Design of the New Mike O'Callaghan Pat Tillman Memorial Bridge at Hoover Dam

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Summary

A dramatic new concrete arch joins the setting of the historic Hoover Dam, spanning the Black Canyon between the States of Arizona and Nevada, USA. This 1060 foot (323 m) long arch span is the 4th longest concrete arch in the world, and the longest in the United States. The scale of concrete construction for the bridge is impressive. Four form travelers advanced to the crown of the cast-in-place arch supported by 88 carefully tuned stay cables, while precast segmental construction was used for the tallest precast columns erected to date.

Introduction

A project team of five US government agencies, lead by the Central Federal Lands office of the Federal Highway Administration (CFL-FHWA) collaborated to develop a highway bypass to the existing US93 roadway over the historic Hoover Dam, shown in Fig 1. The existing highway route 93 over the Dam mixed the throng of tourists for whom the Dam is a scenic destination with heavy highway traffic and commercial trucking mixing with pedestrian traffic and crosswalks. The blend of these two created hazard and hardship for both, and served as a bottleneck for commerce along the major north-south route of US93.

Figure 1 (photo by HST)

The Hoover Dam Bypass Project had a decades long history of planning and process. First discussed in the mid 1960's, plans for a highway crossing of the Colorado River were advanced by the US Bureau of Reclamation to address the increasing highway traffic across the top of Hoover Dam. A series of studies ensued, sponsored by several of the project stakeholders throughout the next two decades. In 1997 FHWA Central Federal Lands Division (CFL) became the lead agency for the Project Management Team comprised of the Bureau of Reclamation, Arizona DOT, Nevada DOT, National Park Service and Federal Highway Administration. The project then advanced through the Draft Environmental Impact Statement, Final Environmental Impact Statement and Record of Decision leading to commissioning the project.

General Project Development

A consortium of firms working under the moniker of HST (HDR, Sverdrup, and T.Y. Lin International) teamed with specialty sub-consultants to deliver the design for the 4-mile long bypass project. HDR was the project manager and led the design of the Nevada approaches. Sverdrup (now Jacobs) led the design of the Arizona approaches. T.Y. Lin International led the design of the new Colorado River Bridge.

Bridge Type Screening Process

With the selection of an alignment so close to Hoover Dam, the new bridge would 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 State Historic Preservation Officers for both Nevada and Arizona – both members of the Design Advisory Panel – emphasized the need to complement and not compete with the architecture of the Dam. The Design Advisory Panel helped establish the mission for the bridge design, which was to "...strive for engineering excellence in the design of today that honors the engineering excellence that went into the Dam in its day" (HDB Design Advisory Panel, 2002).

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, since the Hoover Dam Bypass had been studied in one form or another for over 25 years, 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.

Figure 2 (rendering by TYLI)

Figure 3 (rendering by TYLI)

The Project advanced a full suite of bridge types applicable for a 1000 ft+ span range. Of particular note by all the reviewers was the separation of alternatives. The two most favored options were the natural design choices fitting the site – to span the canyon, or to arch against the canyon walls. The clear spanning suspension option (Fig. 2) was significantly handicapped at the time of this type evaluation in terms of structural vulnerability (time frame was soon after 9/11), 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 (Fig. 3).

Type Study

At the time of the type study, detailed geotechnical engineering had just begun. The topography on the Nevada side of the canyon (Fig. 4) included 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 1060 ft (323 m) or a longer span of 1325 ft (404 m).

Figure 4 (photo by TYLI)

The family of arch designs (Fig. 5) was reviewed based on architectural and technical criteria. The Design Advisory Panel expressed a desire for simplicity, and rejected any notion of ornamentation or art-decco designs that competed with features on the Dam. Six designs were developed - 3 each for the long and short spans - to the point where general quantities and construction methods could be established for review.

Figure 5

The consensus decision to proceed with the concrete composite alternative was made by the Executive Committee, comprised of the operations chiefs from the 5 Agencies on the Project Management Team.

Major Design Features

The final design is an evolution of engineering considerations, creating a form dictated by efficient resistance to the engineering demands on the structure. Every element of the twin rib framed structure shown in Fig 6 is a product of engineering reasoning.

Figure 6 (rendering by TYLI)

The Arch

At the outset of design the initial seismic hazards evaluation and geophysical analysis of the site led us to believe that earthquake could control the lateral design of the bridge. The twin rib configuration with connecting struts was developed first as a ductile frame for lateral loads, following the successful development of the shear linked tower concept by the Designer for a San Francisco Bay Bridge. 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 protect the gravity system of the arch. This ductile frame would allow the concentration of ductility demand in the connecting shear links, rather than in the main arch rib members.

At the time of preliminary design, the current Guide Specification for Seismic Design was in the early stages of development, and the AASHTO design event for the site was a .10g 500 year event. A project specific probabilistic seismic hazards analysis was conducted by AMEC in order to assess the range of ground motion associated with return periods more appropriate for this design. A 1000 year return period was selected (that same return period was later selected by AASHTO for the new Guide Spec), resulting in a design basis PGA of .2g.

Wind was a major environmental loading condition from the outset of design. It played a qualitative role in the type selection, and a key role in design. The unique topography was recognized as a feature requiring special studies. During the preliminary design phase, a site wind study was conducted by West Wind Laboratories to correlate the wind speeds at the bridge site with those at the Las Vegas Airport NOAA station in the valley. With this correlation and a model evaluation of the local terrain effects (Fig. 7), the long term statistics from the Airport were used to develop site wind speeds for design. As a result of this study, the 3 second wind speed was raised

Figure 7

to 56 m/sec, up from the ASCE-7 standard of 40 m/sec. Dynamic studies resulted in a gust loading factor of 2.4 (against mean hourly), which collectively resulted in wind controlling the lateral forces design. Chamfers for the main arch rib were introduced both to control vortex shedding and reduce design-controlling drag forces on the arch. Chamfers were added to the tall columns to control vortex-shedding vibrations observed in the wind tunnel. Wind recordings continued throughout construction, establishing a more complete on-site record. The forecasts produced by West Wind Laboratories based on the NOAA correlation were tested according to the methods of Scanlon based on 4 years of continuous on site record. These records confirmed the accuracy of the initial wind studies conducted with only 6 months of site data.

The 10,000 psi (69 MPa) concrete arch was 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 was the seismic framing system noted above. The second was one of practical construction for the open arch section as it cantilevered during construction. A single box would be almost 65 ft (20 m) wide, and weigh approximately 20 kips per ft (292 KN/m). This section size would rule out a precast segmental option. It is for both of these reasons that a twin rib arch framing system was selected (Fig. 8).

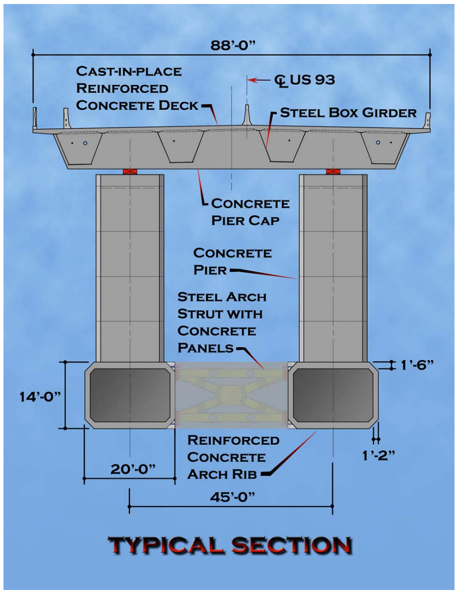

Figure 8

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 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 nominal 120 ft (36.5 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.

One of the many lessons from the smaller Crooked River Arch Bridge in Oregon was that spandrel construction and integral crown construction was very time consuming and expensive. The high rise of the Hoover arch added to the focus on construction of the spandrels, since the height of these columns would exceed what had been built in past segmental structures. Lateral bracing was a system design consideration, affecting the arch, spandrel and approach columns. Bracing for the arch is affected by deck stiffness and continuity conditions in the deck and columns.

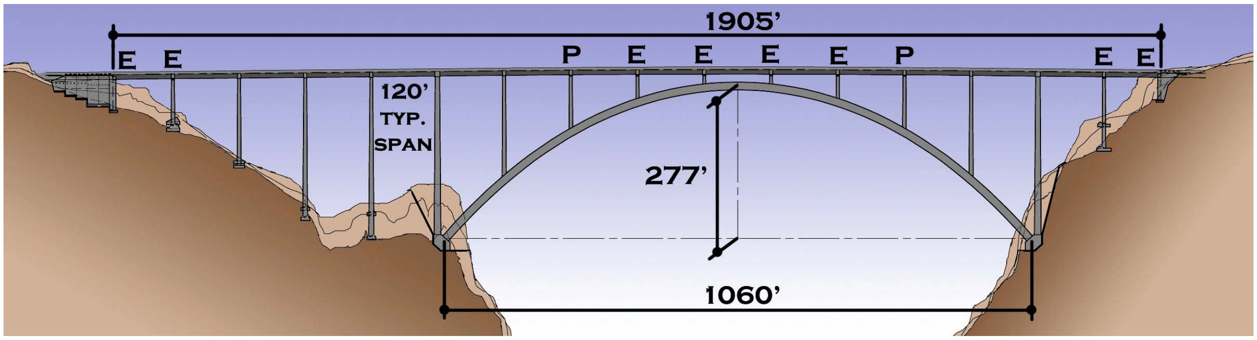

Figure 9

An open arch crown was selected as the best balance for constructability and consistency with the composite deck system. A special consideration for the visual presentation of the short span arch was that the composite steel deck would result in a very abrupt, mechanical looking connection at the crown if an integral crown was selected, due in large part to the high rise of the arch. When studied in either concrete or steel, an integral crown solution for the short span alternatives looked blocky and massive at the crown, and ran counter to the architectural goal of lightness and openness when viewed from Lake Mead. Once selected as an open crown, the statical system included sliding bearings for the short, stiff piers over the arch crown and similar piers near the abutments. This was necessary due to the large secondary moments developed in these piers from creep deflections of the arch. Bearings were also helpful in producing a more even distribution of longitudinal seismic forces among the piers.

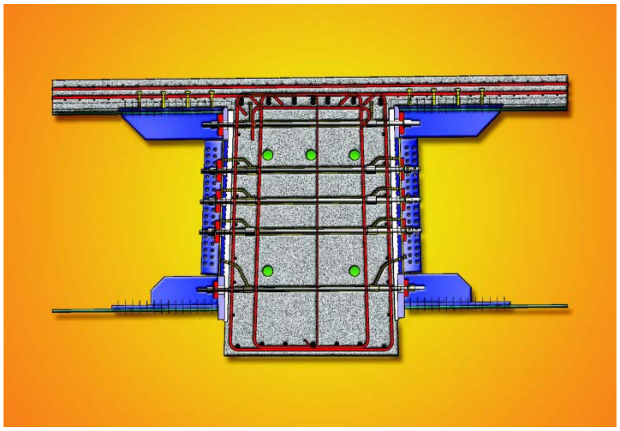
Figure 10

Integral pier caps (Fig. 10) were designed as part of a continuous deck/diaphragm system used for lateral and longitudinal bracing of the columns. Integral concrete pier caps were selected over steel box cap sections to avoid the fracture-critical design and inspection considerations for a steel cap. The integral cap framing was selected to develop the diaphragm action of the deck used to avoid lateral bracing of the spandrel columns and to provide for stability of the flexible columns along station through direct diaphragm action.

Construction Methods

As with any large bridge structure, the dead load design is dominated by the assumptions of a construction scheme. The concrete arch needs little reinforcing for the final closed arch configuration, operating primarily in compression. However prior to closing at the crown, the arch rib is a cantilever box girder. Since post-tensioning has no purpose for the final configuration of the arch, design was based on a conventionally reinforced concrete box for cantilevering conditions. Design for construction was based on allowable stresses in reinforcing and associated crack controls according to the AASHTO code, eliminating the need for temporary or permanent post-tensioning.

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 management team believed that more informed bids could be developed if there was a more complete erection scheme shown with the plans, even if the contractors elected to use alternative methods. Therefore, the decision was made to show a complete erection scheme for dead load on the plans and allow the contractor to use that scheme or his own.

There are at least two practical erection methods that can be used to erect a cantilevered arch. One is a simple cable-stayed cantilever erection (Fig. 11). The second is the use of temporary stay truss diagonals, erecting the arch, deck and spandrels as a cantilever truss (Fig. 12). In selecting the simple cast-in-place stayed method, we opted for the most conservative method in

Figure 11

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).

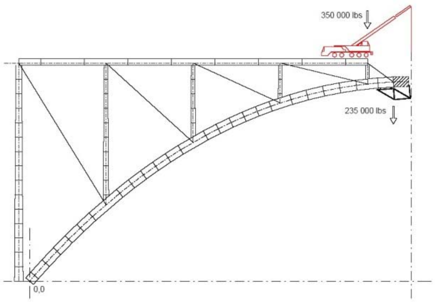

Figure 12

Both precast and cast-in-place methods were permitted for the arch and spandrel columns. The contract was written to allow alternative methods of erection, however both the arch and the columns each were to be of a single type (precast or cast in place) in order to conform to the time dependent assumptions inherent in design. All equipment and ancillary temporary works were also to be designed by the contractor.

Construction

The construction contract was awarded in September of 2004 to Obayashi-PSM, JV, after about a year delay in the funding process. A limited notice to proceed was issued for November, 2004, with full field work beginning in 2005.

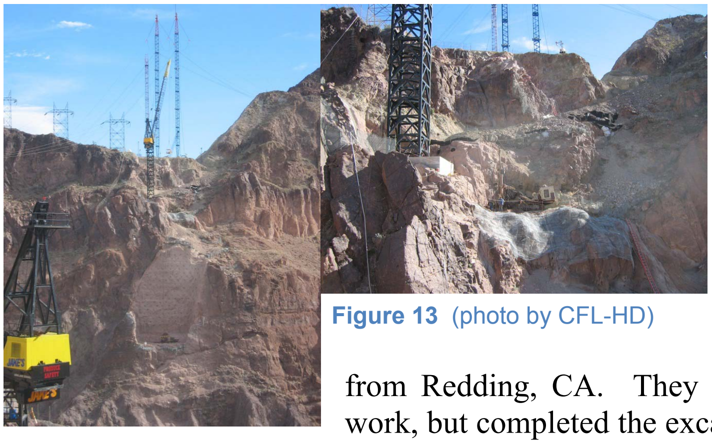

Figure 13 (photo by CFL-HD)

The first challenge for the construction team was creating a foothold for foundation construction (Figs 13, 14). Climbing on the side of the cliff 800 feet over the river below was difficult enough, but excavating (and doing so within the loss limits in the specification) was a considerable challenge. The subcontractor who met this challenge was Ladd Construction from Redding, CA. They not only met the tight schedule for this work, but completed the excavation allowing about half of the rockfall into the river that was permitted.

Initial bridge construction began on site with footing and abutment work, and in the precast yard outside of Boulder City where the contractor set up their own precasting facility and self-performed the precasting. Column sections were trucked to the site as needed for erection, and set into place using both the high-line crane and conventional cranes located at the hairpin in Nevada (Fig. 14, 15).

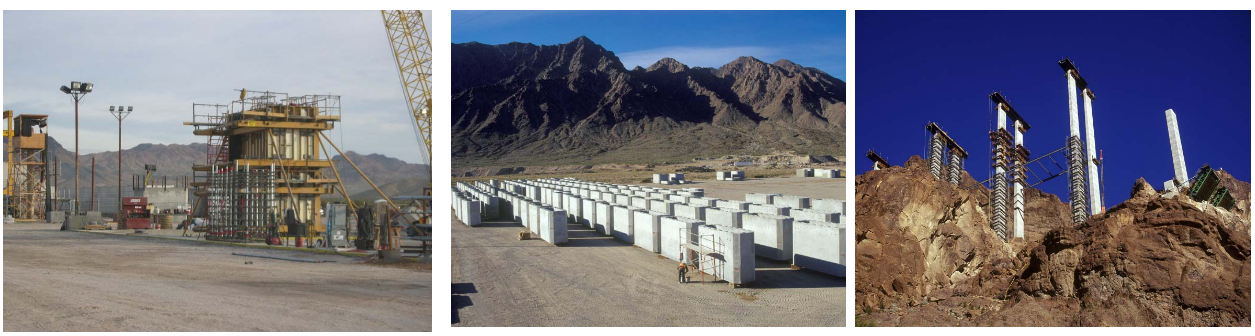

Figure 14 (photo by CFL-HD)

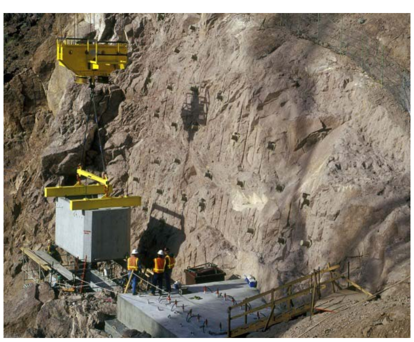

Figure 15 (photo by CFL-HD)

In September, 2006, the high line crane was lost in a strong wind, removing the high line crane from service. The contractor mobilized additional land cranes to continue construction in Nevada, and an S-70 derrick in Arizona (Fig. 16), to both complete approach columns and set approach steel box girders until a new high line could be design, fabricated and erected. Arch Erection was being initiated at the time of the high line crane collapse. The temporary cranes were able to service

Figure 16 (photo by CFL-HD)

the first few arch segments from the springing, allowing the piece work for the starters and the initial setup of the form travelers to proceed.

Four form traveler headings were used for erection of the arch. Every second arch segment was supported by a temporary stay cable. After erection of the new high line and restarting the main arch erection, the contractor reached a reliable cycle of 2 weeks, and often bested that cycle on segments that did not have a stay cable to install. The arch was closed in August of 2009 within an impressive ¾ inch (19mm) tolerance at closure (Fig. 17).

Figure 17 (photo by CFL-HD)

While the arch construction was the more dramatic effort, construction of the spandrel columns (Fig. 18) and deck structure was just as challenging from a construction standpoint. As the spandrels and deck superstructure are set on the arch, the arch deflects. Staging of the spandrel column erection, column cap construction and box girder placement had to be engineered to achieve final geometry. The contractor was continually monitoring and analyzing the response of the structure as each spandrel column and cap was placed, updating his forecast of geometry throughout the erection process.

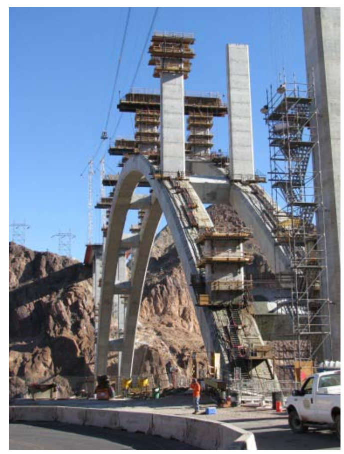

Figure 18 (photo by TYLI)

The assumption during design was that the arch, spandrels and deck would each be completed in series. The contractor decided to complete these tasks in parallel in order to shorten the construction schedule. Deflections were not limited to those from the spandrel columns and caps, but now included the superstructure loads and thermal effects of the steel box girders as they were placed in the partially completed frame. All of this sequence was analyzed in real time by the contractor in the field.

Figure 19 (photo by CFL-HD)

Demobilization of the high line and related temporary works was a project in itself, and had to be completed before final paving and finishing could be completed for the roadway. Bridge construction was essentially completed by August, 2010 (Fig. 19).

The new Colorado River Crossing now frames the view of Black Canyon from Hoover Dam for the coming generations of tourists, and is the cornerstone in a new, efficient highway system funneling commercial traffic between the States of Nevada and Arizona. The project reflects the skill and determination of the people who built it, all of whom take pride in their accomplishment.

The new bridge has been dedicated as the Mike O'Callaghan Pat Tillman Memorial Bridge in memory of two heroes of the US armed forced from the States of Nevada and Arizona.

CREDITS:

Program Management:	Central Federal Lands Highway Division of FHWA, Dave Zanetell, Project Manager; Bonnie Klamerus, Structures Manager
Construction:	Obayashi/PSM, a Joint Venture, Ken Hirschmugl and Jeff St. John, Construction Management
Design:	T.Y. Lin International w/HDR, David Goodyear, PE SE, Designer and Chief Engineer

(photo by TYLI)