Design and Construction of the Bronco Arch Bridge

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ABSTRACT:

The Bronco Arch Bridge is an elegant new structure that replaced a seriously deteriorated steel arch bridge supporting IH25 over the Platte River adjacent to Mile High Stadium in Denver, CO. The bridge was built in multiple phases of demolition and construction to accommodate maintenance of traffic. The design heavily utilized precast concrete elements and an innovative construction sequence to reduce the construction schedule and minimize disruption to existing traffic.

INTRODUCTION

The IH25 Bridge over the Platte River has been a Denver landmark structure since the first section was constructed in 1951. Additional sections were added in 1961 and 1971 as the city grew and traffic increased. The steel arches, supporting the bridge superstructure, became a local landmark that came to be known as the Bronco Arches after the Denver Broncos began to play football in the adjacent Mile Hi Stadium in 1960.

Fig. 1: Construction of original Bronco Arches, 1961

The bridge carries over 200,000 vehicles per day over the Platte River on a busy section of IH25. After many years of service the bridge deck, superstructure and supporting arches became seriously deteriorated resulting in the bridge having one of the lowest sufficiency ratings in Colorado.

The Colorado Department of Transportation, CDOT, performed a study to determine whether the existing bridge could be repaired and widened to meet current and future demands. CDOT determined that replacing the bridge was a more desirable, cost effective solution. A replacement bridge was designed in-house by CDOT and bid in March of 2011. The new bridge is 371' long and 197' wide to accommodate 4 through lanes of traffic in each direction as well as acceleration lanes and on and off ramps. The superstructure consists of a 3 spans with eight parallel girder lines that are severely skewed at the abutments. The substructure was designed to align with the Platte River and the bike trails and a trolley line that line the banks.

Fig. 2: Aerial View, IH25 Bridge over the Platte River

The new bridge was built on the same location as the original bridge but is shorter in length and has a wider deck. The bridge was planned to be constructed in five separate stages. Each stage of construction included demolition of the existing bridge, construction of the substructure and superstructure of the new bridge and movement of traffic lanes.

Fig. 3: Bronco Arches spanning over the Platte River, March 2011

VALUE ENGINEERING PROPOSAL

The Contractor, Lawrence Construction Co. of Littleton, CO requested that CDOT consider a number of Value Engineering proposals that would enhance the design of the bridge, reduce the number of stages of construction, shorten the schedule and greatly reduce the impact on existing traffic. CDOT recognized that the Value Engineering proposals suggested by the Contractor would result in less disruption and a shorter schedule and allowed them to proceed. Lawrence retained Summit Engineering Group, Inc., of Littleton CO to design an alternate bridge structure as well as the retaining walls at the embankments at each abutment.

Fig. 5: New Bronco Arch Bridge spanning over the Platte River, March 2013

The Value Engineering Proposals included the following modifications:

- Reduction of the number of construction stages for the bridge 5 to 4.
- Design of all retaining walls using conventional cast-in-place cantilever walls.
- Design of abutment foundations to use steel piling instead of drilled shafts.
- Driving of abutment piling beneath the existing bridge.
- Construction of all retaining walls and abutments prior to commencing any demolition of existing structures.
- Design of fully precast interior piers.
- 40% reduction in the number of precast girders per girder line.
- Design of continuous, post tensioned precast girder superstructure framing plan.

The primary objectives of the Value Engineering modifications were to:

- Maximize the amount of construction that could take place prior to moving traffic and commencing demolition of the existing bridge.
- Reduce the number of phases of construction and shorten the duration of each phase.

The effort necessary to achieve the Value Engineering goals required extensive, complex engineering. Summit Engineering assumed the role of Engineer of Record for the bridge. In addition to performing design engineering, Summit also performed Construction Engineering, which included the development of Demolition Plans, Superstructure Erection Plans, and preparation of all precast element shop drawings, including precast girders and deck panels.

Because the project was bid prior to performing any preliminary Value Engineering, all designs had to be accomplished within the overall project construction schedule to avoid delays. To accomplish, Summit established a design schedule with priorities driven by the construction schedule. Summit was challenged to determine the overall concept and then design each element on a "first things first" basis. The design priorities became:

- Development of Overall Concept and Analysis of the Structural System
- Design of Retaining Walls
- Design of Abutment Foundations
- Design of Abutments
- Design of Precast Piers and Pier Foundations
- Design of Superstructure Precast Girders
- Design of Precast Deck
- Miscellaneous Designs and Completion of Contract Documents.

Summit also performed the supporting construction engineering for each of these stages of construction. Close coordination and cooperation between the Contractor, Engineer and CDOT was essential to keep the project on schedule.

DEVELOPMENT OF STRUCTUAL CONCEPT

The first step of the design process was to develop a structural concept for the bridge and retaining walls that would accomplish all of the previously stated objectives. The resulting Value Engineering proposal utilized the all of the original roadway, bridge and retaining wall geometry and foundation locations was determined to be the most desirable approach.

The VE design proposal maintained the original number of girder lines, girder spacing and cross section and the full depth precast deck system. The design also maintained the heights and locations of all retaining walls.

The project incorporates extensive retaining walls line at approaches at each end of the bridge. The walls were originally designed using a proprietary, mechanically stabilized earth (MSE) wall system. The Contractor performed a cost-benefit analysis of cast-in-place retaining walls versus MSE walls after preliminary designs for an alternate cast-in-place system were developed by the Engineer. The study determined that while costs were not significantly different, the construction schedule would be greatly enhanced by using a cantilever wall system, which could be constructed by the Contractor's workforce with little interaction with the bridge construction.

The new bridge structure was designed as a rigid frame with integral connections between the substructure and superstructure founded on flexible foundations. All permanent bearings were eliminated. The revised superstructure framing consisted of a post tensioned, precast deck slab supported on continuous, post tensioned girder lines during construction. The rigid frame design enhanced the structural efficiency and stiffness of the system which allowed for greater optimization of the precast, pre-stressed elements.

The design of the wall system enabled the Contractor to get an early start and significantly complete construction prior to commencing bridge construction operations. The bridge design was developed with a sequence of construction that relied heavily on the utilization of precast elements to shorten the duration of each of the four stages of construction and minimized the time between each stage. Integration of the Design and Construction Engineering through the process resulted in a well developed set of operations that could be successfully repeated in each Stage of construction.

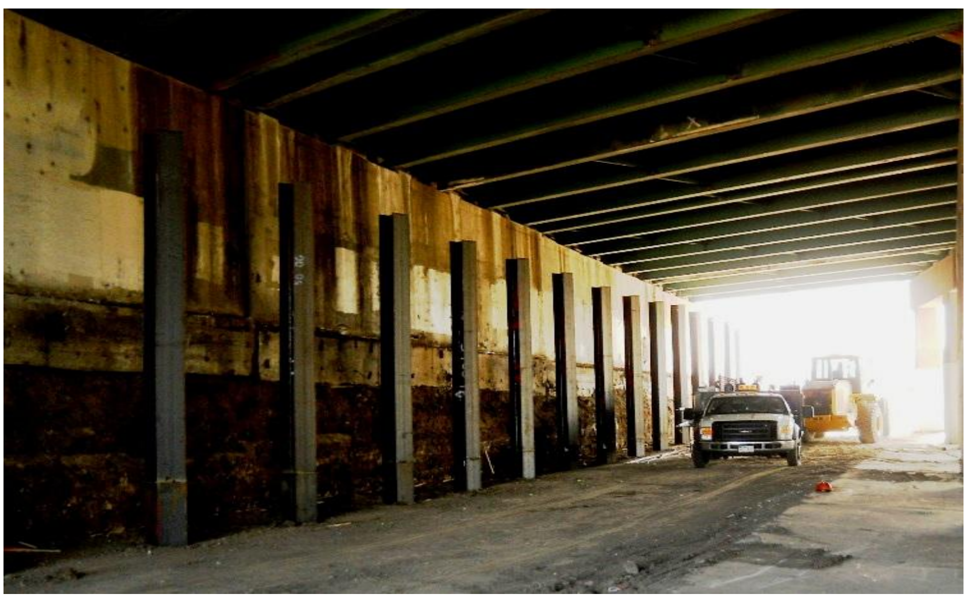

Fig. 6: Abutment Piling Driven under Existing Bridge

DESIGN AND CONSTRUCTION OF RETAINING WALLS AND ABUTMENTS

The project's retaining walls line the approach embankments at each end of the bridge and wrap around the abutments. The new bridge is shorter and wider than the original bridge, which enabled the Contractor to construct the new walls outside of the approaches and under the existing bridge. This approach greatly reduced the amount of excavation and backfill required and enabled the Contractor to use his existing workforce to complete the walls in one operation. Construction required only minor excavation shoring and coordination with piling installation for the new bridge abutments.

Design of the abutment foundations used a single row of steel piling instead of the drilled shafts in the original design. Piling was driven under the existing bridge while the retaining walls were being built. A vibratory hammer mounted on an excavator drove the piling in long 25’ sections that were spliced and re-driven to refusal into a bedrock layer approximately 30’ below existing grade. PDA testing verified the piling capacities. The original design, using drilled shafts, would have required mobilizing drilling equipment and installing caissons for each phase of construction. By driving all of the abutment piling under the existing bridge, this operation was no longer on the critical path.

Fig. 7: Abutment Piling Encased in Corrugated Pipe through Retaining Wall Footing

The abutments were designed to be integral with the foundation and utilize the flexibility of the steel piling to accommodate longitudinal movements. Piling flexibility was enhanced by encasing the top 12’ in a void formed by a 30” diameter, corrugated steel pipe.

A detailed lateral analysis of the piling verified the system’s flexibility and member stresses. Analysis results were used to develop boundary conditions for the superstructure analysis model as well.

Once the piling was installed, the retaining walls were cast and backfilled and the abutment caps were cast between the new walls and the existing abutment on the backfill. The entire cap was cast across the width of the bridge. All of this work was accomplished before any disrupting to existing traffic.

Fig. 8: Abutment and Wall Construction under existing Bridge

Fig. 9: Interior Pier and Pedestal Details

DESIGN AND PRECASTING OF INTERIOR PIERS

The most distinctive architectural feature of the Bronco Arch Bridge is the interior piers. The pier aesthetics simulate the look of the arches they replace. Each of the 16 precast, reinforced concrete piers consists of a pair of slender, arched shafts that converge into a square base.

The pier shafts are connected with a concrete strut at mid height. The piers connect to the drilled shaft foundation with a cast-in-place, reinforced concrete pedestal. A capital at the top of each pier shaft supports the each girder line of the superstructure.

Fig. 10: Precasting of Interior Piers

All of the precast, reinforced concrete piers are identical. They were cast in the Contractor’s yard adjacent to the bridge site. The piers were cast on their side in a simple casting bed consisting of conventional curved wall forms on a smooth finished concrete mud slab. Casting of the piers commenced during construction of the walls and abutments and continued until all 16 piers were cast. Piers were stored in the construction yard until needed.

Pier reinforcing extended out of the pier base and at the top of each of the capitals where the pier connects to the drilled shafts below and superstructure girders above. Vertical PVC sleeves, placed in the cross strut accommodated lifting and handling of the piers during construction.

Fig. 11: Storage of Precast Interior Piers

DEMOLITION OF EXISTING BRIDGE

After construction of the new abutments and retaining walls was complete, demolition of the first stage of the existing bridge commenced. Bridge Demolition consisted of saw cutting and removing the deck slab in sections, then removing all superstructure framing members followed by removal of the support arches. Concrete piers were demolished after all superstructure framing was removed.

Fig. 12: Demolition of Existing Bridge

Each stage of the construction process involved demolition of a section of the existing bridge, then erection of a section of new bridge. All of the steel framing in the existing bridge was coated in lead paint which complicated their removal. The duration of demolition operations of all phases varied from 11 to 23 days.

CONSTRUCTION OF INTERIOR PIERS

The shaft foundations for the interior piers were drilled immediately following completion each phase of demolition of the existing bridge. The pier foundation consists of a single, 54” diameter drilled shaft under each pier. The single drilled shaft foundation provides the necessary strength to resist all design loads while providing the flexibility to accommodate longitudinal movements.

The pier foundations were designed with 4,000 psi minimum concrete strength and approximately 1.5% vertical reinforcing that extended 4 feet into the column pedestal above. The supporting bedrock consists of a siltstone layer approximately 30 feet below existing grade. Drilled shafts penetrations into the siltstone varied from 14 to 18 feet. The recommended nominal design values of resistance of the bedrock were 6 kips of side friction and 200 to 240 kips of end bearing per square foot.

Fig. 13: Erection of Precast Piers

A square, temporary footing was cast on top of each drilled shaft which in turn supported the precast piers during erection. Once the foundations were complete, the precast piers were loaded in the storage area onto conventional trailers, retrofitted with transverse support beams. The piers were shipped up an existing ramp on to the existing bridge during a traffic closure. Two cranes lifted the piers from locations at the top of the cross strut and at lifting loops embedded in the end of the pier base.

Erection required rotating the piers a horizontal to vertical position and threading them into a shoring tower supported on the temporary footing. A special head frame at the top of the shoring tower was designed to support the pier. Adjustable jacks were used to support the pier on the shoring tower head frame. The jacks were also used to adjust and grade the piers into their final alignment.

After the piers were secured on the shoring towers, the reinforcing and forms for the support pedestal were set in place and the pedestals were cast. Pedestal concrete had minimum design strength of 4500 psi. Typically the pedestals were cast the day after the piers were erected. Once the pedestal concrete reached design strength, the bridge was ready for precast girder erection. Superstructure girders were erected 8 to 14 days following erection of precast piers.

Fig. 14: Precast Piers on Temporary Shoring

SUPERSTRUCTURE DESIGN

The bridge superstructure is a continuous, composite girder/deck system with rigid, integral connections to the substructure. The superstructure framing consists of 8 continuous girder lines supporting a composite deck slab. The girders are standard CDOT U72 precast concrete cross section with 5" and 7 ½" webs. They were cast with SCC concrete with a design strength of 8500 psi.

Each girder line consists of 3 precast U72 girders cast in lengths of 95.0', 136.5' and 133.5'. Girder weights varied from 170 kips to 210 kips.

Fig. 15: U72 Precast Girders on Abutment Cap

When erected the girders are spliced with a concrete pour between adjacent girder ends and connected to the piers and abutments with cast-in-place concrete diaphragms. A detailed, time dependent, staged construction analysis of the bridge superstructure was performed to understand all of the various loads and support conditions that the superstructure experienced during construction as well as under service loadings.

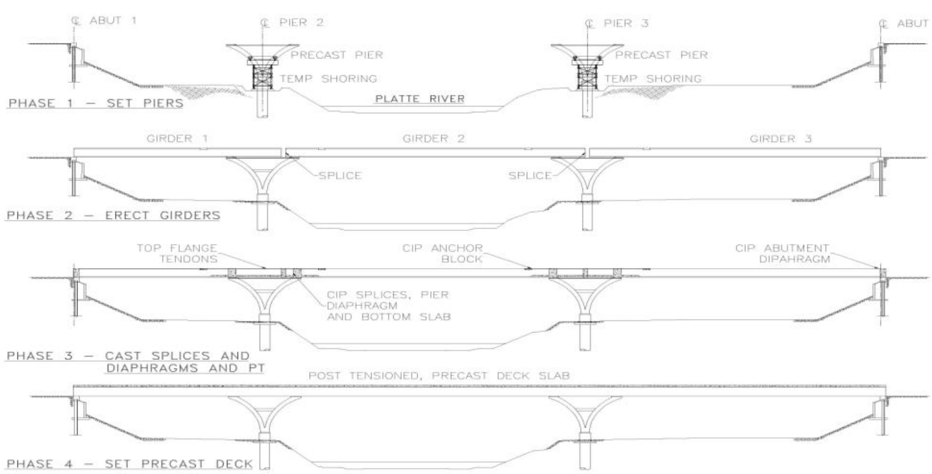

Fig. 16: Sequence of Superstructure Construction

Unique prestressing patterns were developed each of the 3 different girders using a combination of straight, draped and debonded strands. Strand profiles differed at each end of each individual girder as well. Once the girders were spliced and connected to the substructure, they are post tensioned with a 12 x 0.6" diameter, 270 ksi strand tendons in each of the girder top flanges over each interior pier. The design creates a combination of pretensioning and post tensioning that resulted in a fully prestressed, continuous girder line prior to setting the bridge deck panels.

Fig. 17: Continuous Girder Line

The deck slab consists of full depth, 8" thick, precast concrete deck panels with concrete design strength of 7400 psi. The panels are transversely pretensioned and longitudinally spliced and post tensioned. Once erected, the deck panels are made composite with the precast girders with a continuous haunch pour and continuous with a series of transverse closure pours.

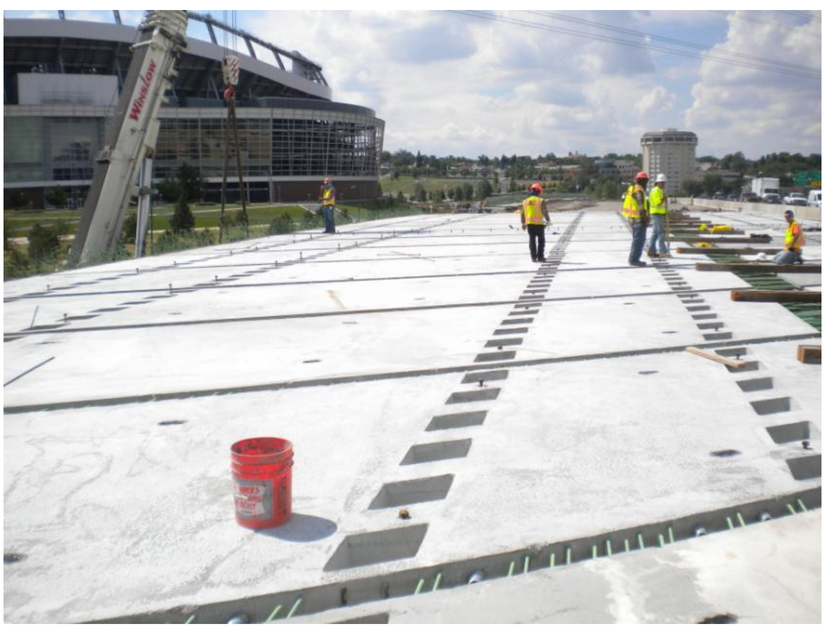

Fig. 18: Precast Deck Panel Erection

The same concrete mix was used to cast the deck panels, haunches and closure pours between the panels. Once the haunch and closure concrete reached design strength, the deck panels were post tensioned. The deck post tensioning consists of 4 – 0.6" diameter strand tendons spaced at 2'-6" and located at the center of the precast panels.

After the deck tendons were stressed, the approach slabs were cast at each end of the bridge. Expansion joints were installed at the end of the approach slabs and an asphalt overlay was applied prior to shifting traffic. Once traffic is shifted on to the new section of bridge, the next phase of demolition and construction begins until the bridge is complete.

Fig. 19: Completed Bridge, March 2013

ACCELERATED CONSTRUCTION

The construction of the Bronco Arches was completed within budget and ahead of schedule.

The construction of the bridge was accomplished on the following dates:

Phase	Start Date	End Date	Duration
1	Nov. 22, 2011	May 4, 2012	164
2	May 7, 2012	Aug. 19, 2012	104
3	Aug. 23, 2012	Dec. 3, 2012	102
4	Dec. 4, 2012	April 4, 2013	121

Each phase of construction included demolition of the existing bridge, construction of a new bridge, paving and shifting traffic.

The design and construction process developed in the Value Engineering proposal made schedule acceleration possible by maximizing the use of precast concrete elements. Precast piers, girders and deck panels were all fabricated well in advance of the time they were needed and efficient operations were repetitively executed in all phases minimizing the time necessary for each stage of construction.

Reducing the impact of construction to the public was the primary objective of the Value Engineering proposal. Considering the project was a full replacement of a busy section of Interstate highway over a waterway in a downtown urban area, maintenance of traffic was the primary concern of CDOT. Because IH25 represents both a vital local commuter artery and a key interstate commerce route, the impact of the schedule improvement extends beyond project schedule acceleration and cost savings.

By building a significant part the project prior to commencing bridge construction and streamlining operations necessary to construction each phase of the bridge, the Contractor achieved this goal.

SUMMARY

The design and construction of the Bronco Arch Bridge is an excellent example of Accelerated Bridge Construction that was well conceived and executed. A landmark structure was rebuilt within budget and schedule. New and innovative technologies and construction methods were developed and successfully executed. All of this was accomplished while minimizing inconvenience to the citizens of Colorado.

Fig. 20: Bronco Arch Bridge over the Platte River

The success of the Bronco Arch Bridge was made possible by the environment of cooperation that existed between CDOT, the Contractor, the Engineer and all of the various subcontractors and suppliers who worked on the project. An open, cooperative environment that encourages innovation, such as we have in Colorado, has resulted in a number of nationally recognized bridges and the Bronco Arch Bridge is another recent example.