# The New Colorado River Arch Bridge at Hoover Dam – An Innovative Hybrid of Concrete and Steel


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## Summary

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. When complete, the 323 m arch will be the 4th longest concrete arch in the world, and the longest in the United States. What makes the design distinctive is the combined use of steel and concrete in order to optimize construction and structural performance. The design is the first arch structure built on such a scale to combine a composite steel deck with a segmental concrete arch and spandrels. In addition, the design is unique in its use of steel sections for Vierendeel struts between twin concrete arch ribs – a feature that both speeds construction and adds ductility to the lateral framing system for extreme seismic loads.



**Keywords**: Hoover Dam; concrete arch, precast; prestressing; cable stayed construction; composite deck; steel struts; high performance concrete.


## 1. Introduction

*Fig. 1 Hoover Dam, USA*

A project team of five US government agencies, lead by the Central Federal Lands office of the Federal Highway Administration (CFL-FHWA) is developing a highway bypass to the existing US93 roadway over Hoover Dam, shown in Fig 1. The existing highway route over the Dam mixes the throng of tourists for whom the Dam is a destination, with heavy highway 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, who operates Hoover Dam.

## 2. Project Development

A consortium of firms working under the moniker of HST (HDR, Sverdrup, and TY Lin International) teamed with specialty sub-consultants and CFL to deliver the final design for 1.6 km of approach roadway in Arizona, 3.5 km of roadway in Nevada, and a major 610 m Colorado River crossing about 450 m feet downstream of the historic Hoover Dam. A bridge design group of TY Lin International and HDR was led by the Olympia office of TY Lin International for development of the bridge type study and final bridge design.

The design project was highly structured by CFL, who was the client for development of all design work. Of note in relation to the bridge design work was CFL's formation of both a Design Advisory Panel (DAP) and a Structural Management Group (SMG) as advisory groups for the design.

## 2.1. Bridge Type Screening Process:

With the selection of 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. The environmental document set a design goal to minimize the height of the new bridge crossing on the horizon, both from the Dam and from a boater's view on Lake Mead.

The typical design approach for a project of this significance would be to conduct a comprehensive type study of all candidate bridge types, carrying design to a level that would permit architectural and economic evaluations of each type. However, the Hoover Dam Bypass had been studied in one form or another for over 25 years (the first bridge study is dated 1972). Therefore, CFL decided to use previous information developed for prior studies along with new information developed by the design team in an initial Type Screening Process – as a precursor to the type study. 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 rating matrix in Table 1 was the result of this process.

**HOOVER DAM BYPASS - RIVER BRIDGE TYPE CANDIDATE SCREENING FEATURE-IMPACT ANALYSIS**

| Bridge Options | Structural Redundancy | Height and Mass on Viewscape | Rock Excavation/Canyon Impact | Engineering Cost | Technical Suitability for the Site | Cost of Construction | Construction Wind Risk | Inspection and maintenance requirements | Architectural Potential | | | RATING |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Truss | 3 | 5 | 2 | 4 | 2 | 3 | 4 | 3 | 1 | | | 89 |
| Box Girder | 5 | 2 | 1 | 5 | 1 | 3 | 5 | 5 | 1 | | | 84 |
| Cable-Stayed | 2 | 3 | 2 | 3 | 2 | 3 | 1 | 2 | 2 | | | 70 |
| Suspension | 1 | 4 | 5 | 1 | 5 | 1 | 2 | 1 | 5 | | | 103 |
| Deck Arch | 5 | 5 | 2 | 4 | 5 | 5 | 4 | 4 | 5 | | | 139 |
| Thru Arch | 2 | 2 | 3 | 2 | 1 | 2 | 3 | 3 | 2 | | | 71 |
| **Impact Weight** | 1 | 4 | 4 | 1 | 5 | 4 | 3 | 5 | 5 | | | |

**Rating 1 to 5 - 5 is preferred**

*Table 1 Bridge Type Screening*

*Fig. 2 Suspension Alternative*

Of particular note is the separation of alternatives in the ranking. The two most favored options were the natural design choices – to span the canyon, or to arch against the canyon walls. But also of note were the extremes of rankings for the various criteria. The clear spanning suspension option (Fig. 2) was significantly handicapped in terms of structural vulnerability, first cost and maintenance cost. While being one of the more architecturally alluring options, the suspension span was seen as both the highest life-cycle cost option and the most vulnerable design type, which was a special concern for the Agencies who would soon be maintaining the bridge. As a result of this screening process, the type study proceeded with only deck arch options.

## 2.2. Type Study:

*Fig. 3 Nevada Foundation*

At the time of the type study, detailed geotechnical engineering had just begun. The topography on the Nevada side of the canyon (Fig. 3) includes a massive outcropping of rock below the US93 switchback, with a fault line running between this block and the canyon slope behind. Without detailed geotechnical and mapping information, we could not confirm the suitability of the short block as a foundation. Therefore, the type study progressed in parallel with geotechnical exploration assuming either of two different arch spans could be selected; a short span of 323 m or a longer span of 405 m.

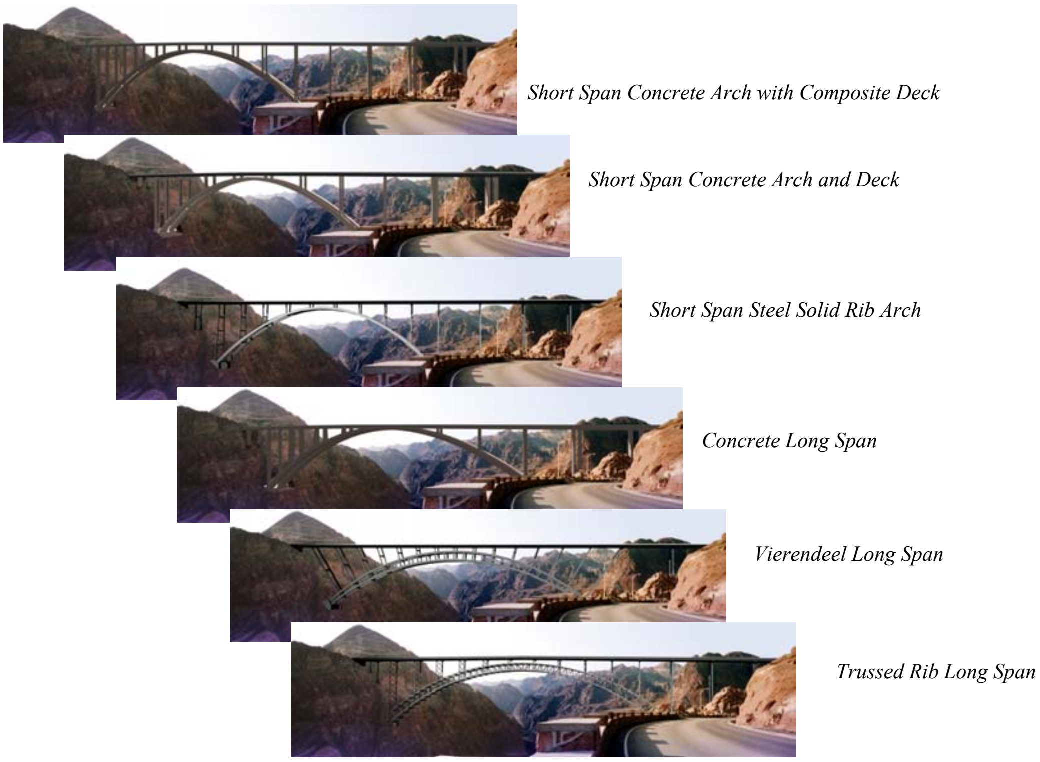


*Fig. 4 Type Study Alternatives*

The family of arch designs (Fig. 4) was reviewed by both the DAP and the SMG based on architectural and technical criteria. The DAP expressed a preference for simplicity, and rejected any notion of ornamentation or art-deco designs that mimicked features on the Dam. Six designs were developed to the point where general quantities and construction methods could be established for pricing purposes.

Rating of the alternatives was conducted by both the DAP and the SMG, each according to their own criteria. The SMG criteria were similar to those used for the Screening Study. The DAP rated all of the alternatives as acceptable with the exception of the trussed rib, which they declared to be architecturally unacceptable. The Vierendeel arch was controversial in the sense that it contrasted with the historic character of the Hoover Dam District. The integrated ranking was a combined formula with the SMG ranking, DAP rating, cost and schedule estimates. The final decision to proceed with the Concrete Composite alternative was made by the Executive Committee, comprised of the operations chiefs from the 5 Agencies.

## 3. Major Features

*Fig. 5 Final Design Solution*

The final design went through an evolution of form dictated by the engineering demands on the structure to arrive at the twin rib framed structure shown in Fig 5. At the outset of design it was assumed that earthquake would control the lateral design of the bridge. During the preliminary design phase, a site wind study was conducted to correlate the wind speeds at the bridge site with those at the Airport NOAA station. With this correlation, the long term statistics from the Airport were used to develop site wind speeds for design. As a result of this study, the mean hourly design wind speed was raised to 44 m/sec. Dynamic studies resulted in a gust loading factor of 2.4, which collectively resulted in wind dominating the lateral forces design.

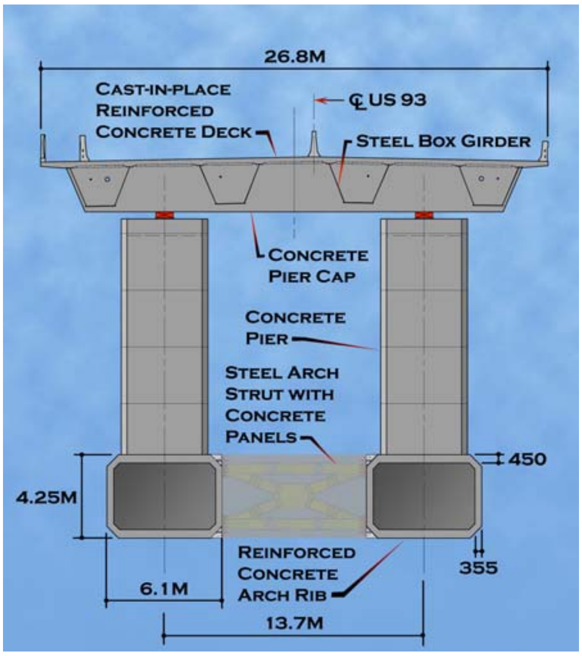


*Fig. 6 Typical Section*

## 4. Form and Function

### 4.1. The Logic of Framing

4.1.1. Arch Framing

Once given the arch span, the founding elevations for the springings, and the roadway profile, the framing plan for the arch and girders could take a number of forms. The 70 MPa concrete arch is an efficient element for gravity loads in its final form. There were two aspects of design that favored a twin rib layout instead of the typical single box section for this arch. The first is one of practical construction. A single box would be almost 20 m wide, and weigh approximately 30 tones per meter. This section size would rule out a precast segmental option. The second is the matter of performance under extreme lateral forces. At the time the framing plan was devised, the level of seismic ground motion had not been determined. Based on initial geophysical studies, there was the potential for a very high seismic design basis. A single arch rib would leave no opportunity for tuning stiffness or for providing for frame ductility, whereas twin ribs could provide an excellent means of creating ductile Vierendeel links that could otherwise fully protect the gravity system of the arch. It is for both of these reasons that a twin rib arch framing system was selected (Fig. 6).

4.1.2. Spandrel Framing

The composite superstructure was selected for speed of erection and to lower weight on the arch. The spacing of spandrels was an extension of the erection concept to erect the bridge using a highline (tramway) crane system. Above 50 tons, there is a jump in highline cost, so the decision was made to target a 50 ton capacity for major superstructure elements. The span was set in the range that a highline crane could deliver the steel box sections, which resulted in a regular 37 m span. This same 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. This was necessary due to the large secondary moments developed in these piers from creep deflections of the arch, and also produced a more even distribution of longitudinal seismic forces among the piers.

4.1.3. Pier Cap Framing

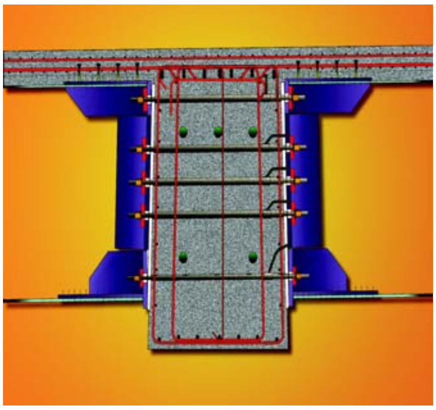

*Fig. 7 Integral Cap*

Integral concrete pier caps were selected over steel box cap sections. The integral cap framing (Fig. 7) 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 over steel due to the higher maintenance and inspection costs associated with a fracture critical steel diaphragm; even though estimates showed that a steel cap could have a lower first cost.

4.1.4. Open Spandrel Crown

An open spandrel crown was selected over the option of an integral crown. The first consideration was that the composite steel deck would result in a very 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 for the short span alternatives looked too blocky and massive at the crown, and ran counter to the architectural goal of lightness and openness when viewed from Lake Mead.

### 4.2. Cross Section Forms

The first natural frequency of the arch system is over 3 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 92 m tall. Wind studies included considerations of drag and vortex shedding on the main structural sections exposed to the long canyon fetch from over Lake Mead. Studies showed that substantial advantage could be gained both in terms of vibration and drag by chamfering the corners of both the columns and the arch. While this adds somewhat to the complexity of construction, the aid in terms of reduced demand was substantial.

## 5. Construction Methods

As with any large bridge structure, the dead load design is dominated by the assumptions of a construction scheme. The typical approach in the US is to nominate an erection scheme, but to show it only schematically, and defer responsibility for both the scheme and the details to the contractor. The design team decided that this structure was so unique that the typical approach would prove counterproductive in several respects. First is that a substantial length of time for reviewing and approving an erection scheme might delay the project. More importantly, the risk of having a contractor overlook critical erection requirements would both increase the risk dollars in the bid and raise the potential for an errant bid. Therefore, the decision was made to show a complete erection scheme on the plans – one that the Owner took responsibility for.

*Fig. 8 Stayed Arch Erection*

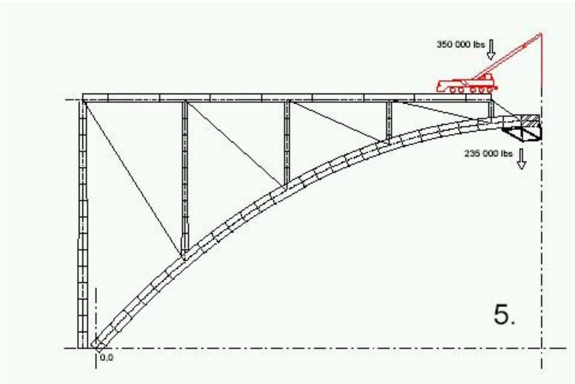


*Fig. 9 Alternative Erection Scheme*

There are two practical erection methods that can be used to erect this arch. One is a simple cable-stayed cantilever erection (Fig. 8). The second is the use of temporary stay truss diagonals, erecting the arch, deck and spandrels as a cantilever truss (Fig. 9). In selecting the simple cast-in-place stayed method, CFL opted for the most conservative method in that arch geometry can be controlled and corrected at each step of construction with stays and traveler settings. In addition, this method allows the most flexibility for closing the arch without affecting the geometry of columns and deck (since they are not in place until after closure). Both precast and cast-in-place methods are permitted for the arch and spandrel columns. The contract is written to allow alternative methods of erection, however only the method shown on the plans is engineered for the contractor. All equipment and ancillary temporary works are also to be designed by the contractor.

## 6. Conclusions

The commission set forth by the Design Advisory Panel to the design team was to create a landmark bridge structure that represents the same design excellence today as the designers of Hoover Dam created in their day. The result is a product of creative adherence to the adage of form follows function. Expanding the basis of design beyond the traditional concrete or steel solutions, designers utilize both concrete and steel in roles of superior form and efficiency to create the subtle, graceful traverse of Black Canyon that respects the grandeur of Hoover Dam, yet has an identity all its own.

At the time of the conference, bridge construction should be in the beginning stages of foundation excavation. The arch is scheduled for erection approximately 18 months after the beginning of bridge construction. Documentation and progress may be tracked on the project web site, www.hooverdambypass.org.