INNOVATIVE APPLICATIONS OF PRECAST CONCRETE ON COMPLEX BRIDGE PROJECTS IN COLORADO

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ABSTRACT:

A number of recent urban bridge projects with long spans and complex geometry have been designed and built using a variety of innovative applications precast concrete girder and deck slab construction. Concrete U girders, cast in both curved and straight segments, are spliced and post tensioned to create a new alternative approach to complex bridge construction.

The success of these projects, which are all currently in service, clearly demonstrates the advantages of using commercially precast concrete products to construct cost-effective, complex long span structures in high profile applications where aesthetics and urban geometrics are significant design consideration.

This paper will review the development of design concepts and the project involved and will describe the design and construction challenges and the solutions that were successfully implemented.

Keywords: Girders, Post-tensioning, Falsework, Spliced, Erection, Design, Construction

INTRODUCTION

The majority of interchange construction with longer spans and complex geometry have been constructed using steel I or trapezoidal box girders or post tensioned cast-in-place concrete. Precast concrete girders have been used in interchange bridges with medium length spans but have been limited to applications with large horizontal curvature that could be accommodated with straight beam sections. The majority of these bridges consisted of precast box and I sections.

Advancements in the use of spliced, post tensioned girders have extended the span range of precast concrete construction. The development of the U girder introduced a new cross section that had sufficient strength and stability to make casting curved sections feasible. Combining these two advancements opened up the possibility of using precast concrete for long span interchange projects.

DEVELOPMENT OF THE CONCEPT

In the 1990ís, the Colorado Department of Transportation began using spliced, precast I girders to build a number of long span bridges with straight alignments. During this time, CDOT engineers also began to develop standard sections for a new series of precast U girders. In the late 90ís they designed and built a number of overpass bridges were using spliced U girders.

In 1995 CDOT designed the Park Avenue Bridge which spans over I-25 near downtown Denver. The bridge was completed and opened to traffic in 1997 and received the PCI Award in 1999 for long span bridges. The superstructure consists of to lines of curved, trapezoidal box girders that were spliced and post tensioned to accommodate a tight horizontal curvature and spans up to 70 meters. The bridge girders were site cast using custom forms.

SHAPE * MERGEFORMAT

Fig. 1: Parker Road Interchange, Ramp G

In 2000, CDOT designed Ramp G, a third level connector bridge for the Parker Road interchange project with spans up to 76.25m on a 213m radius. Ramp G was similar to the Park Avenue Bridge, with two lines of spliced, trapezoidal concrete box girders that were intended to be a blend of precast and cast-in-place sections. In 2003, CDOT began designing the Ramp Y connector, a bridge that utilized curved, precast CDOT U84 standard girder. The design concepts used on Ramp Y were the culmination of years of work by the Department to develop a viable alternative to steel and cast-in-place construction for complex, long span bridges using standard, plant manufactured precast concrete.

In 2004, CDOT allowed Contractors to bid a precast concrete alternate design to a steel trapezoidal box girder bridge with spans up to 61m and an 245m radius horizontal alignment. The Ramp K bridge was the first project designed, constructed and opened to traffic that used curved, precast concrete U girders manufactured in a commercial plant.

Fig. 2: Aerial View, I-25 Ramp K Flyover Bridge

In 2005, the Bijou St. Bridge was constructed as a part of the COSMIX design/build expansion of I-25 in Colorado Springs. The bridge spans from I-25 to downtown Colorado Springs over Monument Creek and the BNSF rail yard. The bridge was designed using details developed during the design of the Ramp K. The bridge superstructure constructed of seven lines of spliced, precast U girders that were splayed and kinked at the splices to accommodate a roadway width that varied from 27m to 54.25m.

In 2006 three more projects were designed and constructed using spliced precast concrete girders. The Austin Bluffs overpass and the Ramp Y and Ramp H bridges were constructed using spliced girders with spans up to 70.12m and horizontal radii from 233m to 366m. In 2007, two more projects, SH58 Ramp A and I-25 viaduct in Trinidad, CO were designed and issued for construction. These projects have maximum spans of 71.65m for a constant depth girder and 80.79m for a variable depth girder.

SHAPE * MERGEFORMAT

Fig. 3: 265í Main Span of I-25 viaduct in Trinidad CO

All seven of these bridges have been successfully completed and opened to traffic and several new projects are being designed in Colorado with curved precast U girders.

ADVANTAGES OF PRECAST CONCRETE

Enhanced durability and lower life cycle and construction costs make precast concrete an attractive design option. Recent volatility of steel costs and longer fabrication lead times have been a an additional motivating factor for developing precast concrete as an option for long span interchange bridges. Colorado has a number of precast plants that can produce highway girders. Having a strong local market has enhanced the economics of using precast concrete while reducing lead times for fabrication and shipping costs. In addition, the close proximity of these plants has enabled contractors and engineers to work with the local plants to refine design details to improve constructability.

Fig. 4: Curved Girder Casting Bed

When the Colorado DOT began building curved precast concrete bridges, the local precast plants purchased adjustable forms capable of casting girders on varying horizontal curves. The initial cost of forms was modest and the volume of girders produced in the last five years has enabled the investment to be quickly amortized. Future projects in Colorado will realize even greater economy as the technology matures without need for further setup costs.

Spliced girder construction only requires vertical shoring which greatly simplifies the design of temporary works and reduces interference to existing roadways. The elimination of horizontal shoring enhances maintenance of traffic during construction. Conventional construction methods and equipment are used to erect the girders eliminating the need to invest in specialized equipment. The cost of spliced precast concrete construction has been very competitive and costs are typically more stable than steel construction. Lead times for fabrication and delivery of girders have been greatly reduced further enhancing the attractiveness of this type of construction.

The use of precast U girders enables a project to unify the appearance of a project for all conditions. The structural shape is suitable for both long and short spans with straight and curved alignments. Girders with sloped webs create an attractive structure that has been well received in high visibility locations. The success of these initial projects clearly demonstrates that precast concrete can be used to provide a cost effective design for long span bridges in high profile applications where aesthetics, environmental impact and urban geometrics are a significant design considerations.

Fig. 5: I-25 Ramp K Flyover Bridge

SUBSTRUCTURE DESIGN

The use of continuous structures with integral diaphragms between the substructure and superstructure has been a common design practice in Colorado to enhance durability, reduce maintenance costs and prevent damage to bridge components from snow removal and de-icing of roads in the winter months. The bridges are broken into a number of distinct units when the overall length becomes too long for the substructure to accommodate longitudinal movements. Expansion joints and bearings are located at abutments at the ends of the bridge and interior expansion piers.

The substructures of the bridges described in this paper, with the exception of the Austin Bluffs overpass, were designed with multiple units. Both integral and conventional abutments were used at the ends of the bridge. Piers consisted of single shaft columns with hammer head caps. Transverse integral diaphragms were cast between girder lines at all interior piers. Expansion joints were used at expansion piers at the ends of each bridge unit.

The piers and abutments were supported on a single row of side by side drilled shafts founded in bedrock at varying depths below final grade. The columns were proportioned to enhance longitudinal flexibility and while providing significant strength and stiffness in the transverse direction. Each bridge unit was designed as a continuous frame that utilized frame action, pier flexibility and soil/structure interaction to accommodate longitudinal movements.

Fig. 6: I-25 Ramp K, Interior Pier Cap and Diaphragm

The superstructure was supported on expansion bearings at conventional abutments and expansion piers. At interior piers and integral abutments the superstructure was directly connected to the substructure at the transverse diaphragms which were cast directly over the pier caps without bearings. The elimination of bearings at all interior piers resulted in significant cost savings on a number of projects.

The majority of piers were relatively short so a pinned connection was designed between the pier cap and diaphragm at interior piers. The connection consisted of a single row of reinforcing was placed at the center of the pier cap along the interface between the cap and diaphragm. The composite cap and diaphragm carried gravity loads from the girder lines to the pier shaft but could freely rotate longitudinally. To prevent spalling, the perimeter of the interface was lined with expansion material.

SH58 Ramp A was designed with fully fixed integral caps at interior piers to enhance aesthetics and accommodate clearance requirements at the I-70 crossing. The bridge was divided into three units of moderate length with interior expansion joints at two locations to reduce the longitudinal movements at interior piers. The resulting substructure consisted of a more slender pier cap that was fully integral with the transverse diaphragm. Vertical pier reinforcing was extended into the diaphragm in the space between the girders lines. The cast-in-place concrete diaphragm was transversely post tensioned through the girders after casting and resulting connection between the substructure and superstructure was fixed in both the transverse and longitudinal directions.

Fig. 7: SH58 Ramp a, Interior Pier Diaphragm Reinforcing

Precast girders were set directly on expansion bearings at conventional abutments and expansion piers. Bearing top plates were embedded in the bottom flange of the precast girders which were set directly on the bearing assemblies when erected. Transverse diaphragms were cast through a notched section at these locations to connect the girders and anchor the longitudinal post tensioning. The diaphragms were cast in stages at expansion piers to accommodate double end stressing of the longitudinal post tensioning.

Fig. 8: Abutment Diaphragm on Bearings and Post Tensioning Anchorages

SUPERSTRUCTURE DESIGN

Spliced precast girder construction is similar in performance to a traditional cast-in-place post tensioned box girder bridge. Precast U girders have the advantage of providing a torsionally rigid cross section. Using precast elements eliminates the need for horizontal shoring and extensive site forming. Precast concrete girders are manufactured in plant controlled conditions with more predictable concrete mix designs and the opportunity for better quality control than cast-in-place construction.

The U girder has a robust cross section which does not require internal bracing to control internal stability during construction. The U girder has sufficient torsional strength to enable them to be handled and erected without closing the cross section which greatly reduced shipping weights. Segmented girder lengths were limited by the plantís lifting capabilities and restrictions on trucking. The largest precast girder segment cast for these bridges was 36.60m long and weighed 120 tonnes.

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Fig. 9: Spliced U Girders supported on Temporary Shoring

Optimizing girder lengths can reduce the number of segments which reduces shipping costs and the amount of temporary shoring.

CDOT requires all prestressed members to be fully compressed under all design dead loads. Temporary tensile stresses are allowed under construction and live loading and are limited based by AASHTO design requirements. The primary post tensioning in the final structure consisted of continuous tendons placed in the girder webs that ran the full length of the bridge unit along a parabolic profile similar to conventional cast-in-place box girder construction. Mild reinforcing was detailed to control radial forces in the webs of curved girders.

Fig. 10: Post Tensioning Details - SH58 Ramp A

Shorter tendons were placed in the bottom flange of typical girders at mid span and occasionally in the top flanges of the girders over interior piers in longer spans to supplement the continuous web tendons. Tendons were spliced at the closure pours between precast girders and anchored at cast in place diaphragms at the end of each unit.

Fig. 11: Precast Girder Reinforcing Details

The design of longitudinal post tensioning was controlled by negative moment stresses at interior piers. This was due to the limited amount of space available for tendons in the top flange and smaller eccentricities in negative moment regions. The bottom slab over interior piers was thickened or haunched to reduce service stresses in the and to increase the compression block in the ultimate cross section. The wide bottom flange of the U girder cross section allowed ample room for placement of prestress in positive moment regions.

Girders were reinforced for handling and erection stresses with nominal amounts of pretensioning in straight girders and post tensioning in curved girders. Pier girders were lightly prestressed in the bottom flange to control erection and handling stresses. Occasionally erection prestress in the pier girders was removed after they were erected. Mid span girders were designed with more permanent prestressing in the bottom flange than what was required for handling and erection to improve the final design. In general, the level of prestressing force in these bridges was significantly lower than conventional prestressed concrete girder designs.

Fig. 12: Curved Girder Erection on Temporary Shoring

When possible, curved girders were not prestressed when they were removed from the casting bed. Longer curved girders were lightly prestressed, prior to lifting, with mono-strand tendons to control cracking during handling and storage in the plant. All permanent tendons designed for erection were stressed and grouted in the plant before girders were shipped to the job site.

Standard CDOT U girder cross sections are designed in 305mm increments of depth from 1220 to 2440 with web thicknesses that vary from 125 to 250mm depending on the application. The bridges described in this paper had 190 and 305mm webs to accommodate post tensioning ducts. AASHTO Guidelines set maximum duct to web thickness ratio to 40% and limit the principal tensile stress under design loadings. These guidelines were followed in all designs and the resulting designs provided adequate room for reinforcing placement and concrete consolidation during casting.

The open, U shaped cross section was closed soon after the girders were erected on temporary shoring. A lid slab was cast between the top flanges or pre-tensioned, precast deck panels were placed over the webs and a continuous closure strip was cast creating a closed box. By creating a closed section, the torsional rigidity was greatly increased and shear forces and stresses in the webs were reduced. The size and quantity of vertical shear reinforcing in the webs for design loadings was similar to conventional precast girder construction.

Fig. 12: Lid Slab Details during Construction

Following stressing of longitudinal post tensioning, the continuous girders were self supporting and all falsework was removed. Pre-tensioned, precast deck panels were placed between the girder lines and overhang forms were installed. All deck slabs were designed with mild reinforcing in the transverse and longitudinal direction. Deck slabs were cast, whenever possible, in an unshored condition to allow for future deck replacement or widening. The rigidity provided by closing the girder cross section reduced torsional deformations during deck slab casting to levels that could easily be accommodated by haunches in the girder top flanges.

CONSTRUCTION CHALLENGES AND SOLUTIONS

Construction of these bridges involved handling and erecting large, heavy curved girders in challenging site conditions that required temporary support and stabilization. Locations for temporary shoring controlled much of the design of the superstructure and were controlled by existing site conditions and the need to maintain traffic. Significant levels of engineering support for construction were required to design temporary works. Detailed lift plans were developed to locate the large cranes that were required to set the large, heavy girders. Detailed designs and procedures were developed to safely erect and stabilize curved girders on temporary shoring in close proximity to existing traffic. Sequenced operations were developed to control stresses and deformations of the structure during construction.

Fig. 13: Ramp K, Cantilevered Construction over Existing Bridge

Many unique techniques and details were developed during design between the designers and contractors that improved the constructability of these projects. Cooperation between CDOT, designers, fabricators and contractors during design and construction facilitated the rapid development this new type of bridge construction.

SUMMARY

The development of the U girders has created an opportunity to use precast concrete in new applications for bridge construction. By splicing precast girders with post tensioning we can expand their use into long span construction. By casting them in curved segments, precast concrete can be used as a viable, economical design option for projects with complex roadway geometry.

The projects described in this paper were constructed in challenging site conditions where maintenance of existing traffic was essential. Further refinement of design details and construction methods on future projects will continue to enhance the economy and ease of construction of this concept and make it even more attractive to engineers, owners and builders. The success of these projects clearly demonstrates that the potential for application of precast concrete for use for long span bridges is only bounded by the engineer and contractorís creativity and imagination.