INNOVATIVE PRECAST / PREFABRICATED BRIDGE INITIATIVE IN TEXAS

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ABSTRACT

The Texas Department of Transportation (TxDOT) is implementing innovative design and construction techniques for bridges to reduce traffic disruption and construction project duration while enhancing safety for the motoring public and constructability for the contractor. This initiative is being accomplished through research projects, new design techniques resulting from research findings, partnering with contractors and field performance data for precast / prefabricated systems in service. TxDOT research projects are currently investigating innovative design and construction methods for off-system bridges, development of precast bridge construction systems, behavior of connections between precast slab elements, and rapid bridge replacement techniques. Highlights are discussed and design procedures and implementation of results are presented.

Keywords: Precast, Prefabricated, Rapid Bridge Construction

INTRODUCTION

The Texas Department of Transportation (TxDOT) is implementing innovative design and construction techniques for bridges to reduce traffic disruption and construction project duration while enhancing safety for the motoring public and constructability for the contractor. This initiative is being accomplished through a multifaceted approach involving completed and ongoing research projects, new design techniques resulting from research findings for precast element connections, partnering with contractors and suppliers to develop construction techniques and field performance data for precast / prefabricated systems in service.

THE NEED FOR RAPID BRIDGE CONSTRUCTION TECHNIQUES

Texas is experiencing one of the highest population growth rates of any state in the country. The need to move people and goods around the state is crucial in serving the increasing demands of the growing population. Road capacities must be increased to meet this need, but the construction of these larger facilities can severely impact the motoring public. The impact and costs associated with disrupted traffic flow have increased significantly in recent years. Traffic delays impair mobility and motorist and worker safety is compromised. Goods and services may not reach the people requiring them. Direct and indirect costs related to traffic disruption are a major concern. One of the many ways TxDOT is responding to the challenge is by devising ways to construct bridges with less impact to the motoring public and greater safety for the workers who build them.

EARLY INNOVATIVIONS IN PRECAST BRIDGE CONSTRUCTION

TxDOT has used precast concrete bridge elements and systems for many years. In 1960, TxDOT used precast concrete beam spans involving four precast / prestressed beams with full depth deck slab cast integrally to facilitate construction over water of the 2.25 mile long Lavaca Bay Causeway. In 1963, Texas developed a deck construction system whereby about half of the bridge slab could be prefabricated utilizing precast concrete panels. Precast interior bent caps supported on precast concrete piling were used to speed construction across the Redfish Bay and Morris & Cummings Cut in 1994. Precast interior bent caps were used to minimize traffic disruption on US 290 in Austin in 1994 and in Houston in 1996. In downtown Houston a 113-span section of IH 45 know as the Pierce Elevated Freeway was replaced in just 190 days. An outgrowth of this was a research project carried out by the University of Texas at Austin investigating precast cap to column connections, resulting in design procedures used for the Lake Ray Hubbard Bridge completed in 2002 and the Lake Belton Bridge, which is currently under construction. Precast elements are being utilized elsewhere in the State as well, notably on the Texas State Historic Railroad and UPRR at SH 46 in New Braunfels.

THE NEED FOR A PRECAST BENT CAP SYSTEM

Two construction projects that successfully used precast bent caps motivated TxDOT to initiate the formal development of a precast bent cap system. These were the Redfish Bay and Morris & Cummings Cut Bridges along the Gulf Intracoastal Waterway on SH 361 near Port Aransas and the Pierce Street Elevated section of IH 45 in the Houston central business district.

The Redfish Bay and Morris & Cummings Cut bridges were being replaced because of severe salt-water induced deterioration. The original replacement design was for cast-in-place bent caps on precast piles for the substructure but the contractor requested to use precast concrete piling connected to precast concrete bent caps with a grout pocket connection instead. The use of 74 precast bent caps over water enabled work to be completed six months ahead of schedule.

Little performance data was available at the time so the connection was designed empirically to provide similar strength to the usual cast-in-place cap to precast prestressed concrete pile connection through an elastic analysis of a semi-fixed connection. Capacity provided was similar to a stripped back concrete pile embedded in a cast-in-place cap.

The precast concrete piling for these structures were cast with four galvanized metal 1-½ inch diameter post-tensioning ducts in the top three feet of the piling. Interior bent caps were precast with a pocket ready to accept the piling at the site and make the precast connection. The pilings were accurately driven into position with the aid of a frame and template resting on the bottom of the bay. Epoxy-coated #9 hairpin-shaped reinforcing bars were grouted into the tops of the piles. Friction collars were placed around the piles to support the precast caps. The caps were set in position, grades were checked and the grout pockets were filled with a 3/8" aggregate concrete mix to complete the connection. The substructure was now ready to accept the precast double Tee beams, as bearing seats had been precast with the cap.

The Pierce Elevated Freeway Bridges presented a unique challenge. Traffic counts were high in the central business district of downtown Houston. One hundred thirteen spans of the superstructure and bent caps needed replacement due to damage from reinforcement corrosion, but the columns and foundations could be reused. Use of precast bent caps allowed completion of each of the twin structures in 95 days, a total of 226 spans replaced in 190 days, instead of 1.5 years typical for a project of this magnitude with cast-in-place construction.

The connection was designed to provide similar strength to the usual cast-in-place cap to column connection through an elastic analysis of a fixed connection. Again, this was done empirically as little performance data was available at the time.

The bridge deck and prestressed beams were removed and the cap was wire-sawn from the top of the columns. A gang-drill was used to drill all holes simultaneously in the top of the columns and Dywidag threadbars were grouted in with a fast curing polyester resin. A precast inverted Tee bent cap with 3 inch diameter galvanized metal post-tensioning ducts was lowered onto the columns on steel shims. The bedding layer was formed and grouted, grades were checked and the cap was "bolted" into place. The threadbars were stressed, ducts were grouted, beams were set, precast concrete deck panels were laid in position and the top half of the deck was cast-in-place. Just five days elapsed from the time demolition started to when the first concrete deck was poured.

TXDOT RESEARCH PROJECT 0-1748: "DEVELOPMENT OF A PRECAST BENT CAP SYSTEM"

Under this study completed in January 2001, a project panel was assembled consisting of TxDOT bridge engineers, DOT engineers in other states that have developed precast substructure systems, and precast and construction industry representatives. With the panel input, Project 0-1748 developed four categories of connection details. These are grout pockets, grouted vertical ducts, bolted connections and grout-sleeve couplers. Multiple details were developed for the connection categories to provide options to accommodate a wide range of applications and required connection capacities. Other criteria used in development of connection details were the capacity to resist large unbalanced moments, avoiding conflicts between cap longitudinal reinforcement, confinement of the connection region to ensure development of full capacity of the connection and providing proper durability of the connection and protecting connectors from corrosion. The ease of setting the cap in final position and adjusting grade of the cap and bearing seats, and completing the connection were also considered.

Issues with the transfer of forces between precast cap and cast-in-place columns or precast concrete piling were targeted in the investigation. These were bar or connector anchorage development within grout pockets or grouted vertical ducts, interlock of grout pockets and development of ducts in precast caps, influence of confinement on the connection region, and failure modes of the connections.

To address these concerns a three phase testing program was established. Phase 1 consisted of 32 pullout tests conducted on single line and double line grout pockets and grouted vertical duct specimens to investigate connector anchorage. Initial tests were conducted to examine grout types and to determine the depth at which failure transitioned from a concrete breakout to yield of the connector steel. Several tests were conducted to examine the effects of straight versus headed bars, two closely spaced bars loaded simultaneously, multiple grout pockets or ducts, and confining effects on anchorage behavior. Results of the Phase 1 tests were used to proportion and detail four full-scale precast bent cap to column connections for Phase 2 of the testing program. Phase 2 connection specimens were a single line grout pocket, double line grout pocket, grouted vertical duct connection, and a bolted connection in duct. Phase 2 specimens were fabricated and loaded to service load level, factored load level and failure to verify design provisions and specification under development. Phase 3 consisted of construction of a full-size trestle-pile bent with four connections and a full-size column bent with three connections. Phase 3 investigated constructability issues such as construction tolerances for multiple connections, assembly and grouting of multiple connections in the field, grout mix and grout placement.

Phase 1 testing provided information on the load versus slip behavior of the connectors, which was critical in developing anchorage provisions and connection capacity criteria. Phase 1 also provided information on grout mixes and placement of grout. Phase 2 tests confirmed the adequacy of the anchorage provisions and design procedures developed following the Phase 1 tests. Tests indicated that the anchorage provisions were somewhat conservative. Phase 3 again confirmed the adequacy of the anchorage provisions and verified the constructability of the system.

TxDOT Research Report 1748-2 presents a full description of the research, testing and connection design recommendations. This report should be carefully reviewed before applying the design procedures. Some of the highlights of the connection design procedure are:

- All loads and load combinations and load directions should be considered in connection design.
- Bent caps should be designed with pin connections at support points. Columns or piles should consider the governing case of pinned or fixed connection at column or pile top. Engineering judgement should be used in determining degree of fixity.
- Precast connections should be designed as a rigid connection.
- Connector embedment length and connector spacing should be carefully considered in evaluating the capacity of the connection. Durability and constructability should be considered when devising connector details.
- The area of the connector steel should not be less than 0.7 percent of the gross cross-sectional area of the conventionally reinforced column or less than 1.0 percent of the gross cross-sectional area of the prestressed pile.
- Confining reinforcement is an important component of the connection system. It significantly decreased required embedment length for a given connector capacity in the laboratory tests.
- Grout mix and grout placement is crucial to adequate connection strength. Long term durability of the grout mix must be carefully considered. Grout specification and placing procedures must be carefully considered. Plans for inspection during and after grouting should be established and documented prior to grouting. Connection mock-up and grout mixing and placing tests should be done before precasting any caps or grouting any connections in the bridge structure.
- Bedding layer thickness must be within the 1 ½ to 4-inch limits outlined in the report and must be fully grouted.
- Allowance must be made for construction and fit-up tolerances in detailing the precast connections.

IMPLEMENTATION OF RESEARCH RESULTS

The design procedure developed under Project 0-1748 was implemented on the SH 66 bridge over Lake Ray Hubbard, the East Fork of the Trinity River, in Rockwall, Texas. The contractor requested the use of precast caps on the eastbound structure to overcome some of the difficulties of cast-in-place construction on a long water crossing and to eliminate the need for a barge crane near a 345 KV power line on the south side of the structure. Using 43 site-precast bent caps saved nearly a week per cap on tasks associated with formwork, reinforcement, casting, curing and inspection.

Double-line grouted vertical duct connections were utilized to connect the precast caps to the cast-in-place columns. The grouted duct connection was chosen because it minimized the amount of connection grouting to be done in making each connection. Plastic ducts were used for durability since the duct went all the way up to the top surface of the precast caps. A reduction in development of capacity of the plastic duct over a galvanized metal duct for the given length was considered. The cast-in-place columns were held in exact position with respect to each other with the column formwork work platform and uncoated reinforcing bars were cast into the tops of the columns with the aid of a template. The precast caps were held in position with adjustable friction collars on the columns and a plastic collar formed the bedding layer at the tops of the columns. The friction collars allowed accurate setting of the cap elevation with precast bearing seats. A prepackaged non-shrink grout, meeting the specification as outlined in the research report, was used to complete the connection by pressure grouting through the plastic collar at the bedding layer up to the top of the ducts.

The design procedure developed under Project 0-1748 was extended for use on a hammerhead bent design with higher moments than the multi-column bents previously constructed with this technology, for the SH 36 bridge over Lake Belton currently under construction near Belton, Texas. This is a 3800-foot long structure over the lake used for the drinking water supply of Waco, Texas. The difficulties of cast-in-place concrete 40 foot above the water surface and the environmental concerns of the site dictated the use of precast bent cap construction. Weighing 160,000 pounds apiece, these are the largest precast caps TxDOT has undertaken to date.

Due to the hammerhead bent design there are three layers of main reinforcing bars in the top of the cap to provide sufficient moment capacity for the superimposed loads. This necessitated the use of a four-line grouted duct connection that did not extended the full height of the cap, except for four threaded bars in ducts used to temporarily hold the cap in place during connection grouting. Grout is pumped into the bottom of the galvanized metal ducts via a ¾ inch inlet tube just above the bedding layer and vented out of the top of each sealed duct by a ½ inch diameter tube. Different inlet and outlet tube sizes positively identify inlet tubes; the grout must be pumped in from the bottom and up to the top to drive air out of the connection. Due to aesthetic considerations in design, the limits of the bedding layer are oval in shape. This complicated sealing of the bedding layer before pressure grouting and necessitated the use of dry-pack grouting to seal the bedding layer. Aesthetics also made the use of friction collars difficult and dictated the use of shims to set bedding layer thickness and adjust cap elevation.

To ensure a good quality connection in the field and familiarity of contractor personnel with the necessary construction procedures, connection mock-up tests were done at the off-site precasting yard. A full-scale mock-up of the connection core in the cap and of the top of column with protruding connectors was cast. The connectors were smooth, however, to facilitate dismantling the specimen so that the connection integrity could be assessed. The cap core was set on shims, the edge of the bedding layer was dry-packed with grout and the connection was pressure grouted by contractor personnel. Dismantling of the specimen proved the dry pack and pressure grouting method was good, however excessive segregation and free water in the grout indicated the use of another grout in the structure. The mock-up tests illustrated that the dry pack grout must be a very dry mix to work properly but it will develop a seal for pressure grouting. Additional grout mix and grout pumping mock-up tests will be done before any connections are made in the bridge structure.

The contractor building The Dallas High Five Interchange, at the intersection of IH 635 and US 75 in Dallas, Texas requested a change from cast-in-place to precast caps to minimize lane closures for bent cap construction. These structures also utilize grouted duct connections for precast caps with ducts sealed at the top and filled by grout tubes. A double grout mixer and pump is utilized to ensure a constant flow of grout to the connections as much as 60 feet off the ground. The large single column inverted Tee caps are held in place temporarily during grouting operations by four ASTM A193 B7 threaded rods in full height ducts bolted on the top surface of the cap.

DEVELOPMENT OF FULLY PRECAST BRIDGE CONSTRUCTION SYSTEMS

TxDOT is currently developing fully precast bridge construction systems for use in locations such as important mobility hubs, high traffic volume areas, key travel routes, difficult construction access areas, or sites lacking a viable detour where speed of construction is of the utmost importance. Project 0-4176 "Development of Precast Bridge Construction Systems", initiated September 2001, is examining design, constructability and detailing issues for fully precast bridges. These are systems employing conventional foundations with hollow precast columns set in position and in-filled with reinforced cast-in-place concrete. Stacking components together and in-filling with concrete makes precast column connections. Abutment substructures are drilled shafts and precast columns set in front of mechanically stabilized earth retaining walls. In this way the earth retaining structure of the abutment can be built independently of the superstructure support portion of the abutment, as dictated by the site conditions to minimized impact on traffic. Tub girders (U section steel beams) are utilized at a spacing allowing elimination of the bent cap, simplifying construction. In a casting yard off site, full depth precast slabs are cast on to the tub girders blocked in their final position with connection strips formed for on-site connection of the full depth precast slabs. The weight savings of steel beams over concrete beams allow the beam and slab assembly to be light enough for a 100-foot span to be moved with conventional equipment. Project 0-4122 “Behavior of Cast-in-Place Slabs Connecting Precast Slab and Steel Girder Assemblies”, initiated September 2002, is examining the behavior and developing a design procedure for the longitudinal and transverse connections between the full depth precast slab and tub girder elements. The goal is to establish connections that can be made quickly, over traffic if necessary, so that a complete 2 span bridge superstructure could be erected in an 8-hour period.

DEVELOPMENT OF RAPID BRIDGE CONSTRUCTION SYSTEMS

TxDOT is also examining the rapid replacement of off-system bridges with Project 0-4375 “Innovative Design and Construction Methods for Off-System Bridges”, initiated September 2001. In this study university personnel in conjunction with representatives from fabricators, large and small contractors, counties, TxDOT and other DOT engineers are examining ways to construct smaller off-system bridges more quickly. Here site accessibility and heavy equipment available to the contractor are important issues. Spans are generally short but the contractor may not be able to get equipment to the other side of the bridge easily either due to channel accessibility or the low load rating of the existing bridge. Rapid replacement is necessary because a long detour could affect such issues as delayed response time for emergency services.

SUMMARY

The Texas Department of Transportation is implementing innovative precast and prefabricated design and construction techniques for bridges to reduce traffic disruption and construction project duration while enhancing safety for the motoring public and constructability for the contractor. Design and construction details were discussed and several projects where these ideas are implemented were presented. Several other TxDOT projects utilize this technology, but were not presented for brevity.

Precast and prefabricated bridge components can shorten construction project duration and enhance safety. They are best implemented in the early phases of the design process so that other aspects of the total project package such as roadway and bridge geometry and bridge aesthetics are still fluid enough to be molded to enhance the benefits of precast / prefabricated bridge construction. Replication of similar precast elements enhances speed of construction and economy of scale. Other issues to be considered are where the precast components will be fabricated and how they will be transported to the site and lifted into position, and how this will affect traffic movements. Also, how will inspection of the precast connections be done and what tests will be required for quality assurance. The total project package should be considered in maximizing the benefits of this technology.

The use of component and connection mock-up tests can be a very important quality assurance tool. This gives all parties involved familiarity with the techniques of prefabricated construction and is a good test for grout material properties and pumping techniques. All parties must achieve complete confidence in the successful execution of precast connections before a connection is made on the bridge structure.

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