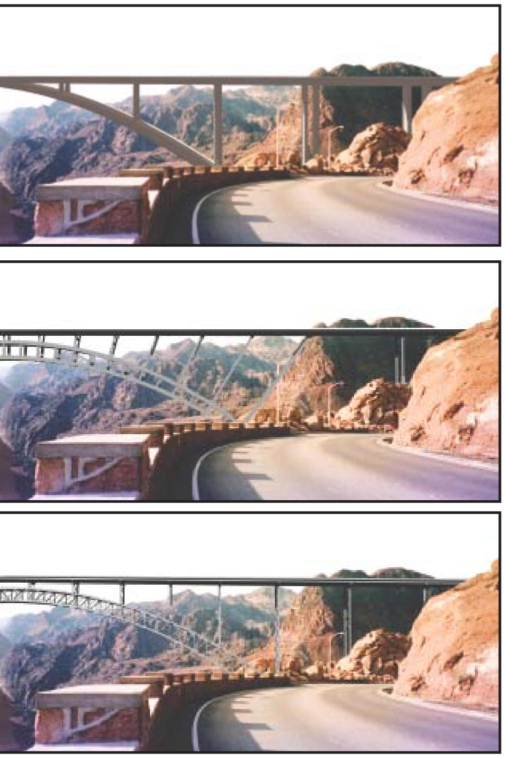
Pier Cap Framing

The integral cap framing (*Figure 6*) was selected, both for aesthetics and to develop the diaphragm action of the deck used to avoid lateral bracing of the spandrel columns. Concrete was selected to avoid the higher maintenance and inspection costs associated with a fracture critical steel cap.

Open Spandrel Crown

An open spandrel crown was selected over an integral crown to avoid an abrupt, mechanical looking connection at the crown. Equally significant was the high rise of the arch. When studied in either concrete or steel, an integral crown solution looked blocky and massive, and ran counter to the architectural goal of lightness and openness.

Figure 4: Final design alternative



Cross-Section Form

The first natural frequency of the arch system is over three seconds — a range normally reserved for flexible, cable-supported structures. Since wind forces dominated the lateral load design, shape became a primary design issue.

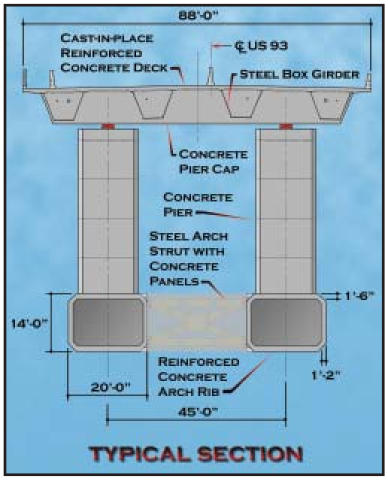
The tallest of the tapered spandrel columns is almost 300 feet tall. Wind studies considered drag and vortex shedding on the main structural sections exposed to the long canyon fetch from over Lake Mead. Substantial advantage was gained both in terms of vibration and drag by chamfering the corners of the columns and the arch.

Construction Methods

The dead load design is dominated by the assumed construction scheme. The design team and owner agreed that a complete and detailed erection procedure should be shown on the plans. This approach will lessen review times often associated with erection of structures this size, while reducing the risk that the contractor would overlook erection requirements critical to the performance of the final structure.

Two practical erection methods could be used to erect this arch. One is a simple cable-stayed cantilever erection (*Figure 7*). The second is the use of temporary stay truss diagonals, erecting the arch, deck and spandrels as a cantilever truss (*Figure 8*). The simple cable-stayed method provides the most conservative method, in that arch geometry can be controlled and corrected at each step of construction with stay and traveler settings. This method also allows the most flexibility for closing the arch without affecting the geometry of columns and deck, since they are not placed until after closure. Both precast and cast-in-place methods are permitted for the arch and spandrel columns. The contract allows alternative methods of erection, but only the cable-stayed method shown on the plans is engineered for the contractor.

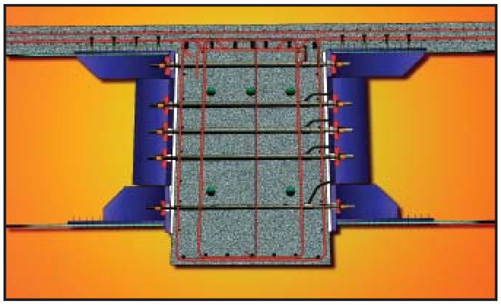
Figure 5: Typical section



All equipment and ancillary temporary works are also to be designed by the contractor.

Documentation and progress may be tracked on the project web site, *www.hooverdambypass.org*.

Figure 6: Integral cap connection



Conclusions

The commission from the DAP was to create a landmark bridge demonstrating the same design excellence that the designers of Hoover Dam exhibited. The bridge adheres to the adage that form follows function. Expanding the basis of design beyond the traditional concrete or steel solutions, designers used both concrete and steel efficiently to create the subtle, graceful crossing of Black Canyon that respects the grandeur of Hoover Dam, yet has its own identity. *Figure 9* is a rendering of the completed bridge anticipated to be open to traffic in 2008.▪

Figure 7: Stayed arch erection

Figure 8: Alternative erection scheme

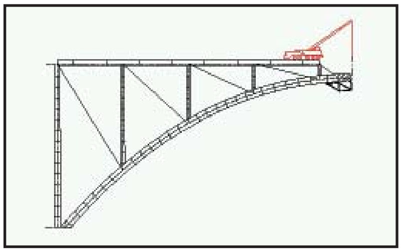
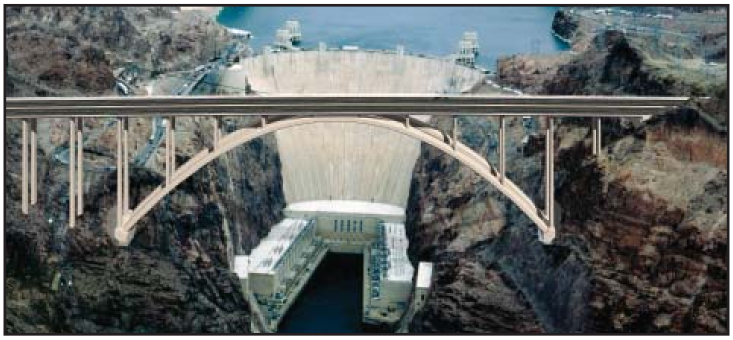


Figure 9: Rendering of completed bridge



David Goodyear is a Senior Vice President with T.Y. Lin International in Olympia, Washington. Bonnie Klamerus is a Structures Manager for FHWA Central Federal Lands and is located in the Denver, Colorado office. Robert Turton is a Vice President with HDR Engineering, Inc. in Phoenix, Arizona. Portions of this article have been previously published in the Pittsburg Engineer, June 2005 and the FIB Proceedings, April 2004