Design and Construction of the IH25 / Santa Fe Boulevard Interchange Bridges in Denver Colorado

ABSTRACT:

The reconstruction of the interchange at IH25 and Santa Fe Boulevard in Denver CO includes two new bridges that utilized innovative design conceptsds. The two bridge structures include the Ramp 1 bridge which accommodates exiting NB IH25 traffic and the IH25 overpass at Santa Fe Boulevard. The two bridges are curved, interchange structures with complex geometry that utilize spliced precast concrete girder and slab construction but with two different design approaches.

The Ramp 1 Flyover Bridge consists of 11 spans of curved, precast U girders that were spliced to accommodate spans up to 200' in length on an 1100' horizontal curve. The IH25 overpass bridge at Santa Fe Boulevard consists of two parallel, 3 span bridges on a 1700' horizontal curve that were constructed using straight precast U girders. The girders were spliced to accommodate a 240' main span and were kinked at the splices to accommodate a 1700' curved horizontal alignment. The IH25 bridge is the most significant application of this type of construction in the United States.

The paper will describe the design process and the innovative design features and construction engineering used to design this innovative bridge project.

Author Biography

Gregg A. Reese, P.E., is the President of Summit Engineering Group in Littleton, CO. He has worked in the field of structural engineering with a focus on bridge design and construction for thirty years. He is currently involved in the design and construction of numerous concrete bridges in Colorado, Oregon, Florida and Texas. He holds a BSCE and MSE from the University of Texas.

Paper Summary:

The IH25 / Santa Fe Interchange bridges are two excellent examples of innovative design concepts using precast, post tensioned construction. The bridges incorporate both curved and straight precast girders with kinked splices to accommodate complex, urban interchange construction with moderate to longer spans.

INTRODUCTION

The intersection of Interstate Highway 25 (IH25) and Santa Fe Boulevard (SH85) is a significant section of roadway south of downtown Denver, CO. The intersection was old and outdated for modern traffic demands and suffered from serious deterioration of the all of the bridge structures. For these reasons it was designated as the number one infrastructure project scheduled for reconstruction in 2011.

The original design of the interchange was constructed in the 1960's and was improved and expanded multiple times to accommodate the increasing traffic demands of a growing major metropolitan city. The volume of traffic began to wear out the existing structures and several bridges were retrofitted and repaired many times since they were originally constructed. Eventually the load ratings for the bridges decreased to some of the lowest in the state as traffic congestion increased.

Fig. 1: IH25 / SH85 Interchange at begin of Construction, July 2011

The geometry of the interchange is complicated by the fact that the two major roadways that intersect, IH25 and SH85, are both north-south highways. In addition, they both are close to a parallel section of the Platte River and an overpass for Alameda Parkway, another busy arterial. The design of the new interchange required careful planning in all phases of roadway and structure design as well as a complex maintenance of traffic plan to accommodate more than 200,000 vehicles per day.

The reconstruction of the interchange is on going and will be accomplished in multiple phases. Prior to this phase of construction, the Alameda Parkway overpass was reconstructed and IH25 widened to the north of the interchange. The interchange was constructed next which involved complete replacement the Overpass Bridge and addition of a NB onramp to IH25 as well as significant rerouting and widening of IH25 to the south.

The current phase of construction, the replacement of the SH85 Bridge over the Platte River, is in the bidding process. The final phase will be the Ramp 5 Bridge from IH25 to Alameda Parkway which has not been designed but is not scheduled for construction at this time. All of the infrastructure described in this paper is all owned and maintained by the Colorado Department of Transportation. This paper will focus on the design and construction of the two bridges at the centre of the interchange, the new northbound IH25 Ramp 1 Bridge and the overpass bridge where IH25 crosses over SH58 which was completed in April 2013.

Fig. 2: IH25 / SH85 Interchange, near completion March 2013

PROJECT DESCRIPTION – IH25/SH85 INTERCHANGE BRIDGES

The project was bid in March 2011 and Hamon Contracting was the low bidder at $30M. Hamon's bid was primarily based on the Contract Documents but included a Contractor Alternate design concept for the IH25 overpass bridge. The project included two separate bridges. One was a flyover ramp (Ramp 1) that allows north bound traffic on SH85 to access northbound IH25 and the IH25 overpass at SH85. The overpass bridge consisted of two twin structures and was built in two phases to accommodate the maintenance of traffic plan.

The Ramp 1 Bridge is 1754' long and 39' wide. It consists of 3 units and eleven spans which vary in length from 118' to 119'. The bridge support two lanes of traffic with 8' and 4' wide shoulders and spans over 7 traffic openings, including IH25 and SH85, along it's length. The superstructure consists of two CDOT standard U72 girders spaced at 22' o/c and an 8 ½" deck slab. The horizontal alignment includes two curves section with radii of 1172' and 2000'.

Fig. 3: Ramp 1 Bridge

The typical substructure consists of piers with hammerhead caps founded on two, side by side drilled shafts. One pier which is located in the median of IH25 has a 72" diameter circular pier shaft with a hammerhead cap founded on a single 72" drilled shaft. Typical interior piers have a

4’x 10’ shafts connected to the superstructure with an integral pier cap that does include any bearings. Expansion piers have a post tensioned hammerhead cap that supports the superstructure on two rows of expansion bearings. Abutments are designed with a conventional cap and back wall founded on two drilled shafts. The superstructure is supported on two expansion bearings at each abutment.

The IH25 Overpass Bridge is 545’ long and each bridge is 75’ wide. It consists of 3 continuous spans with lengths of 153’, 240’ and 154. Each bridge supports five lanes of traffic and an 11’ wide shoulder. The bridge spans over six lanes of traffic on an at-grade section of SH85. Each of the twin superstructures consists of four CDOT standard U86 girders spaced at approximately 18’ o/c and an 8” deck slab and a 3” asphalt overlay. The bridge has a curved horizontal alignment with a radius of 1788’.

Fig. 4: IH25 Overpass over Santa Fe Boulevard (SH85)

The substructure consists of circular interior piers supporting each girder line and integral abutments at each end of the bridge. The superstructure is supported at each pier on a unique, reinforced concrete and steel pipe pin connection to enhance longitudinal flexibility. The abutments consist of a cap supported on a single row of driven steel piling. The use of flexible foundation elements resulted in a substructure that does not utilize any manufactured bearings.

RAMP 1 BRIDGE

The Ramp 1 bridge is significant in that uses a relative new structural system consisting of curved, precast concrete U girders that are spliced to accommodate a variety of span lengths up to 195' long. The bridge was constructed in a very challenging site where two major highways intersect with heavy daily traffic. As previously stated, the bridge spanned over 7 separate traffic openings. The precast girders, which weighed approximately 220 kips each, were supported on heavy shoring towers that were assembled and dismantled adjacent to existing roadways and varying site conditions. The curved girders were braced at each supported end to prevent rolling.

Fig. 5: Ramp 1 Bridge during construction

A step by step erection scheme was utilized to safely erect the precast girders and progressively add precast and cast in place concrete structural elements which include splices, pier and abutment diaphragms and a lid slab to close the cross section prior to applying post tensioning. Once the splices and diaphragms are cast each girder line is fully continuous. The addition of a continuous lid slab, which closes the open U girder section, greatly increases the torsional strength of the cross section. After all of these elements are installed, the girders are ready for longitudinal post tensioning.

Fig. 6: Casting of Splices. Lid Slabs and Pier Diaphragms prior to Post Tensioning

Longitudinal post tensioning is anchored in the cast in place diaphragms at the abutments and expansion piers at the ends of each unit. All continuity tendons are internal and are located in each web of the girders. No temporary post tensioning was used and girder webs were proportioned to maintain a 0.4 duct/web thickness ratio for both bridges. Once the girders are post tensioned they are fully self supporting and the support falsework is removed. The continuous bridge girders also have sufficient strength to carry all of the weight of the deck slab concrete. The deck slab was cast in an unshored condition.

The advantages of this using this sequece of construction is that it results in an easily replaceable deck slab where deck grades are easier to control and monitor during casting and since the composite cross section carries less dead load, it is less susceptible to deck cracking in negative moment regions. After the deck concrete sets, the bridge cross section is fully composite to resist all subsequent loads and long term effects including creep, shrinkage and time delayed redistribution of locked in forces.

The Ramp 1 Bridge is in a high visibility area where approximately 200,000 vehicles per day pass under it. The bridge's slender depth, integral substructure and smooth curved lines of the superstructure produces an aesthetically pleasing solution.

Fig. 7: Bridge 1 Construction Completed in Early 2013

IH25 OVERPASS BRIDGE

The IH25 Overpass consists of twin bridges that were constructed in two phases over a busy state highway that carries traffic into and out of downtown Denver. The bridge was designed as a Contractor Alternate to the Contract Plan design that was a similarly conceived spliced precast concrete structure. The alternate design modified the layout of the precast girders to follow the traffic patterns which complicated the design of the girder designs but greatly simplified construction of the bridge. The alternate design allowed the use of a shallower, 86" cross section which was more readily available. Modifications to the pier and abutment designs were also developed in the alternate design.

Fig. 8: IH25 Overpass Bridge Girder Lines with Kinks at Splices

The IH25 Overpass is a particularly important structure which includes the following innovative design features:

- 240’ Main Span with a slenderness ratio (L/D) ratio of 30.
- Continuous, Post Tensioned girder construction, designed for significant horizontal curvature with straight girders, kinked at the splices.
- Reinforced concrete and steel pipe bearings at interior piers
- Integral, flexible abutment on steel piling which eliminated bearings.

The bridge was designed as rigid frame with pinned interior piers and an integral connection at the abutments that eliminated the need for bearings. The superstructure framing of each of the twin bridges consists of 4 continuous lines of U84 girders that are spliced, post tensioned and eventually made composite with an 8” deck slab. Each girder line has a unique layout with varying numbers of girders and splice locations to accommodate the site conditions during construction which required maintaining traffic on SH85 at all times as shown in Figure 9.

Fig. 9: IH25 Bridge during Construction

The substructure and foundations were designed to provide both adequate strength and flexibility to account for longitudinal movements lateral design loads. The interior piers consist of a single 48” circular shaft and are founded on a single drilled shaft and connected directly to the girder line above. The abutments, which are fully integral with the superstructure, consist of a cap and diaphragm supported on a single row of steel piling which was driven to refusal into a bedrock layer approximately 30’ below existing grade.

The piers are designed with an innovative pinned connection to the superstructure that does not require manufactured bearings. The connection is accomplished by casting a concrete bearing between the top of the pier and bottom flange of the girders and 4’ thick diaphragm inside the U girder directly above. The concrete is placed monolithically through a hole in the bottom flange of the precast girders directly above the interior piers. A 6” wide layer of isolation material is placed around the perimeter at the top of the pier to avoid spalling at the edge of the bearing surface.

A 4’-0” long section of 10” Schedule 80 steel pipe is the only structural connection across the interface to provide a pinned connection with significant lateral load capacity. The pinned connection greatly enhances the flexibility of the substructure to enable it to accommodate longitudinal movements.

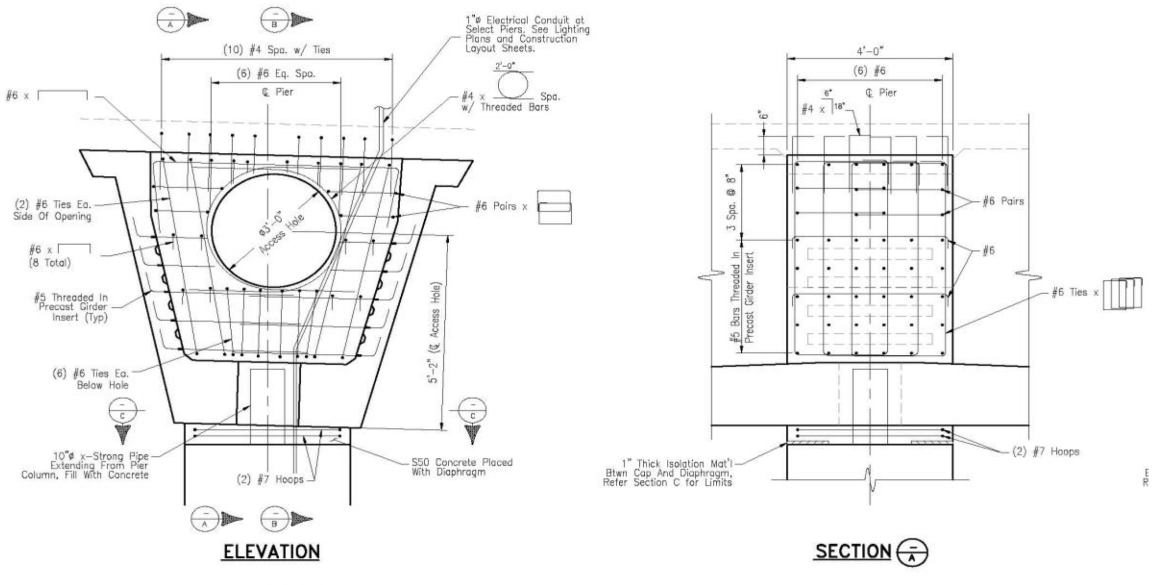

Fig. 10: Connection of IH25 Bridge Piers to Superstructure

The integral abutments consist of a lower cap which is rigidly connected to the steel piling foundation. The top 12' of piling, below the abutment cap, is encased in a 30" diameter corrugated steel pipe to increase the flexibility of the foundation. The precast girders are set directly on top of the lower cap on a ¾" neoprene levelling pad when erected.

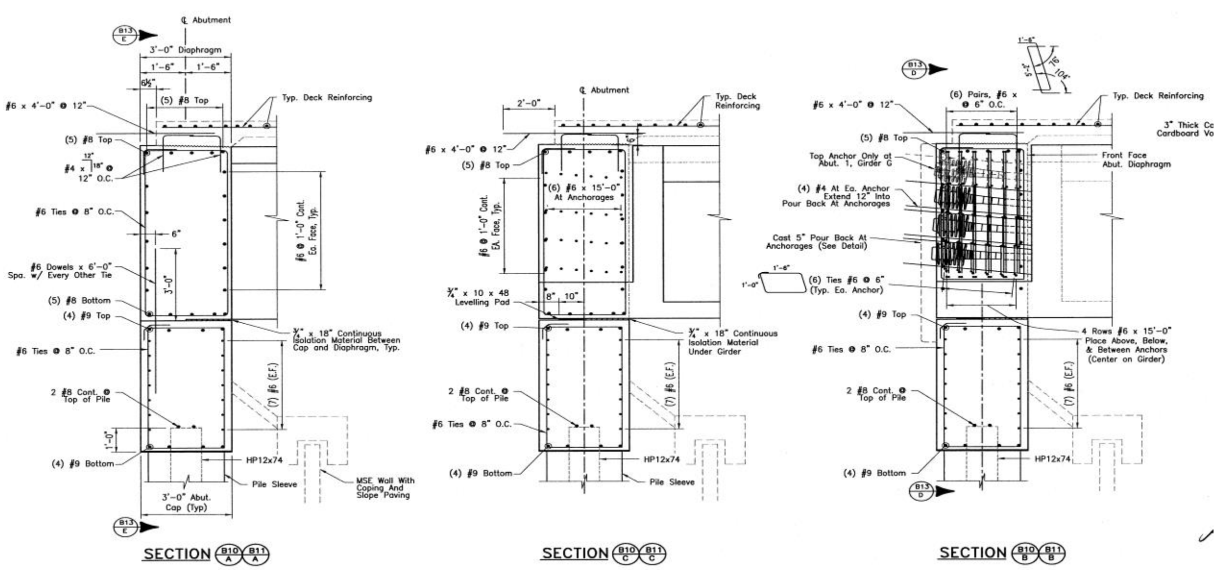

Fig. 11: Design Details, Integral Abutments, IH25 Overpass

Following girder erection a transverse diaphragm is cast which fully encases the end of the girders and connects the superstructure to the abutment cap below. The reinforcing pattern between the cap and diaphragm is placed in a single row at the back of the cap/diaphragm interface to provide significant lateral load capacity but very little rotational restraint. A 12" wide, continuous layer of isolation material is placed at the outside edge of the interface between the cap and diaphragm to prevent spalling.

Fig. 12: Completed Integral Abutments, IH25 Overpass

The longitudinal post tensioning for the superstructure is anchored in the back face of the cast in place abutment diaphragms. Therefore the post tensioning is stressed after the superstructure is integrally connected to the abutments. To simplify construction, no allowance was made in the design to isolate the abutments from movements due to axial shortening of the superstructure. The abutments were designed with sufficient flexibility to accommodate the axial shortening on the bridge as well as all other longitudinal design movements.

One of the more unique design features of the IH25 Bridge is how the framing system is designed to accommodate the curved roadway alignment. At the time of this writing the use of kinked, spliced precast girders to accommodate horizontal curvature in a bridge structure in North America is rare. The IH25 Overpass Bridge is one of the most significant examples of this type of design approach to complex long span bridges in the United States. Kinked, spliced precast girder construction will produce an aesthetically pleasing design for bridges with moderate curvature as shown in Figures 4 and 8. The IH25 Overpass Bridge has a design radius of 1788’ with girders lengths between splices up to 110' which makes the use of straight sections possible without unsightly variations in overhangs or noticable kinks at the girder splices.

The design of the 240’ main span section over SH85 involved a detailed design of the longitudinal post tensioning to control stresses and limit long term deflections and cambers. Each girder line consisted of CDOT U84 girders with an 8” composite deck slab. This section creates a slender structure with a final span to depth ratio slightly greater than 30 in the main span. To control girder service stresses and deflections during the life of the structure while providing adequate ultimate strength, an erection scheme, differing from Ramp 1, was used that included staged stressing and shored construction during the casting of the deck slab.

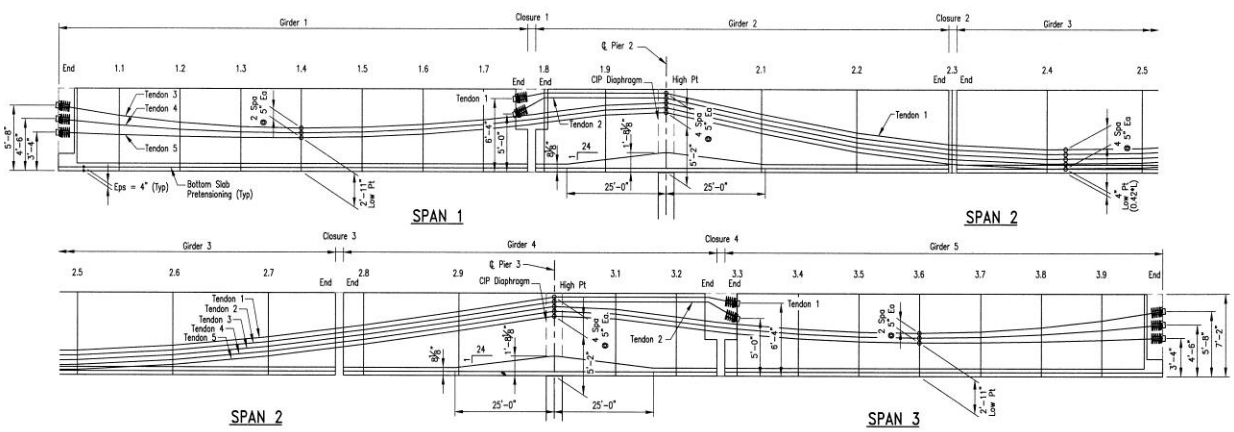

Fig. 13: Longitudinal PT Layout, IH25 Overpass

The precast girders were erected on the temporary shoring and the splices and diaphragms at the abutments and interior piers were cast. After the concrete reached design strength, the first stage of longitudinal post tensioning was stressed into the open U girder section. Following first stage stressing, the shoring was shimmed, if necessary, to restore contact with the girders prior to casting the deck slab. Following adequate curing of the deck slab, the final stage of longitudinal post tensioning was stressed and the shoring was removed.

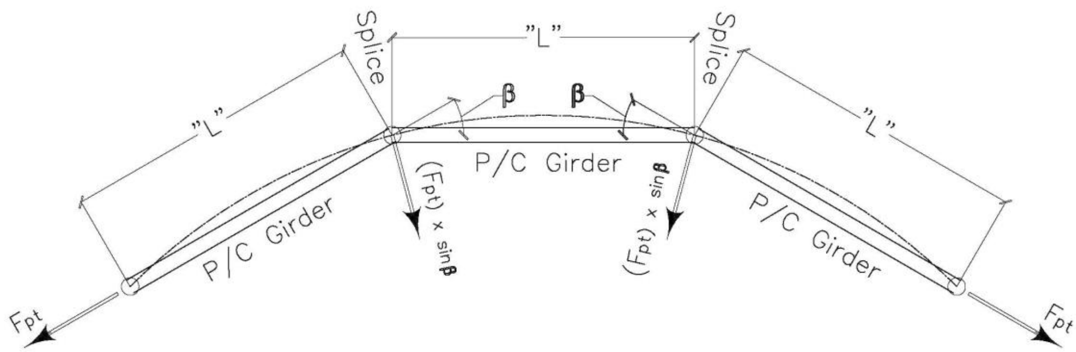

Fig. 14: Lateral Forces from Kinks in Post Tensioning at Splices

One of the challenges in designing curved bridges in this way involves resolving the concentrated lateral forces at the girder splices due to the horizontal deviation of the longitudinal post tensioning into the structure. While this requires serious consideration in design, the lateral loads resulting from curvature similar to the IH25 Overpass produce nominal loads that can be easily accounted for by moderate strengthening the section at the end of the girders.

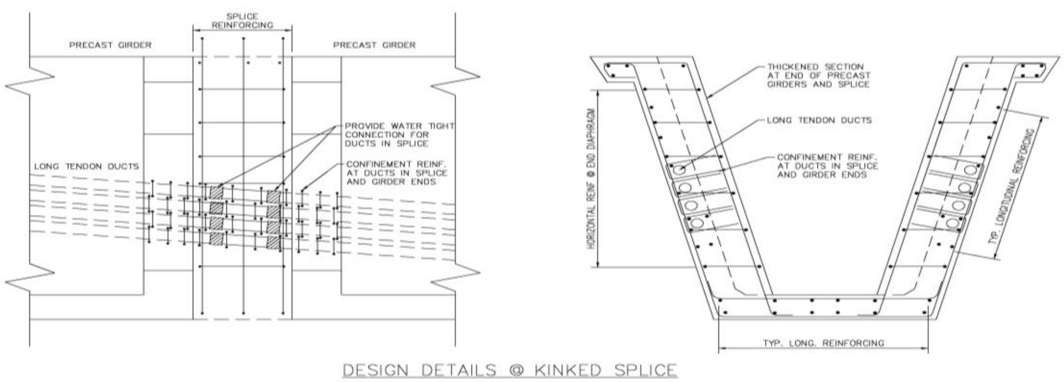

Fig. 15: Strengthening at Precast Girder Ends for Out of Plane PT Forces

Strengthening of the kinked section consisted of a nominal thickened concrete section at the end of the girders which was cast through the splice with sufficient confinement reinforcing as shown in Figure 15. The out of plane flexure in the continuous girder line must be checked as well. The IH25 bridge U girders have a cross section with ample out or plane strength and stiffness to resolve these forces without the need for transverse diaphragms. The final design produces an open space under the bridge with minimal substructure elements.

Fig. 16: IH25 Bridge Completed, Spring 2013

SUMMARY

The design and construction of both IH25 / Santa Fe Boulevard Interchange bridges is an excellent example of how innovative designs using precast concrete construction can be used to produce a successful, cost effective infrastructure project. The project was well conceived and executed which resulted in completion within the budget and ahead of schedule. New design details and construction methods were developed and successfully executed and all of this was accomplished while minimizing inconvenience to the citizens of Colorado. A necessary and aesthetically pleasing improvement of the transportation infrastructure was completed for citizens of Denver and the State of Colorado.

ACKNOWLEDGMENTS

The success of the IH25 / Santa Fe Boulevard Interchange 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 IH25 Interchange bridges are another recent addition to that list.