PREFABRICATED BRIDGES – CURRENT U.S. PRACTICE AND ISSUES

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ABSTRACT

In 2001 the Technology Implementation Group (TIG) of the American Association of State Highway and Transportation Officials (AASHTO) selected prefabricated bridge elements and systems as an innovative technology that was ready for national implementation. The TIG created the Panel on Prefabricated Bridge Elements and Systems and charged it with extending the use of prefabricated elements and systems in bridge design and construction by increasing awareness of and confidence in innovative prefabrication, and by promoting the further development and refinement of this technology.

The panel’s and others’ national search for prefabricated bridge projects revealed a number of innovative projects being designed and constructed as specialty applications across the country. This paper discusses the current usage of prefabricated bridge elements and systems for bridges in the U.S., and a perspective on what is needed to further implement this innovative technology to make it the standard for high traffic volume locations.

Keywords: Prefabricated Bridge Elements and Systems, Prefabricated Bridges, Prefabrication, Superstructure Systems, Closure Joints, Substructure Systems, Precast Bent Caps, Self-Propelled Modular Transporters, Contracting Strategies, Incentives/Disincentives
INTRODUCTION

“Too often, ‘impossible dreams’ are looked at not as inspirational motivators to achieve great things, but rather as the subject of derision as foolish fantasies. Yet, it is just such goals that move us ahead as a civilization. … The highway community has its own ‘impossible’ dreams, such as roads without traffic fatalities and without congestion caused by construction.”

The State Departments of Transportation (DOTs) own approximately 286,000 bridges nationwide. Local governments own another 308,000 bridges. Of these 594,000 publicly-owned vehicular bridges greater than 20 feet in length, approximately a quarter – about 153,000 bridges – are currently either structurally deficient or functionally obsolete according to classifications by the Federal Highway Administration (FHWA). While many of these bridges are rehabilitated or replaced annually, about 3,000 additional bridges become structurally deficient or functionally obsolete each year. In addition, much of the highway system is reaching the end of its design or useful life, and traffic volumes and weights continue to increase.

The combination of current deficiency statistics and the impact of heavier and more frequent loads on an aging infrastructure caused the American Association of State Highway and Transportation Officials (AASHTO) Technology Implementation Group (TIG) to select prefabricated bridge elements and systems (PBES) as one of its first three ready-to-use technologies in 2001. Since that time, the PBES panel, in cooperation with FHWA, has been working to extend the use of prefabricated bridge elements and systems in bridge design and construction in two ways – by increasing awareness of and confidence in innovative prefabrication, and by promoting the further development and refinement of this technology.

During the past three years, the PBES panel and others have searched for innovative prefabricated bridge projects to promote across the country and have found a number of progressive applications of this technology. However, these projects are typically specialty applications rather than typical construction. Bridge design and construction must fundamentally change to meet the challenges of today and the future.

The fundamental change that must occur to meet today’s and tomorrow’s challenges is moving from conventional bridge design and construction to prefabricated bridge design and construction for high traffic volume locations, and in each case engineering the solution to meet the unique constraints at that location.

Bridges will then be installed in hours or days rather than months, thus minimizing impact to travelers and achieving the additional benefits of improved work zone safety and reduced traffic control costs. Other benefits, depending on the requirements at the site, may include minimized environmental impact and improved constructability. The controlled conditions during prefabrication also lead to improved quality of components
and lower life-cycle costs. Current practice and issues related to bridge prefabrication are discussed below.

SUPERSTRUCTURE SYSTEMS

Decks are typically the first major structural elements of a bridge to require maintenance or replacement. Therefore, emphasis has been placed on prefabricated deck systems to achieve quick deck replacements and to extend deck life. Whether for deck replacements on existing bridges or for decks as part of new prefabricated superstructures, deck prefabrication offers several advantages. Prefabricated deck replacement systems can be installed overnight, thereby limiting traffic disruption. Such systems are typically full-roadway-width panels with transverse closure joints to tie the panels together, as shown in Figure 1. Prefabricated superstructure systems may consist of beam/deck segments, with each segment a single beam or multiple beams, erected into place with longitudinal deck closure joints to tie the segments together, as shown in Figure 2. Alternatively, entire superstructure spans may be installed as a unit, as shown in Figure 3.

Fig. 1 Full-depth Precast Transverse Deck Panels used on the Dead Run and Turkey Run Bridges in Virginia on the George Washington Memorial Parkway

Fig. 2 Full-depth Longitudinal Prefabricated Superstructure Segments used in Virginia on Interstate 95 James River Bridge
Fig. 3 Entire Superstructure Span Installed in Louisiana on Interstate 10 Bridge over Lake Ponchartrain

CLOSURE JOINTS

Deck closure joints, whether transverse or longitudinal, present the biggest challenge to achieving long-term durability with minimum maintenance during the life of the structure. While the prefabricated segments are constructed in controlled environments where constant mix proportions and curing can be more easily achieved, the closure joint pours are exposed to the variability inherent in field construction. In addition, closure joints must be designed to distribute loads laterally without distortion, and the interface between the prefabricated components and the closure joint must be sealed to prevent moisture from leaking through the interface. Three general classes of closure joints are typically used: post-tensioned joints, passively reinforced joints, and welded or bolted joints. Most use some form of shear key infilled with non-shrink cementitious grout or custom-designed concrete mix.

Post-tensioned joints, as shown in Figure 4, use the induced compression to close shrinkage cracks at the joint interface, prevent cracking under live load, and enhance load transfer. The post-tensioned joints can be a female-female shear key arrangement infilled with grout or match cast with epoxied joints if precise tolerances can be maintained. While providing assurance of good long-term performance, post-tensioning requires an additional step and complexity during onsite construction.

Fig. 4 Post-tensioned Longitudinal Joints Match Cast with Shear Keys on Interstate 95 James River Bridge Replacement
Passively reinforced joints, as shown in Figure 5, use some form of projecting lapped reinforcing steel and custom-designed concrete mix for load transfer. The lapping of steel may be achieved with overlapping looped bars or short straight bars whose development is improved by the geometry of the joint or by external means such as confining spirals. The greater widths that are typical for these types of joints, relative to post-tensioned or welded/bolted joints, may increase the likelihood of shrinkage cracking and may require erecting and wrecking formwork from below. Cure time for the closure concrete may become a critical path activity as well.

Fig. 5 Examples of Cast-in-place Closure Joints with Passive Reinforcing Steel
Welded or bolted joints use steel connectors in conjunction with a grouted keyway. For the welded type, vertical or inclined weld plates are cast into a prefabricated concrete member at a discrete spacing. The plates, spaced anywhere from 4 ft to 8 ft, are typically anchored into the member with shear studs or deformed bar anchors. Connection plates inserted and welded in the field, as shown in Figure 6, connect adjacent precast superstructure members. The connectors resist the tensile forces due to differential twisting from live load and provide clamping force to mobilize the shear strength of grouted keyway. Bolted joints are typically used with proprietary precast deck panel and superstructure systems.

Fig. 6 Examples of Welded Connection between Precast Pretensioned Beams

A number of research projects have been conducted on prefabricated bridge systems\(^{10,11}\), including deck closure joints. In the mid-1980s, the National Cooperative Highway Research Program (NCHRP) Project 12-24, “Design of Multi-Beam Precast Bridge Superstructures,” looked at closure joint lateral distribution and connection details for prefabricated deck systems\(^{12}\). The project gave recommendations for the design of grouted keyways and steel connectors between multi-beam precast members.

Recent research sponsored by TxDOT has led to the connection detail shown in Figure 7\(^{13}\). An advantage of this detail is the simplicity of the continuous lateral connector rod with 8-inch weld at 5-ft intervals that also serves as the bottom form for the vee-shaped grout closure pour. The research showed that this system performed well without a composite deck topping. The first use of this detail is for a double-tee bridge currently being designed to include an asphalt overlay. TxDOT envisions this system could also be constructed without an asphalt overlay by providing up to 2 inches of additional sacrificial deck thickness, depending on estimated beam camber and desired profile grade, to allow grinding for the final ride surface.

GROUTS, CONCRETES, AND SEALANTS FOR JOINTS

Non-shrink cementitious grouts are typically specified for the smaller closure joints, and standard or special concrete mixes for larger joints. Researchers have indicated that
Alternate materials such as magnesium ammonium phosphate mortars and polymer modified concretes exhibit superior bond strength, greater compressive strength, and lower permeability. Currently, many owners consider these materials risky, given the care and expertise required for their installation. More information on the long-term durability and ease of construction is needed to implement these materials.

Fig. 7 Recent Texas Lateral Connection Detail for Double-Tee Bridges

The interface between the precast deck and the cast-in-place closure is of particular concern since cracks can develop due to shrinkage or poor bonding from the outset, and grow under the application of live loads. Prior to grouting, the precast interface surfaces should be sandblasted and water washed to remove laitance and enhance bond. The precast faces should be kept moist prior to grout installation, and the grout cured with the aid of moisture. A penetrating sealant should be applied to the top surface of grouted joints after curing to enhance durability, and a super-low viscosity epoxy should then be
applied to the interface between the precast deck and the cast-in-place closure to seal cracks that may develop.

ACHIEVING RIDE QUALITY

In conventional bridge construction, overlays with waterproofing membranes are used by some States to help seal the bridge deck concrete from exposure to moisture and deicing salts. Today’s availability of low permeability concretes and corrosion-resistant reinforcing steels allows owners to forego the use of overlays on bridge decks. With prefabricated superstructure construction, the challenge is to develop methods that achieve the final ride surface without the use of overlays. While the application of an overlay helps overcome finite geometric tolerances, it also requires another significant critical path activity prior to opening a structure to traffic. An attractive option is diamond grinding decks with sacrificial cover to obtain the desired surface profile. Such a method is faster and generally more cost effective. If an overlay cannot be avoided, the application of a thin bonded epoxy overlay offers an adequate alternative.

CURRENT RESEARCH

TxDOT is sponsoring Research Project 4122 “Behavior of Cast-in-Place Slabs Connecting Precast Slab and Steel Girder Assemblies.” The researchers are testing the strength and service performance of the connection shown in Figure 5(c), which will form the longitudinal joint between precast girder assemblies.

Two ongoing NCHRP projects also concern prefabricated bridge deck systems. NCHRP Project 12-65, “Full-Depth, Precast-Concrete Bridge Deck Panel Systems,” was initiated in mid-2003 and is to be completed in early 2006. Its purpose is to develop connection details for full-depth precast concrete deck systems for steel and prestressed concrete girders, and to develop guidelines and proposed specifications for the design and construction of these systems. NCHRP 12-69, “Design and Construction Guidelines for Long-Span Decked Precast, Prestressed Concrete Girder Bridges,” was initiated in mid-2004 and is to be completed by mid-2007. Its purpose includes development of design and construction guidelines for constructability and performance of connection details between adjacent long-span integrally-decked concrete girder units.

As can be seen, significant research is being conducted on connection details for prefabricated deck systems to simplify construction and ensure good long-term performance without the need for an overlay.

SUBSTRUCTURE SYSTEMS

Several examples of prefabricated substructure systems have been constructed, although these systems have not been researched or constructed to the extent of prefabricated deck systems. By precasting substructure elements, time intensive operations such as erection and wrecking of forms, placement of reinforcing steel, and placement and curing of
concrete are avoided. If soil conditions permit, precast prestressed piles or steel piles can be used as foundation elements. For shorter substructures such as trestles over streams or bays, these piles can extend to the level of the precast cap, as shown in Figure 8. For taller substructures or substructures employing drilled shaft foundations, hollow core prefabricated column elements may be used, as shown in Figure 9. If the column is short enough, the entire column length can be prefabricated as a unit. Otherwise multiple column segments can be post-tensioned together. The hollow core columns can act as stay-in-place forms for cast-in-place void concrete that can form the connection to the foundation and provide resistance to vehicle impact in the case of grade separations. Also, steel column/cap systems, as shown in Figure 10, can be quickly installed.

Fig. 8 Precast Trestle Pile Bent Construction in Texas on SH 361 over Redfish Bay

Fig. 9 Segmental Precast Columns in New York on Interstate 287 Cross Westchester Expressway Viaducts
The most common prefabricated substructure construction to date has been the precast bent cap. Precast bent caps, as shown in Figure 11, offer a number of advantages related to speed, constructability, and work zone safety depending on the constraints at the site. Recent research at the University of Texas at Austin has been completed on the development of a precast bent cap system for non-seismic regions\(^ {17} \). This research addresses three types of precast cap-to-substructure connection details – grout pockets, grouted vertical ducts, and bolted connections – and includes a design methodology, construction guidelines, connection grout specifications, and example connection details. Research and design methodologies are also needed for precast bent cap-to-column connections used in seismic regions. Accordingly, a research problem statement to address this need has recently been submitted by the AASHTO Highway Subcommittee on Bridges and Structures for proposed NCHRP funding.
Abutments, as shown in Figure 12, have the dual function of supporting the bridge superstructure and resisting the pressures of embankments, and usually can be classified as perched or stubbed types. In addition to cap elements, abutments will most likely involve some combination of backwalls, headwalls, and wingwalls. Precast abutments typically involve grouted reinforcing bar couplers or weld plate connections. For speed of construction, these abutments will often be backfilled with flowable fill.

Fig. 12 Examples of Precast Abutment Construction

Multiple repetitive substructures with similar details are needed on a project for prefabricated substructures to be cost competitive for an off-site fabricator who must obtain forms prior to first use. Alternatively, a contractor may choose to precast the elements adjacent to the bridge site; in this case, cost competitiveness is obtained because the precasting can be done concurrently with other work onsite to reduce the construction timeline, and the need for repetitive elements is not as critical. Once steel forms are made on the first large jobs and standard drawings are available on the internet, prefabricated substructures will become more cost competitive for smaller projects.

PREFABRICATED BRIDGES MOVED INTO POSITION

The most revolutionary bridge construction method is moving the entire single- or multi-span bridge or bridge superstructure to its final location with self-propelled modular transporters (SPMTs). This innovative construction method is currently used in the U.S. for specialty work, and has been increasingly looked at recently due to the significant need to reduce traffic disruption and improve work zone safety at bridge construction sites. This technology allows the installation of a bridge in hours, to dramatically reduce traffic disruption and improve work zone safety.

Each bridge installation must be engineered for the constraints at the site, to determine to what extent prefabrication can be used to reduce onsite construction. An upcoming project in Texas demonstrates this process. First, departmental bridge engineers and a
SPMT equipment supplier visited the existing bridge site at IH-35 and Hill Road in Central Texas, shown in Figure 13. The IH-35 Mainlanes have an average daily traffic count of 48,000 at this location.

![Fig. 13 Site Photo of Existing IH-35 at Hill Road Bridges in TxDOT’s Waco District](image)

At 270 feet each, the two proposed bridges are significantly longer than the two existing 114-ft bridges, as shown in Figure 14.

![Fig. 14 Elevation & Plan Comparison of Existing & Proposed IH-35 at Hill Road Bridges](image)

A brainstorming meeting was then held to determine if the use of SPMTs could reduce traffic disruption. The solution that was reached involved the following sequence that requires only one overnight detour of one direction of mainlane traffic onto a frontage road:

1) Build Phase I approaches and new Phase I and II bridges, with Phase II bridge built in Phase I bridge's final location and Phase I bridge built adjacent to Phase II bridge between Phase II bridge and Northbound frontage road. (Note: Phase II final bridge location overlaps with existing Northbound mainlane bridge.) See Figure 15.
Fig. 15 Sequencing of Phases I and II for IH35 at Hill Road Bridge Construction

2) Route Northbound mainlane bridge traffic onto Phase II bridge that is in Phase I bridge's final location.

3) Take out existing Northbound mainlane bridge.

4) Build Phase II approaches and Phase II bridge's drilled shafts (and abutments and bents if subsequent move doesn't include them).

5) Detour Northbound mainlane traffic currently on Phase II bridge in Phase I location, to Northbound frontage road for one overnight period (on a Monday, Tuesday, or Wednesday night). Roll Phase I and II bridges into final locations.

6) Route Northbound mainlane traffic from Northbound frontage road onto Phase I bridge, and Southbound mainlane traffic from old Southbound mainlane bridge onto Phase II bridge.

Building bridges near site and moving them to their final location can significantly minimize traffic disruption and improve work zone safety. Conventional construction, even with high cement content to achieve rapid early concrete strength gain, would require significant mainlane traffic detours. In addition, the high cement content could reduce long-term durability.

TYPICAL MINIMIZED TRAFFIC DISRUPTION CLOSURE TIMES

As demonstrated in the IH-35 at Hill Road example discussed above, innovative prefabricated bridge systems and innovative technology (e.g., SPMTs) can be used to minimize the traffic disruptions that are associated with conventional construction. This project and others nationwide reflect that replacement of bridges with reduced closures – hours, overnight, or weekends – are becoming more typical. Table 1 gives examples of bridge projects that used prefabricated components to significantly reduce traffic disruption.
Table 1 Bridge Projects that Significantly Reduced Traffic Disruption

<table>
<thead>
<tr>
<th>Closure Times</th>
<th>Project</th>
<th>Location</th>
<th>Disruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours</td>
<td>IH 10 over Lake Ponchartrain</td>
<td>Louisiana</td>
<td>Replaced a 65-ft long by 46-ft wide 350-ton span in less than 24 hours.</td>
</tr>
<tr>
<td>Overnight</td>
<td>IH 95 over James River</td>
<td>Virginia</td>
<td>Replaced approximately 100 superstructure spans, with no impact to rush-hour traffic.</td>
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<tr>
<td></td>
<td>Tappan Zee Bridge, New York State Thruway</td>
<td>New York</td>
<td>Replaced 250,000 square feet of deck, with no impact to rush-hour traffic.</td>
</tr>
<tr>
<td>Weekend</td>
<td>SH 86 over Mitchell Gulch</td>
<td>Colorado</td>
<td>Replaced 44-ft long by 44-ft wide span in one weekend.</td>
</tr>
<tr>
<td></td>
<td>Baldorioty de Castro Avenue Overpasses, San Juan</td>
<td>Puerto Rico</td>
<td>Erected four bridges (2 at 700 ft and 2 at 900 ft) each over two weekends, with no impact to rush-hour traffic.</td>
</tr>
<tr>
<td>Overnight plus Weekend</td>
<td>Lewis and Clark Bridge, SR 433 over Columbia River</td>
<td>Washington / Oregon</td>
<td>Replaced deck on 34 spans with overnight work plus four weekend closures, with no impact to rush-hour traffic.</td>
</tr>
</tbody>
</table>

Note: Projects may be found at the FHWA Prefabricated Bridges website.

CONTRACTING STRATEGIES

Contract documents must clearly specify traffic-impact constraints, time constraints, and incentives/disincentives for early completion of projects in high traffic volume locations. The incentives/disincentives must have a high enough dollar value to make it worthwhile for contractors to change their typical operations to achieve the reduced traffic disruption timelines.

Examples of contracting strategies to obtain early delivery of the project may include the following:
- Liquidated damages – financial penalties for late delivery
- A+B bidding – cost-plus-time bidding, based on a combination of contract bid items (A) plus the time bid for construction multiplied by daily road user cost (B)
- Incentive/disincentive – financial bonus or penalty for delivery before or after a set time, with a typical specified maximum
- No-excuse bonus – modified incentive with no time adjustment for problems such as weather, utility conflicts, etc., regardless of who is responsible
• Lane rental – assessed rental fee for lanes taken out of service during temporary lane closures for construction
• Calendar day – project schedule based on a number of days for completion, instead of days where work activities take place, effectively transferring weather risks to the contractor
• Work week definition – used in combination with the “calendar day,” can define the number of days a week where work activities take place (5, 6, or 7)

CONCLUSIONS

The fundamental change that must occur to meet today’s and tomorrow’s challenges is moving from conventional bridge design and construction to prefabricated bridge design and construction for high traffic volume locations, and in each case engineering the solution to meet the unique constraints at that location. To facilitate use of prefabrication to minimize traffic disruptions, owners must also specify allowable closure times in their contracts and enforce them with incentives/disincentives that are high enough to be a primary consideration for the contractor.

The impossible can become possible with attention to detail and the use of innovative prefabricated systems to install bridges onsite in hours or days compared to the months that are required for conventional construction, or overnight or over weekends with no impact to rush-hour traffic. Significant prefabricated bridge research, design, and construction are ongoing because of the significant needs and demands of the traveling public, and the multiple advantages that can be achieved with prefabricated bridge elements and systems – minimized traffic disruption, improved work zone safety, minimized environmental impact, improved constructability, improved quality, and reduced life-cycle costs. AASHTO, FHWA, State DOTs, and their consultant, industry, and academic partners are continuing to provide leadership to further improve these systems and facilitate their use.

REFERENCES


