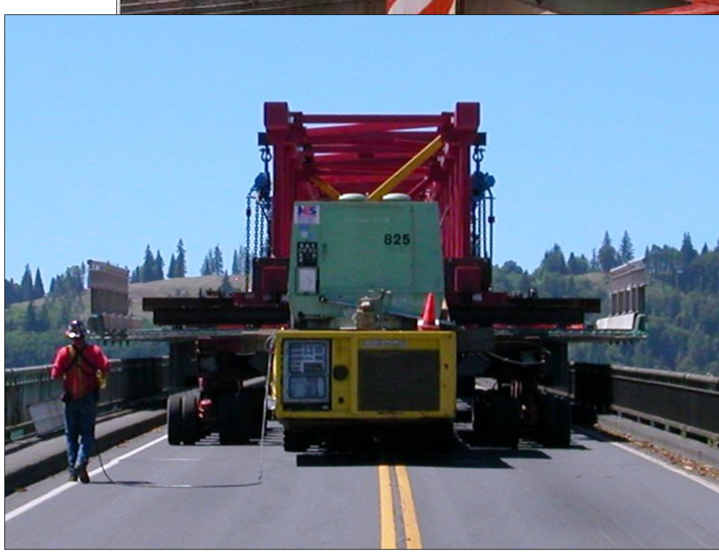







Benefits & Costs of Prefabricated Bridges

by Mary Lou Ralls, P.E.

as part of UDOT-sponsored Accelerated Bridge Construction Study

May 2008

Benefits and Costs of Prefabricated Bridges

Introduction

The mission of state Departments of Transportations (DOTs) is to provide safe, effective, and efficient movement of people, goods, and services on the nation's highways. This movement, however, is being negatively impacted by congestion and an aging bridge inventory.

In 2005, congestion caused motorists to waste 4.2 billion hours and 2.9 billion gallons of gas, for a $78 billion economic cost.[1] Each year a typical peak-period traveler wastes 38 hours and 26 gallons of gas due to congestion, for a cost of $710. Congestion in the nation's urban areas is getting worse, and solutions to this congestion are being implemented at rates below the rate of travel demand growth.[1]

At the same time as congestion is increasing, the nation's aging and heavily used bridges are requiring increasing rehabilitation and replacement. As of December 2007, 25 percent or about 150,000 of the approximately 600,000 publicly owned vehicular bridges in the U.S. were classified as structurally deficient or functionally obsolete, for a total deficient deck area of 90.4M sq m (973M sq ft).[2]

Increasing congestion combined with an increasing need for bridge rehabilitation and replacement while maintaining traffic flow are making it imperative that bridges be built faster to last longer. Prefabricated bridges are one solution to address this need. The American Association of State Highway and Transportation Officials (AASHTO) Technology Implementation Group (TIG) recognized the benefits of prefabricated bridge elements and systems (PBES) in 2001 with the selection of PBES as one of three market-ready focus technologies to promote nationwide in conjunction with the Federal Highway Administration (FHWA). In 2004 an international scan on PBES was co-sponsored by the FHWA, AASHTO, and the National Cooperative Highway Research Program (NCHRP) to bring PBES innovations from Europe and Japan to the U.S.[3] The FHWA Office of Bridge Technology and Highways for LIFE Program have provided additional funding for ABC projects with PBES and have sponsored a number of PBES technology transfer tools and workshops in cooperation with the State DOTs to help spread the word about advancements in accelerated bridge construction (ABC) with PBES. With this assistance, significant progress has occurred in the use of PBES for ABC. This paper discusses the transition in prefabricated bridges and associated benefits and costs.

Transition from Constructed-in-Place to Prefabricated Bridges

Prefabricated bridges have elements or systems constructed in an offsite controlled environment, followed by transport to the site for rapid installation. The materials for these prefabricated elements and systems have typically been concrete or structural steel, with a few others such as fiber-reinforced polymers (FRP) for deck panels. Enhancements may include the use of lightweight concrete to reduce dead load of these larger components.

Prefabrication of bridge components is not new. Primary supporting members for superstructures have historically been constructed of reinforced concrete, structural steel, or timber, with the use of prestressed concrete beginning in the 1950s. Over 76,000 publicly-owned vehicular bridges were constructed in the U.S. from 1999 to 2003 as reported by the Portland Cement Association (PCA), Table A.5.[4] Of those bridges, almost half were prestressed concrete (pretensioned or post-tensioned) main-span primary supporting members, slightly over a quarter were structural steel, slightly over a fifth were reinforced concrete, and the remaining four percent were timber. As shown in Table A.5 of the PCA report,[4] about half of the states now use prestressed concrete beams for the majority of their bridge construction.

State DOTs across the country are using various forms of prefabrication in their bridges, from beams as discussed above to more innovative prefabricated components such as full-depth deck panels and precast bent caps.[5] Most recently several states are moving entire prefabricated superstructures into position.

The focus of the recent national initiatives by the AASHTO TIG and FHWA is the newer more innovative prefabricated bridge elements and systems, e.g., bent caps, abutments, full-depth deck panels, and totally prefabricated superstructure and substructure systems. Below are examples of the use of prefabricated bridges by two states.

Use of Prefabricated Bridges in Alabama

As shown in Table A.5 of the PCA report discussed above,[4] Alabama constructed approximately 1,500 bridges from 1990 through 2003. Of those bridges, just under half of the bridge superstructures' main-span primary supporting members were reinforced concrete, almost a third were prestressed concrete, about a tenth were structural steel, and the remaining eight percent were timber.

A portion of the reinforced concrete bridges are being built with Alabama DOT (ALDOT) standards for low-traffic-volume totally prefabricated bridge systems, which have been used in Alabama for the past 40 years.[6] These standards are available on the ALDOT website and include precast reinforced concrete slabs and precast reinforced concrete barrier rails for its superstructures and precast reinforced concrete abutment panels and precast reinforced concrete bent caps for its substructures.[7] Roadway widths for these standards are 24 ft, 24.5 ft, and 28 ft, with a standard adaptation for a 35-ft wide roadway. Span lengths are 24 ft, 34 ft, and 40 ft. ALDOT has designed individual bridges with similar details and wider roadways. Foundations for these standard bridges are typically its standard steel piles although its standard pretensioned concrete piles are used on the Gulf Coast.[6] These standards are currently being updated for the AASHTO LRFD specification.

ALDOT's totally prefabricated bridge standards are primarily used by cities and counties and typically can be built in one to two weeks. Alabama precasters stockpile them at their own expense for use in subsequent projects for low-traffic-volume bridges, defined as bridges with average daily traffic volumes of 4,000 vehicles or less.

Evolution of Prefabricated Bridge Use in Texas

The Texas Highway Department was established in 1917, and a year later a bridge office was created primarily to prepare standard designs and drawings to bring uniformity to bridges being built by the counties.[8] Prefabricated steel beam bridges were constructed since the early days, with continuing enhancements such as replacing field splice rivets with welding in the early 1950s. In the mid-1950s the department's Bridge Division, created in 1928, developed its first set of standard precast pretensioned concrete beams (for use with cast-in-place concrete decks) in cooperation with the state's precasters, and these standards "quickly proved to be the most economical way to construct medium-span length bridges." [8] They were initially developed for medium-span stream crossings and grade separations because of rising costs and slow delivery of steel beams.

As shown in Table A.5 of the PCA report discussed above,[4] Texas constructed approximately 5,800 bridges from 1990 through 2003. Of those bridges, over half of the bridge superstructures' main-span primary supporting members were prestressed concrete, almost a quarter were structural steel, about an eighth were reinforced concrete, and the remaining five percent were timber.

Today TxDOT's pretensioned concrete beam spans typically range to a maximum 135 ft, with spans up to 175 ft in special cases depending on site accessibility.[8] TxDOT provides an online Load and Resistance Factor Design (LRFD) Bridge Design Manual [9] to document bridge design policy in Texas and assist Texas bridge designers in applying the AASHTO LRFD specification. TxDOT's online bridge standards have been updated to be consistent with the LRFD specifications.

Standard Beam Types

The most common superstructure beam types used in Texas construction are TxDOT's standard precast pretensioned concrete I-beams, standard precast pretensioned slab beams, standard precast pretensioned box beams, standard precast pretensioned U-beams, and standard steel I-beams.

The Bridge Division considers its standard precast pretensioned concrete double tee beams and recently issued standard precast pretensioned decked slab beams to be its ABC superstructure systems since those beams do not require a cast-in-place deck.

Details for all TxDOT's standard beams (prestressed, steel, and cast-in-place) are available on its bridge standards website.[10] An online "Guide to Bridge Standard Drawings" is also available there.

Standard Superstructure Spans and Substructures

In addition to standards for superstructure beam types, standards are also available on TxDOT's website for pretensioned concrete I-beam superstructure spans of varying span lengths with 24-ft, 28-ft, 30-ft, 38-ft, and 44-ft roadway widths, and for pretensioned concrete slab beam superstructures and steel I-beam superstructures of varying span lengths with 24-ft, 28-ft, and 30-ft roadway widths. These standard spans require cast-in-place concrete for at least the top half of a composite deck. The pretensioned concrete I-beam and steel I-beam standards allow the use of standard partial-depth precast concrete deck panels or standard permanent metal deck forms as stay-in-place forms. Substructure standards for these superstructure spans are also included but are currently only for cast-in-place concrete construction.

The plan sheets for about two-thirds of the bridge projects are typically not assembled from these standard span and substructure sheets because of complicated and variable bridge geometry. For such cases, unique span and substructure sheets are prepared using the beam standards and supplemental standards.

Supplemental Standards

TxDOT has developed various supplemental standards to go with its beam standards. These include standards for partial-depth precast concrete deck panels, permanent metal deck forms, railing, retaining walls, approach slabs, armor joints, lighting details, mounted clearance signs, piling, riprap, common foundation details, minimum erection and bracing requirements, optional drilled shaft reinforcing, sealed expansion joints, elastomeric bearings, and others. These standards are available on its website.[10]

Standard Partial-Depth Precast Concrete Bridge Deck Panels

Since 1963 TxDOT has allowed the option of partial-depth deck panels in its bridge construction.[8] Through the years it has sponsored significant research to develop details that provide good long-term performance, and its research has shown that a deck with partial-depth deck panels is stronger, stiffer, and more crack-resistant.[11] The precast pretensioned panel standard has evolved to its current four-inch thickness, with cast-in-place concrete completing the top half of the composite deck.

Panel use increased after the bid item “Reinforced Concrete Slab” was changed to measurement by square foot with contractor option to use TxDOT’s stay-in-place partial-depth deck panel standard or permanent metal deck form standard.[8] Partial-depth precast pretensioned concrete deck panels are now the contractor’s preferred choice for bridge construction in Texas due to the speed and improved safety of construction and the lower cost relative to full-depth cast-in-place concrete deck construction.[12]

Full-Depth Precast Concrete Bridge Deck Panels

In 1988 TxDOT experimented with full-depth deck panel construction on a rehabilitation project, Spur 326 Bridge over AT&SF Railroad in the city of Lubbock.[13] The experimental panels were placed in one span only. TxDOT’s next application was in 1995 when full-depth deck panels were used in the four tied arch bridges over U.S. 59 at Dunlavy, Hazard, Mandel and Woodhead Streets in Houston.[13] The third TxDOT project to use full-depth deck panels was the Live Oak Creek Bridge in Crockett County built in 2008 with full-depth deck panels using details from the NCHRP 12-65 Project, “Full-Depth, Precast-Concrete Bridge Deck Panel Systems”.[14] The NCHRP 12-65 research objective was to develop panel details with no post-tensioning or overlay.

Currently TxDOT does not have standards for full-depth precast concrete deck panels.

Precast Bent Caps

TxDOT has used prefabricated bent caps as part of bridge substructures on several projects in the past decade. In 1997 steel and precast concrete bent caps were constructed on existing columns in the I-45/Pierce Street Elevated Bridge rehabilitation project in the Houston central business district; a total of 226 spans were replaced in 190 days.[13] In 1994 precast bent caps on precast concrete piles were used on the State Highway 361 over Red Fish Bay and Morris and Cummings Cut bridge replacements along the Gulf Intracoastal Waterway near Port Aransas; the use of precast bent caps was a contractor-initiated change to minimize concrete operations over water.[13]

Because of the success of these projects in terms of construction speed and cost, TxDOT initiated research to formally develop a precast concrete bent cap system.[15] The details developed in the TxDOT-sponsored research project 0-1748,[16] "Design and Detailing of a Precast Concrete Bent-Cap System," were used in 2002 for the precast bent caps on the State Highway 66 over Lake Ray Hubbard bridge replacement near Dallas[13]; the contractor initiated a field change from cast-in-place to precast caps because of safety concerns related to working over water near power lines (see Appendix D for case study). Then in 2004 precast bent caps were constructed on the State Highway 36 over Lake Belton Bridge near Waco. The Lake Belton Bridge caps were hammerhead bents with the highest-moment-demand cap-to-column connections used with precast caps in Texas.[13]

TxDOT is currently considering the development of standards for precast bent caps.

Totally Prefabricated Bridges

In 1961 TxDOT constructed its first totally prefabricated superstructure, the State Highway 35 bridge over Lavaca Bay between Port Lavaca and Point Comfort.[13] Known as the Lavaca Bay Causeway, the 11,900-ft bridge is one of the longest bridges in Texas. Multiple identical spans made prefabrication of the superstructure the most economical construction method. Except for the three-span continuous steel unit over the navigation channel, the spans were 150-ton precast post-tensioned units. Each of the 192 identical spans was prefabricated on shore and consisted of girders, slab, diaphragms, center median, curb, sidewalk, and parapet walls; they were individually barged to the site and hydraulically lowered into place.

In recent years TxDOT has built several prefabricated bridge superstructures, including County Road 453 over Battleground Creek Bridge in Coupland, which won a Precast/Prestressed Concrete Institute design award in 2006.[17] Battleground Creek Bridge was one of the first bridges built with TxDOT's new pretensioned concrete decked slab beam, now an ABC standard.

In 2007 TxDOT completed its first four totally prefabricated bridges, the Loop 340 bridges over I-35 south of Waco in central Texas.[18] To minimize traffic disruption along the I-35 corridor, both the superstructure and substructure were prefabricated. A total of 104 pretopped pretensioned concrete Type PTU-34 U-beams were transported from the fabrication plant to a staging area approximately a mile from the bridge site. At the staging area composite concrete toppings were cast over the beams, with longitudinal closure joints between beams and transverse closure joints over the interior supports cast after erection. The individual piers were precast concrete shells fabricated in the contractor's staging area, transported and erected at the bridge site, and filled with cast-in-place concrete including footing on conventionally constructed drilled shafts.

Currently TxDOT does not have standards for totally prefabricated bridges.

Benefits of Prefabricated Bridges

Many of the benefits of prefabricating bridges have been described above for specific projects. A significant advantage of prefabrication is the reduced amount of construction work required at the bridge site, thereby decreasing onsite construction time. Various benefits that can result from prefabrication are listed below.[19]

- Reduced traffic disruption, e.g., fewer queues, lane closures, detours
- Improved safety, e.g., less time in the work zone; more rapid emergency bridge replacements
- Reduced impact to other transportation modes, e.g., to railroads or navigable waterways beneath the bridge
- Reduced environmental impact, e.g., in wetlands
- Reduced economic impact, e.g., shorter adverse impact to local businesses
- Reduced social impact, e.g., shorter disruption to school routes
- Improved constructability, e.g., reduced weather delays; repeatability
- Improved quality due to controlled production environment
- Lower initial construction costs due to standardization of identical components
- Lower life-cycle costs due to improved quality.

Improved quality can be achieved in the controlled environment of the prefabrication plant or yard. Concrete components that are fabricated using consistent materials and processes with adequate time for concrete curing can be anticipated to provide better long-term performance. Connection details for prefabricated elements, e.g., field-constructed closure joints, must be properly designed and constructed to ensure good long-term performance of the entire system.

Constructability may drive the use of prefabrication as the preferred construction method. As discussed above for specific projects, contractors have requested field changes to prefabrication to improve their construction operations, e.g., with multiple identical components, when working over water or near power lines, or at sites that are more prone to traffic accidents in the work zones.

Prefabrication can also reduce environmental impacts in sensitive regions such as wetlands and in urban areas with air, water, or noise pollution limits. Short construction seasons due to climate zone or nearby endangered species can also be accommodated with the shorter construction timeline of prefabricated construction, and long haul distances for ready-mix concrete batching plants may make prefabrication the only feasible construction method.

Conversely, site or other constraints may cause challenges to the use of prefabrication. Examples include limitations of transport routes and site accessibility constraints that limit handling of prefabricated components or the use of heavy lifting equipment.

The FHWA *Framework for Prefabricated Bridge Elements and Systems (PBES) Decision-Making*[19] or other decision-making tool should be used in the initial planning phase to ensure cost-effective use of prefabricated bridges.

Costs of Prefabricated Bridges

Costs related to the construction of prefabricated bridges can be broken down into initial construction costs and delay-related user costs. As discussed above, life-cycle costs can be expected to be lower because of the improved quality of the prefabricated components, provided the field closure joints between the prefabricated components are designed and constructed for long-term durability. Life-cycle costs will not be discussed further in this section.

Construction Costs

The reduced onsite construction time of prefabricated bridges results in reduced costs for such daily activities as traffic control, contract administration, and mitigation of environmental impact. In addition to the reduced costs related to the reduced onsite construction time, prefabricated components can result in the least fabrication costs when these components are standardized for repeated use. Construction costs for prefabricated bridges in several state DOTs are discussed below.

Alabama Department of Transportation (ALDOT)

The Alabama DOT's low-traffic-volume standard totally prefabricated bridges have historically been slightly higher in cost than its more typical bridges with pretensioned concrete I-beams because of the small number and size of these standard bridge projects. Recently these construction costs have become comparable.[6] For FY 2007 Alabama bridges with standard AASHTO pretensioned concrete I-beams averaged $80 per sq ft deck area compared to their low-volume standard precast bridges that averaged $68 per sq ft.[6]

Texas Department of Transportation (TxDOT)

TxDOT has used prefabricated bridge elements for half a century and has a significant online selection of standards.[10] As shown in Appendix A, in FY 2007 TxDOT constructed a total of 364 on- and off-system span bridges, with 341 bridges or 94 percent prefabricated with prestressed concrete beams (319 bridges) or steel beams (22 bridges). These bridges typically have partial-depth pretensioned concrete deck panels in the lower half of the deck, with cast-in-place topping to complete the composite deck. Only 23 bridges used cast-in-place concrete for primary supporting members. Looking at the square footage of deck area, prefabricated beam bridges account for over 99% of the 6.46M sq ft of deck area constructed in FY 2007.

The fact that prestressed concrete beams have become the most common primary supporting members in superstructures in Texas attests to the cost competitiveness of prefabrication. Starting in the 1950s, they now dominate the Texas market. Texas has very economical bridge construction unit costs, at an average $78.28 per sq ft deck area for on-system bridges and $69.22 per sq ft for off-system bridges in FY 2007. Looking at FY 2007 average unit costs for specific beam types, pretensioned concrete I-beams and pretensioned concrete U-beams are the most economical on-system bridge beams at $50.67 and $48.91 per sq ft, respectively, and pretensioned concrete I-beams are the most economical off-system bridge beam at $56.29 per sq ft.

Also shown in Appendix A are the numbers for FY 2006. Similar to FY 2007, in FY 2006 TxDOT constructed a total of 492 on- and off-system span bridges, with 461 bridges or 94 percent prefabricated with prestressed concrete beams (443 bridges) or steel beams (18 bridges). Only 31 bridges used cast-in-place concrete for primary supporting members. Looking at the square footage of deck area, prefabricated beam bridges account for over 97% of the 7.64M sq ft of deck area constructed in FY 2006.

For FY 2006, the Texas average unit costs were again relatively low, at $60.02 per sq ft deck area for on-system bridges and $67.91 per sq ft for off-system bridges. Looking at specific beam types, the average unit costs for pretensioned concrete I-beam and U-beam on-system bridges were again relatively low at $52.92 per sq ft and $54.02 per sq ft, respectively, and pretensioned concrete I-beam off-system bridges were again relatively low at $52.92 per sq ft although a couple small-volume cast-in-place concrete bridge types had lower average costs.

Some of the newer prefabricated elements and systems that are designed and constructed on a project-by-project basis may have initial construction costs that are higher than conventional construction methods. One example is the Lake Belton Bridge precast bent caps project mentioned above. The cost of the precast caps was an additional $400,000 of the total $19.6M project cost, or about two percent, with the 62 precast caps reducing onsite construction time more than six months.[12] Another example is the County Road 453 over Battleground Creek Bridge in Coupland discussed above. This was one of the first projects using TxDOT's new decked slab beam type, now a standard, that includes the deck in its cross section to accommodate accelerated bridge construction in the field. It cost approximately 10 percent more than a conventionally designed bridge but was completed in about two months, or four times faster than conventional bridge construction.[17] Lower initial construction costs can be expected with repeated use of this superstructure section as a standard.

Since totally prefabricated bridges (bridges with prefabricated superstructures and substructures) are also currently designed on a project-by-project basis and not standardized, costs for these bridges may also be higher if delay-related user costs are not included. Such is the case for TxDOT's first four totally prefabricated I-35/Loop 340 bridges recently constructed near Waco, also discussed above. The initial construction cost for these bridges was $86.06 per sq ft, compared to $62.00 per sq ft for conventional construction.[18] (Conventional construction in Texas is pretensioned concrete beams, partial-depth deck panels with cast-in-place topping, and cast-in-place substructure.) However, delay-related user cost savings were substantial for motorist and commercial operators traveling I-35, with multiple spans set in only one night instead of three weeks.[20] Again, with repeated use, this totally prefabricated bridge system can be expected to have lower initial construction costs.

Virginia Department of Transportation (VDOT)

Similar to TxDOT, VDOT uses very little cast-in-place concrete for its primary supporting members in its superstructures. As shown in Appendix B, in FY 2007 VDOT constructed a total of 19 on- and off-system bridges, with 17 or 89 percent of the bridges prefabricated with prestressed concrete beams (six bridges) or steel members (11 bridges). Only two bridges used cast-in-place concrete for primary supporting members. Looking at the square footage of deck area, prefabricated beam bridges account for 99% of the 500,000 sq ft of deck area constructed in FY 2007.

Looking at the specific unit costs, the one cast-in-place on-system bridge has the least unit cost of the 13 on-system bridges, and the four prestressed concrete bulb-tee beam bridges have by far the largest total deck area of any type and yet also have the highest unit cost. On the other hand, the one cast-in-place concrete off-system bridge has one of the higher unit costs of the six off-system bridges.

Prefabricated beams allow longer spans, faster construction, etc., that make them the cost-effective option relative to cast-in-place construction even though the FY 2007 data may not show them to be the least initial cost. For example, if a cast-in-place alternative had been a possibility for a specific project, which in many cases it is not because of various constraints including limited maximum span length, the cost would likely have been higher than the costs with prefabricated construction.

Washington State Department of Transportation (WSDOT)

As shown in Appendix C, WSDOT's bridges include prestressed concrete, structural steel, and cast-in-place concrete primary supporting members. As in Texas and Virginia, the majority of WSDOT's bridges use prestressed concrete beams. Around 70 percent of its bridges in the last decade have been prestressed concrete beam bridges, 20 percent have been steel beam bridges, and the remaining 10 percent have been cast-in-place concrete flat slab, post-tensioned boxes, etc.[21]

Delay-related User Costs

While not an out-of-pocket cost for the bridge owner, delay-related user costs are real costs to the traveling public. For example, the delay-related user costs for the I-45/Pierce Street Elevated Bridge rehabilitation project in the Houston central business district, discussed above, were estimated at $100,000 per day in the 1990s.[13] The high impact to motorists drove the use of precast bent caps and other prefabrication that reduced the onsite construction time from an estimated 1.5 years to just 190 days. Also, in 2003 TxDOT estimated delay-related user costs for closing Houston's I-10 to be $145,500 per hour from 5 a.m. and 9 p.m. and $19,400 per hour during off-peak hours, for a total cost to motorists of $2.5M per day.[12]

Chapter 7 of the *FHWA Manual on Use of Self-Propelled Modular Transporters to Remove and Replace Bridges* includes case studies that detail benefits and costs of several projects in which self-propelled modular transporters (SPMTs) were used to quickly removed and install bridges.[22] Included is the 2006 Florida DOT Graves Avenue over I-4 Bridge overnight span replacements which cost an additional $570,000 for use of the SPMTs and saved $2.2M in user costs. In 2007 SPMTs were used to remove and replace the Utah DOT 4500 South over I-215E Bridge over a weekend for an additional cost of $800,000 and user cost savings of $4.0M.

The railroad industry has long recognized the significant costs of onsite construction time. Losses of $50,000 to $100,000 are estimated for each hour a rail line is out of service.[12] Accordingly, conventional railroad bridge construction could result in losses of $1.2M to $2.4M per day for a simple bridge replacement project. As a result, the railroad industry uses prefabricated bridges whenever possible, with many bridges installed with only a few hours of track outage.

Additional examples of prefabricated bridge projects that have effectively incorporated delay-related user costs are discussed in the next section.

Examples of Successful ABC Projects Using PBES

Appendix D is a 2006 FHWA-sponsored prefabricated bridge elements and systems (PBES) cost study that documents project details including costs for nine PBES projects. These projects clearly show the multiple benefits and the cost savings that can be achieved with ABC using prefabricated bridges.

The table below summarizes the projects discussed above and those in Appendix D. Benefits in terms of reduced onsite construction time and other impacts are listed. Construction costs and user-costs are provided where available.

PBES Project	Benefits	Construction Costs	User-Costs
Colorado DOT: SH 86 over Mitchell Gulch single-span bridge replacement	• 46-hr closure over a weekend (vs. 2-3 mo.) • 38 hrs of construction work • No impact to peak-hour traffic • Improved safety	• $365.2K low bid compared to engineer's estimate of $394.2K (7% lower) • After award, contractor proposed no-cost change to prefabrication	$500/hr
Florida DOT: Graves Avenue over I-4 2-span superstructure replacement	• Graves Avenue detour of 8 months (vs. 12 mo.) • I-4 lane closures for 4 nights (vs.32 nights)	• Supplemental Agreement of $570,000 for Change Order to existing contract	$2.2M
Louisiana DOTD: I-10 over LA 35 emergency span replacements (2)	• Maximum I-10 detour of 10 hours for removal and replacement	• $1.0M for 2 new spans • Included $130,000 for SPMT subcontractor	
Maryland SHA: MD Route 24 over Deer Creek FRP deck replacement	• 3 days to install FRP deck • 10-wk bridge closure • Opened in time for school • 40% decreased weight for increased live-load capacity • 40-yr deck life (vs. 70 yrs) • Improved constructability	• FRP deck was $88/sq ft (vs. $35/sq ft)	

PBES Project	Benefits	Construction Costs	User-Costs
New Hampshire DOT: Mill Street over Lamprey River bridge replacement	• 8-day single-span bridge assembly • 2-mo. bridge closure (vs. 5 mo.)	• $1.05M low bid compared to engineer's estimate of $0.95M (10% higher)	
New Jersey DOT: Route 1 over Olden Avenue & Mulberry Street superstructure replacements (3)	• Each bridge opened in less than 57 hours • 3 spans installed over 3 weekends (6 days vs. 22 mo.) • No impact to peak-hour traffic • Anticipated 75-100 yr life (vs. 50 years)	• $3.5M low bid compared to engineer's estimate of $3.8M (8% lower)	$2.0M design & constr. savings incl. user costs
New York City DOT: Belt Parkway over Ocean Parkway bridge replacement	• 256 days of site impact • 285 bid days of site impact (vs. additional 300 days for low bid) • Each half of bridge installed in few days over two weeks • No lane closures during peak-hour traffic • Anticipated 75-100 yr life (vs. 45 years)	• $55.5M "best value" awarded bid compared to engineer's estimate of $60.0M (8% lower)	$25.0M less than low bid
Ohio DOT: US Route 22 over Scioto River bridge replacement	• Completed in 48 days (vs. 18 mo.) • Closed after school ended and opened in time for fall harvest	• $2.7M low bid compared to engineer's estimate of $5.0M (46% lower)	
Rhode Island DOT: I-195 over Providence River superstructure replacement	• Float-in avoided site constraints • Concurrent onsite / offsite construction saved 9-12 months	• After award, contractor proposed float-in of span using SPMTs on barges	
Texas DOT: I-45/Pierce Elevated Bridge rehabilitation	• 226 spans replaced in 190 days (vs. 1.5 years)	•	$100,000 per day
Texas DOT: SH 66 over Lake Ray Hubbard Bridge replacement with precast bent caps	• 215 days fewer days onsite construction • Improved worker safety • Off-the-critical-path fabrication allowed use of 35% replacement of cement with ground-granulated blast-furnace slag for improved concrete durability	• $40.9M low bid compared to engineer's estimate of $48.2M (15% lower) • After award, contractor proposed no-cost change to prefabrication	
Texas DOT: SH 36 over Lake Belton Bridge replacement with precast bent caps	• Onsite construction time reduced by 6 months	• Additional $400,000 for precast caps, or 2% of total $19.6M project cost	

PBES Project	Benefits	Construction Costs	User-Costs
Texas DOT: CR 453 over Battleground Creek Bridge superstructure replacement	• Replaced in 2 months (vs. 8 months)	• Additional 10% cost	
Texas DOT: Loop 340 over I-35 Bridge replacements (4)	• One night (vs. 3 weeks)	• $86.06 per sq ft (vs. $62.00 sq ft)	
Utah DOT: 4500 South over I-215E Bridge replacement	• I-215E closed 53 hrs over a weekend (vs. 6 mo.) • 4500 South Bridge closed 10 days	• $800,000 cost for use of SPMTs	$4.0M
Virginia DOT: I-95 over James River Bridge superstructure replacement	• 137 nights of construction during 17 months (vs. 24-36 mo.) • No impact to peak-hour traffic	• $43.4M low bid compared to engineer's estimate of $48.5M (11% lower)	
Washington State DOT: SR 433 Lewis & Clark Bridge deck replacement	• Closure of 124 nights plus 3 weekends (vs. 4 years) • No impact to peak-hour traffic	• $18.0M low bid compared to engineer's estimate of $28.8M (38% lower)	

Conclusion

Prefabricated bridge construction has been used extensively in the U.S. starting in the 1950s with pretensioned concrete beam bridges which quickly became cost competitive and are now the predominant bridge beam type in a number of states. Starting in the early 2000s AASHTO and FHWA began a national initiative to implement the use of new prefabricated bridge elements and more complete prefabricated bridge systems to address the mounting needs for cost-effective accelerated bridge construction and improved safety in work zones. Less than a decade later impressive reductions in onsite bridge construction timelines are being achieved, in some cases with bridges installed in just minutes.

Until prefabrication of these newer bridge elements and more complete bridge systems is standardized, individual prefabricated bridge projects may not have lower initial construction costs than conventional construction, if in fact conventional construction is even an option. However, prefabricated bridge projects with reduced onsite construction time can be anticipated to have lower overall costs because they reduce the delay-related user costs paid by the traveling public.

With the nation's increasing traffic congestion, aging bridge inventory, and continuing funding limitations, sustained efforts are needed to continue accelerated construction with prefabricated bridges to meet the mission of the state DOTs to provide safe, effective, and efficient movement of people, goods, and services on the nation's highways.

References

1. Schrank, D., and Lomax, T., *The 2007 Urban Mobility Report*, Texas Transportation Institute, Texas A&M University System, September 2007, http://mobility.tamu.edu/ums/.

2. "Deficient Bridges by State and Highway System," Federal Highway Administration, U.S. Department of Transportation, December 2007, http://www.fhwa.dot.gov/BRIDGE/defbr07.cfm.

3. *Prefabricated Bridge Elements and Systems in Japan and Europe*, Final Report FHWA-PL-05-003, International Technology Exchange Program, Federal Highway Administration, U.S. Department of Transportation, March 2005, http://international.fhwa.dot.gov/prefab_bridges/contents.htm.

4. Bhide, S., *Material Usage and Condition of Existing Bridges in the U.S. Based on NBI Data as of December 2003*, Portland Cement Association, December 2004, http://www.cement.org/bookstore/profile.asp?store=main&pagenum=1&pos=6&catID=1&id=2009.

5. *Prefabricated Bridge Elements and Systems to Limit Traffic Disruption during Construction*, NCHPR 20-5, Topic 33-02 [2003 Final Report 324], Transportation Research Board, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_324.pdf.

6. Personal communication with Alabama Department of Transportation former State Bridge Engineer, William F. (Fred) Conway, May 2008.

7. 2008 Precast Standards, ALDOT Bridge Bureau Standard Drawings, Alabama Department of Transportation, http://www.dot.state.al.us/Docs/Bureaus/Bridge/Standard+Drawings.htm.

8. *Bridge Design Manual (for design work begun before 10/07)*, Bridge Division, Texas Department of Transportation, December 2001, http://onlinemanuals.txdot.gov/txdotmanuals/des/index.htm.

9. *LRFD Bridge Design (for design work begun after 10/07)*, Bridge Division, Texas Department of Transportation, April 2007, http://onlinemanuals.txdot.gov/txdotmanuals/lrf/index.htm.

10. Bridge Standards, Bridge Division, Texas Department of Transportation, http://www.dot.state.tx.us/insdtdot/orgchart/cmd/cserve/standard/bridge-e.htm.

11. Tsui, C.K., Burns, N.H., and Klinger, R.E., *Behavior of Ontario-Type Bridge Deck on Steel Girders: Negative Moment Region and Load Capacity*, Final Report 350-3, Center for Transportation Research, The University of Texas at Austin, January 1986.

12. Freeby, G.A., Medlock, R.D., and Slagle, S., “Prefabricated Bridge Innovations,” Second New York City Bridge Conference, October 2003, http://www.dot.state.tx.us/publications/bridge/prefabricated_inovations.pdf.

13. Innovative Projects, Prefabricated Bridge Elements and Systems Website, Federal Highway Administration, U.S. Department of Transportation, http://www.fhwa.dot.gov/bridge/prefab/projects.cfm.

14. *Full-Depth, Precast-Concrete Bridge Deck Panel Systems*, NCHRP 12-65 [2008 Final Report 584], Transportation Research Board, http://www.trb.org/trbnet/projectdisplay.asp?projectid=354, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_584.pdf

15. Matsumoto, E.E., Waggoner, M.C., Sumen, G., Kreger, M.E., and Breen, J.E., “Development of a Precast Bent Cap System,” Project Summary Report 1748-S, Center for Transportation Research, The University of Texas at Austin, March 2001, http://www.utexas.edu/research/ctr/pdf_reports/1748_S.pdf.

16. Matsumoto, E.E., Waggoner, M.C., Sumen, G., Kreger, M.E., Wood, S.L., and Breen, J.E., *Development of a Precast Bent Cap System*, Final Report 1748-2, FHWA/TX-0-1748-2, Center for Transportation Research, The University of Texas at Austin, January 2001, http://www.utexas.edu/research/ctr/pdf_reports/0_1748_2.pdf.

17. “County Road 453 Bridge over Battleground Creek, Coupland, Texas,” *2006 Design Award for Best Bridge with Spans Less than 65 Feet*, Precast/Prestressed Concrete Institute, http://www.pci.org/pdf/publications/ascent/2006/Fall/AS-06FA-3.pdf.

18. Griffin, J., Lloyd Wolf, L., Freeby, G., Hyzak, M., Hohmann, D., and Cox, R., “Preassembled Bridge Facilitates Overpass Construction,” ASPIRE, Precast/Prestressed Concrete Institute, Spring 2008, pp. 44-47, http://www.aspirebridge.org/magazine/index.cfm.

19. *Framework for Prefabricated Bridge Elements and Systems (PBES) Decision-Making*, FHWA-IF-06-30, Federal Highway Administration, U.S. Department of Transportation, December 2005, http://www.fhwa.dot.gov/bridge/prefab/framework.cfm.

20. “Concrete Experiments,” All Business, a D&B Company; *Texas Contractor*; June 19, 2006; http://www.allbusiness.com/construction/heavy-civil-construction-road-bridge-bridge/6268615-1.html.

21. Personal communication with Washington State Department of Transportation State Bridge Engineer, Jugesh Kapur, May 2008.

22. *Manual on Use of Self-Propelled Modular Transporters to Remove and Replace Bridges*, FHWA-HIF-07-022, Federal Highway Administration, U.S. Department of Transportation, June 2007, http://www.fhwa.dot.gov/bridge/pubs/07022/.

Appendix A

Texas Bridges

FY 2007 & FY 2006
Average Unit Costs

*FY 2007 Average Unit Cost**

System	Structure Type	Number Bridges	Deck Area (sq.ft.)	Adjusted Structure Cost **	Average Unit Cost ($/sq.ft.)
Off Culvert					
	Culverts	50	68,405	$8,038,751	$117.52
Off Span					
	Prestressed Concrete Slab Beam (PCSB)	51	103,334	$8,721,522	$84.40
	Girder Prestressed "I" Beam (GP-I)	46	227,678	$12,815,091	$56.29
	Concrete Slab (SLAB)	13	21,867	$1,776,382	$81.24
	Girder Prestressed "Box" Beam (GP-BX)	7	12,480	$1,375,380	$110.21
	Concrete Girder "Pan" (CG-PN)	4	10,518	$763,393	$72.58
	Girder Steel "I" Beam (GS-I)	2	6,360	$1,005,070	$158.03
Off Span Totals					
	Off Totals	123	382,237	$26,456,837	$69.22
On Culvert					
	Culverts	55	327,652	$18,797,432	$57.37
On Span					
	Girder Prestressed "I" Beam (GP-I)	170	4,719,254	$239,124,240	$50.67
	Prestressed Concrete Slab Beam (PCSB)	23	153,087	$11,558,891	$75.51
	Girder Steel "I" Beam (GS-I)	19	505,318	$67,103,998	$132.80
	Girder Prestressed "Box" Beam (GP-BX)	14	160,826	$13,440,688	$83.57
	Concrete Slab (SLAB)	6	24,539	$1,611,387	$65.67
	Girder Prestressed "U" Beam (GP-U)	4	235,335	$11,510,756	$48.91
	Girder Prestressed "T" Beam (GP-T)	2	7,860	$788,366	$100.30
	Girder Prestressed "Segmental" (GPSEG)	2	122,760	$27,852,625	$226.89
	Girder Steel "Trapezoidal" Beam (GS-TR)	1	145,082	$102,493,260	$706.45
On Span Totals					
	On Totals	241	6,074,061	$475,484,212	$78.28

The cummulation of the adjusted structure cost for the year is devided by the cummulation of the desk area to arrive at the approximate average unit cost. Unit costs include only structure work items for deck, superstructure, and substructure. Items for approach roadway are not included.

*****Adjusted structure cost is derived by multiplying the engineer's estimate for structure cost on the project by the ratio of the low bid for the project to the engineer's estimate of the project. This adjusted structure cost off sets unbalanced bids and more accurately represent the cost.***

FY 2006 Average Unit Cost*

System	Structure Type	Number Bridges	Deck Area (sq.ft.)	Adjusted Structure Cost **	Average Unit Cost ($/sq.ft.)
Off Culvert					
	Culverts	33	44,338	$4,069,730	$91.79
Off Span					
	Girder Prestressed "I" Beam (GP-I)	63	405,926	$25,062,160	$61.74
	Prestressed Concrete Slab Beam (PCSB)	46	111,794	$8,455,592	$75.64
	Girder Prestressed "Box" Beam (GP-BX)	9	35,539	$2,747,873	$77.32
	Girder Steel "I" Beam (GS-I)	4	30,416	$3,129,039	$102.87
	Concrete Slab (SLAB)	3	9,578	$927,665	$96.85
	Concrete Girder "Pan" (CG-PN)	1	3,850	$228,737	$59.41
Off Span Totals					
	Off Totals	126	597,103	$40,551,065	$67.91
On Culvert					
	Culverts	78	408,872	$27,350,358	$66.89
On Span					
	Girder Prestressed "I" Beam (GP-I)	263	5,510,155	$291,576,057	$52.92
	Prestressed Concrete Slab Beam (PCSB)	24	211,264	$15,740,338	$74.51
	Girder Prestressed "Box" Beam (GP-BX)	19	257,534	$20,191,383	$78.40
	Concrete Slab (SLAB)	18	89,913	$6,468,160	$71.94
	Girder Prestressed "U" Beam (GP-U)	13	426,187	$23,023,071	$54.02
	Girder Steel "I" Beam (GS-I)	10	276,732	$41,840,399	$151.19
	Concrete Girder "I" (CG-T)	6	136,960	$4,852,379	$35.43
	Girder Prestressed "T" Beam (GP-T)	5	24,581	$1,565,798	$63.70
	Girder Steel "Trapezoidal" Beam (GS-TR)	4	63,482	$9,562,669	$150.64
	Concrete Girder "Pan" (CG-PN)	3	15,289	$996,035	$65.15
	Girder Prestressed "Segmental" (GPSEG)	1	31,280	$6,908,897	$220.87
On Span Totals					
	On Totals	366	7,043,376	$422,725,187	$60.02

The cummulation of the adjusted structure cost for the year is devided by the cummulation of the desk area to arrive at the approximate average unit cost. Unit costs include only structure work items for deck, superstructure, and substructure. Items for approach roadway are not included.

*****Adjusted structure cost is derived by multiplying the engineer's estimate for structure cost on the project by the ratio of the low bid for the project to the engineer's estimate of the project. This adjusted structure cost off sets unbalanced bids and more accurately represent the cost.***

Appendix B

Virginia Bridges

FY 2007
Average Unit Costs

Fiscal Year Average Unit Costs – 10/1/2006 thru 9/30/2007

(Federal Aid Projects Only)

Average Square Foot Cost For On-System Bridges

Structure Type	Number of Bridges	Deck Area	Cost	Avg. Unit Cost / SF
Structural Steel Plate Girders	7	91,901	$11,743,325	$120.93
Prestressed Conc. Bulb-T Beams	4	377,081	$59,581,717	$166.46
Prestressed Conc. Slabs	1	3,238	$490,224	$151.40
Reinforced C-I-P Conc. Slab	1	5,460	$570,384	$104.47
TOTAL	13	477,680	$72,385,650	$151.54

Average Square Foot Cost For Off-System Bridges

Structure Type	Number of Bridges	Deck Area	Cost	Avg. Unit Cost / SF
Structural Steel Plate Girders	2	11,633	$1,525,171	$140.12
Galvanized Prefab Steel Truss	2	6,016	$1,048,065	$177.40
Prestressed Conc. Slabs	1	1,040	$198,244	$96.62
Reinforced C-I-P Conc. Slab	1	1,480	$241,229	$162.99
TOTAL	6	20,169	$3,012,709	$149.37

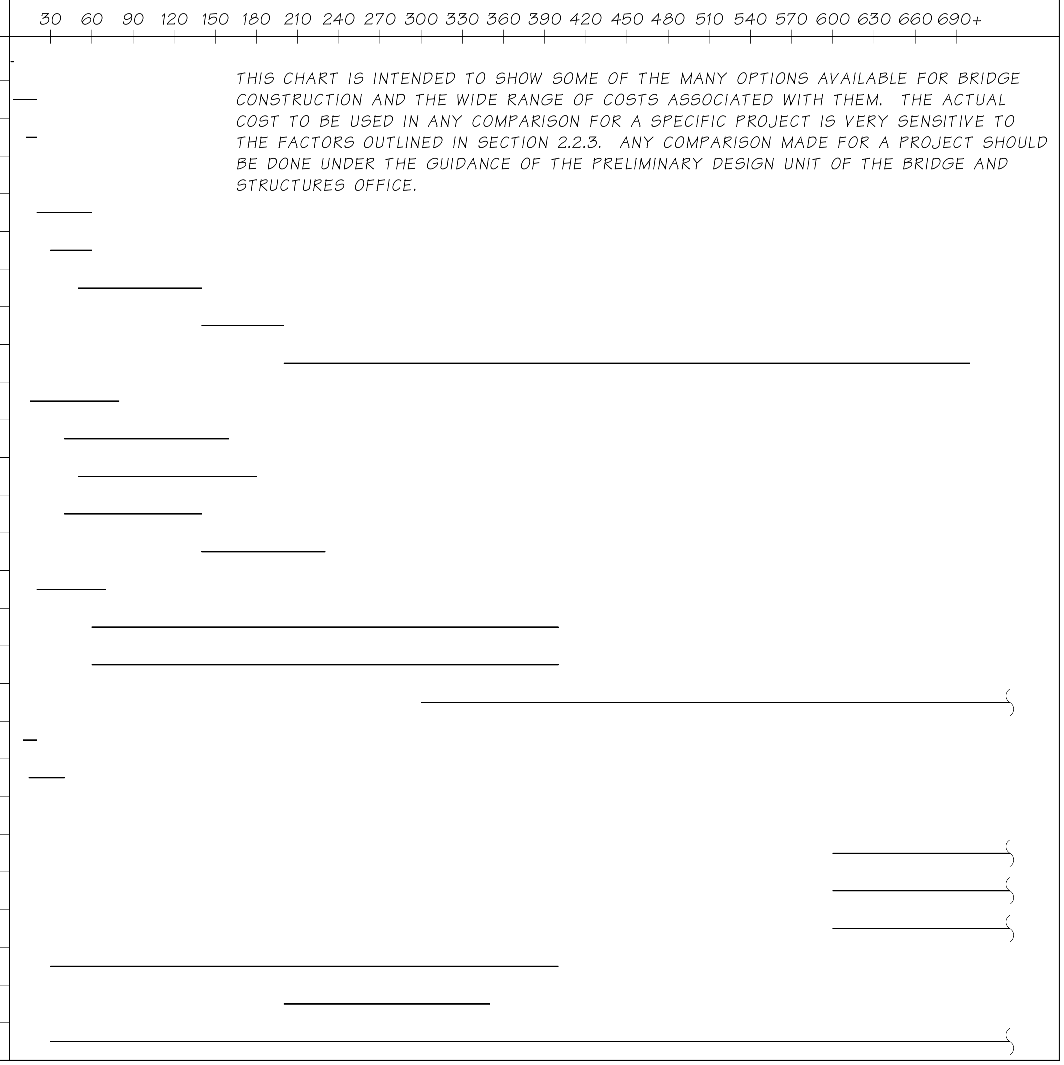
Appendix C

Washington State Bridges

July 2006
Cost Range

	STRUCTURE TYPES	SPAN RANGE, FT.	JULY 2006 COST RANGE $ / FT²
HYDAULIC STRUCTURES	PIPE	1 - 3	30 - 60
	CONCRETE CULVERT	3 - 20	100 - 120
	PLATE ARCH	12 - 20	65 - 80
STRUCTURES FOR CONVENTIONAL SITE CONDITIONS	REINF. CONCRETE SLAB	20 - 60	90 - 130
	REINF. CONCRETE TEE BEAM	30 - 60	90 - 140
	REINF. CONCRETE BOX GIRDER	50 - 120	180 - 250
	POST-TENSIONED CONC. BOX GIRDER	140 - 200	200 - 300
	SEGMENTAL P.T. BOX GIRDER	200 - 700	250 - 300
	PRESTRESSED CONC. SLAB	15 - 80	100 - 120
	PRESTRESSED CONC. DECK BULB TEE	40 - 160	100 - 145
	PRESTRESSED CONC. GIRDER	50 - 180	130 - 190
	PRESTRESSED TRAPEZOIDAL TUB GIRDER	40 - 140	160 - 200
	PRESTRESSED CONCRETE SPLICED GIRDER	140 - 230	150 - 200
	STEEL ROLLED GIRDER	20 - 70	140 - 160
	STEEL PLATE GIRDER	60 - 400	150 - 220
	STEEL BOX GIRDER	60 - 400	200 - 275
	STEEL TRUSS	300 - 1200	250 - 375
	TIMBER	10 - 20	120 - 140
	GLULAM TIMBER	14 - 40	120 - 140
STRUCTURES FOR SPECIAL SITE CONDITIONS	CABLE STAY BRIDGE	600 - 1200	500 - 600
	SUSPENSION BRIDGE	600 - 5000	850 - 1200
	FLOATING BRIDGE	600 +	800 - 1000
	ARCH BRIDGE	30 - 400	400 - 450
	MOVEABLE SPAN BRIDGE	200 - 350	1500 - 2000
	TUNNEL	30 +	1500 - 3000

SPAN RANGE, FT.



THIS CHART IS INTENDED TO SHOW SOME OF THE MANY OPTIONS AVAILABLE FOR BRIDGE CONSTRUCTION AND THE WIDE RANGE OF COSTS ASSOCIATED WITH THEM. THE ACTUAL COST TO BE USED IN ANY COMPARISON FOR A SPECIFIC PROJECT IS VERY SENSITIVE TO THE FACTORS OUTLINED IN SECTION 2.2.3. ANY COMPARISON MADE FOR A PROJECT SHOULD BE DONE UNDER THE GUIDANCE OF THE PRELIMINARY DESIGN UNIT OF THE BRIDGE AND STRUCTURES OFFICE.

Bridge Design Engr.	M:\BRIDGELIB\BDM\Chapter 2\window files\Bridge Selection Guide.wnd	STATE	FED. AID PROJ. NO.	SHEET NO.	TOTAL SHEETS
Supervisor		10	WASH.		
Designed By					
Checked By		JOB NUMBER			
Detailed By					
Bridge Projects Engr.					
Prelim. Plan By					
Architect/Specialist	DATE / REVISION / BY / APP'D				

BRIDGE AND STRUCTURES OFFICE

Washington State Department of Transportation

BRIDGE SHEET NO. SHEET OF SHEETS

SR ___ JOB NO. ___ SHEET ___

Appendix D

PBES Cost Study:
Accelerated Bridge Construction
Success Stories

Federal Highway Administration

2006

Prefabricated Bridge Elements and Systems Cost Study: Accelerated Bridge Construction Success Stories

Introduction

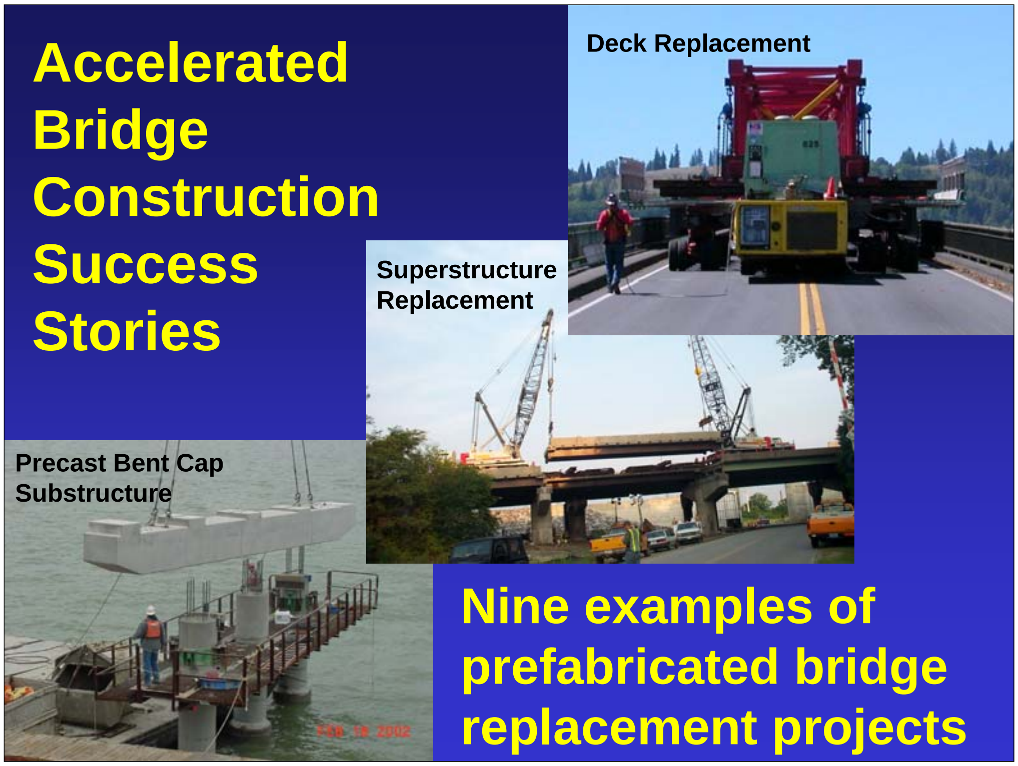
The prefabricated bridge elements and systems (PBES) cost study documents the details related to savings in time and money on nine PBES projects in states across the country. All nine projects are replacement projects, and as such reducing the impact of onsite construction to motorists was a priority. Each project is an example of how various combinations of prefabrication and effective contracting strategies were used to achieve the accelerated onsite construction timeline.

In all cases the onsite construction time was significantly reduced relative to conventional construction, and five of the replacement projects were completed with no impact to rush-hour traffic. The combined construction cost savings on these nine projects is $30M, where savings are defined as the difference between engineer's estimate and awarded bid.

Projects

The owner, the project name, and the year of completion are shown below for each of the nine projects included in this cost study.

1) Colorado Department of Transportation's State Highway 86 Bridge over Mitchell Gulch - 2002
2) Maryland State Highway Administration's MD Route 24 Bridge over Deer Creek – 2001
3) New Hampshire Department of Transportation's Mill Street Bridge over Lamprey River – 2004
4) New Jersey Department of Transportation's Route 1 Bridges over Olden Avenue & Mulberry Street - 2005
5) New York City Department of Transportation's Belt Parkway Bridge over Ocean Parkway – 2004
6) Ohio Department of Transportation's U.S. Route 22 Bridge over Scioto River in Pickaway County – 2003
7) Texas Department of Transportation's State Highway 66 Bridge over Lake Ray Hubbard - 2003
8) Virginia Department of Transportation's Interstate 95 Bridge over James River – 2002
9) Washington State Department of Transportation's SR 433 Lewis & Clark Bridge over Columbia River - 2004



A number of prefabricated bridge projects have been constructed to date across the country. The following nine projects are examples of how prefabrication was used to accelerate onsite construction time. The awarded bids for these projects were also typically lower than the engineer's estimate.

For each project, first an overview is given that includes the name, location, date of construction, owner, brief description of project, benefits including reduced impact to traffic, and duration compared to conventional construction. The construction process is then briefly described, followed by contract requirements that include incentives and disincentives. Construction costs are then discussed, including engineer's estimate, number of bidders, low bid and second lowest bid, savings both in time and money, and incentives paid.

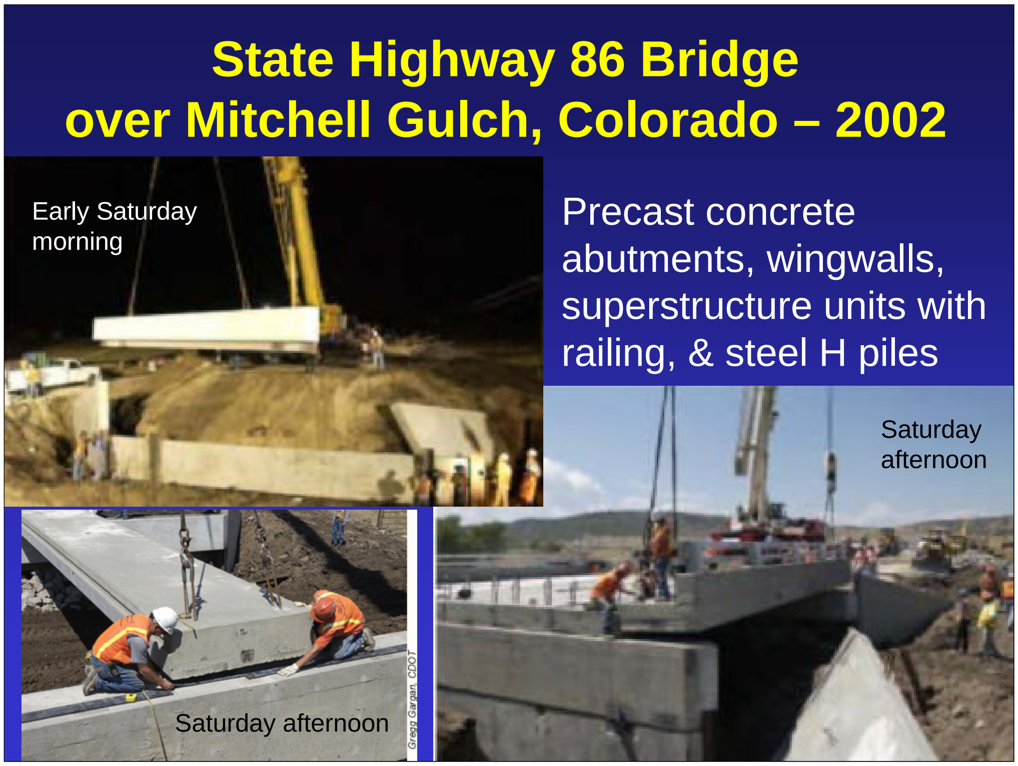
All nine projects are replacement projects, and as such reducing the impact of onsite construction to motorists was a priority. Each project is an example of how various combinations of prefabrication and effective contracting strategies were used to achieve the accelerated onsite construction timeline. In all cases the onsite construction time was significantly reduced, and five of the replacement projects were completed with no impact to rush-hour traffic.

The combined construction cost savings on these nine projects is $30M, where savings are defined as the difference between engineer's estimate and awarded bid.

The State Highway 86 Bridge over Mitchell Gulch between Castle Rock and Franktown in Douglas County southeast of Denver was a timber bridge built in 1953 and rated in 2002 as one of Colorado's worst 10 bridges. That year the Colorado Department of Transportation accepted a value engineering proposal from the contractor and his design team to build a totally prefabricated bridge over a weekend in August 2002. During construction the bridge was closed and the 12,000 vehicles per day were diverted to a short detour around the bridge site.

The existing 40-ft long 2-span bridge was 26-ft wide with two 11-ft lanes and two 1.5-ft shoulders. The new 40-ft long bridge with 35-ft-clear single span was 43-ft wide to accommodate two 12-ft lanes and two 8-ft shoulders.

The new prefabricated bridge was opened just 46 hours after closure. Construction occurred over a weekend, with no impact to rush-hour traffic. Construction would have taken 2 to 3 months using conventional methods.



Prior to the bridge closure, the contractor constructed a short detour to divert traffic for the weekend, and also drove 40-ft deep steel H piles at the abutments in the stream banks just outside the existing roadway width. The precast concrete abutments, wingwalls, and superstructure units were fabricated at Plum Creek Products Company in Littleton and shipped to the site just before being installed.

At 7 p.m. on a Friday in August 2002, the bridge was closed and traffic diverted to the detour. The existing timber bridge was demolished. Early Saturday morning, 44-ft wide precast abutments and 23-ft long precast wingwalls with embedded steel plates were erected with a crane and welded to the steel H piles and to each other prior to placing flowable fill behind the abutments. On Saturday afternoon, the eight 38’-4” long, 5’-4” wide, and 1’-6” deep precast superstructure units were erected, including the edge units complete with precast railing. The units were then transversely post-tensioned and grouted. Work stopped at 11 p.m. on Saturday and resumed Sunday morning at 7 a.m. to complete the earthwork and asphalt overlay.

The bridge was reopened to traffic at 5 p.m. on Sunday, 46 hours after closure of the existing bridge. Only 38 hours of construction work were required for the replacement.

The bridge is expected to see a 75-year service life due to the quality of its prefabricated components and the attention given to connection details.

State Highway 86 Bridge over Mitchell Gulch Contract Requirements

- ☑ Contract specified 3-cell cast-in-place concrete box culvert to replace 2-span timber bridge
- ☑ Value engineering change proposal by contractor/design team
  - ☑ Prefabricated single-span bridge
  - ☑ Completion in one weekend

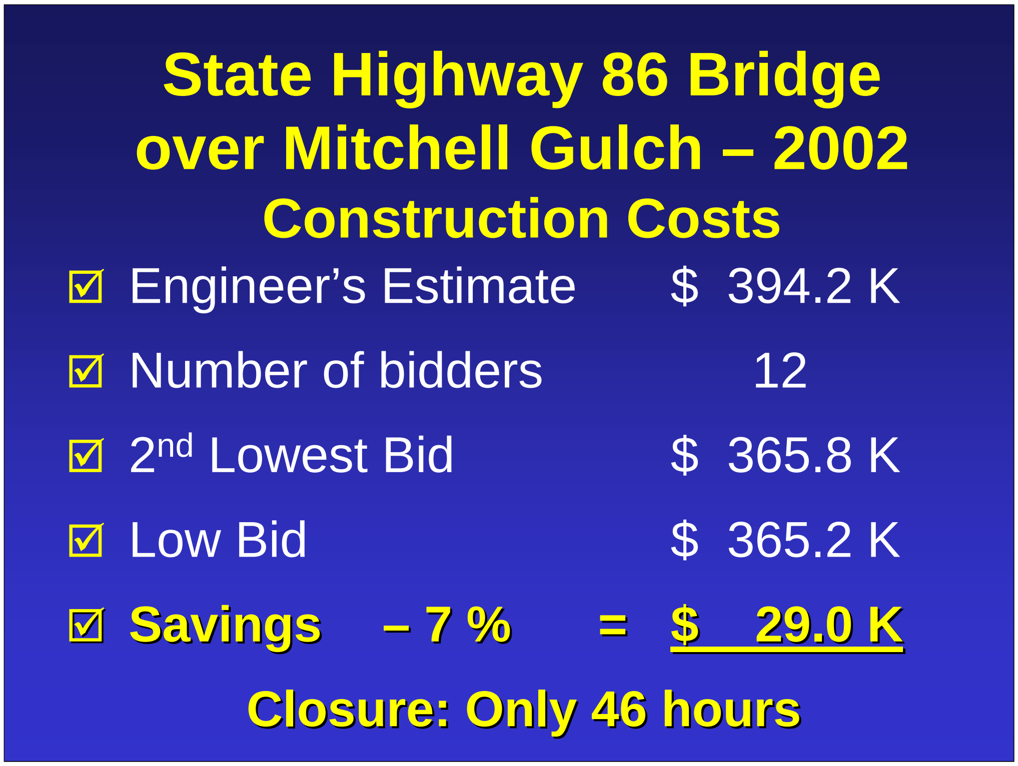
The Colorado DOT awarded the construction contract to replace the deteriorated bridge with a conventional 3-cell cast-in-place concrete box culvert. However, the contractor, Lawrence Construction Company, was concerned about the safety of his construction crews on this project because of the steep downward grade of the highway approach from the west in combination with the nearby curve of the detour around the bridge site. The contractor teamed with Wilson & Company, a local design firm, to submit a value engineering change proposal to build the single-span totally prefabricated bridge over a weekend to limit the onsite exposure time of his crew.

State Highway 86 Bridge over Mitchell Gulch
Contract Requirements, cont'd.

- ☑ CDOT response:
  - ☑ Accepted VE change proposal
  - ☑ Implemented lane rental fee
- ☑ Lane Rental Specification
  - ☑ $500/hr starting 6 a.m. Monday
  - ☑ Fee based on user costs to occupy SH 86

The Colorado DOT accepted the value engineering change proposal, with no change to the project funding. However, as part of the acceptance of the proposal, CDOT implemented a lane rental specification that imposed significant costs should the contractor exceed the allowed weekend closure. If the bridge wasn't opened by 6 a.m. on Monday, the contractor was required to pay a lane rental fee of $500 per hour or portion of an hour of lane closures on SH 86. The lane rental was based on road user costs to occupy SH 86.

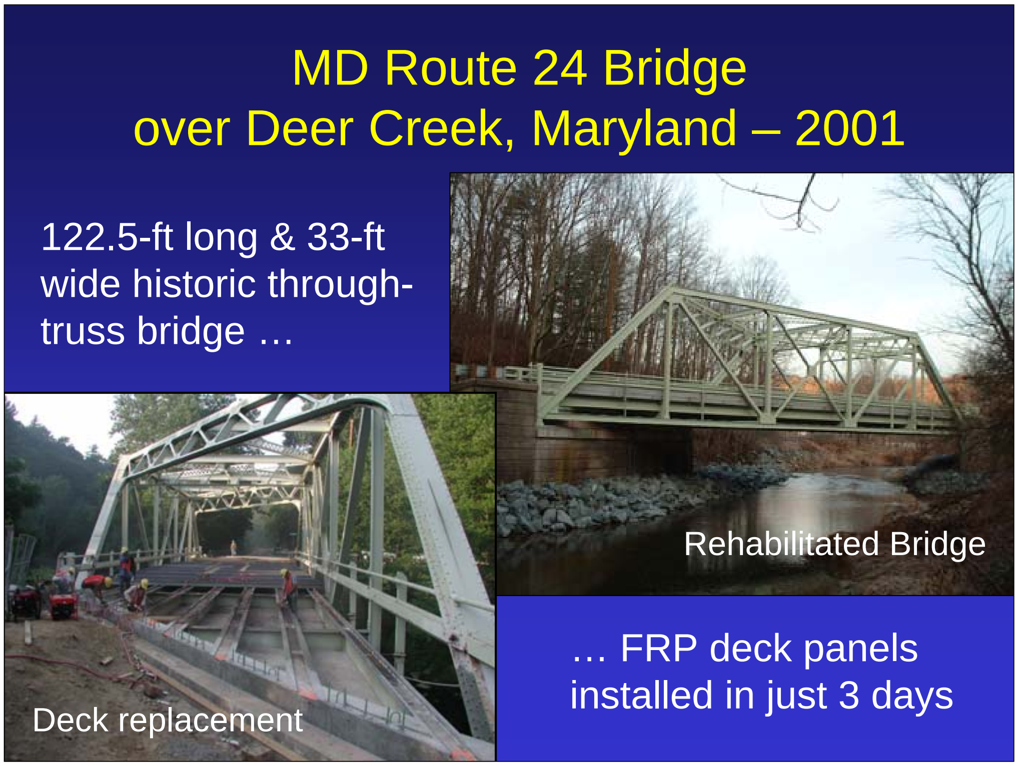
No incentives were included in the contract.



The engineer's estimate for this project was $ 394.2K. The low bid bid of $365.2K from Lawrence Construction Company was 7% or $29,000 less than the engineer's estimate. There was steep competition among contractors on this project. Twelve contractors bid on the project, and the 2nd lowest bid of $365.8K was just $644 higher than the awarded low bid.

The 5 p.m. Sunday opening of the new bridge was 13 hours earlier than the required 6 a.m. Monday opening. No rush hours were impacted and, therefore, no lane rental fees were charged. Motorists who traveled home from work on Friday over the existing bridge and then to work Monday morning over the new bridge never experienced a construction delay or detour.

The existing bridge was replaced with a totally prefabricated bridge in just 46 hours, and the contractor anticipates cutting the time in half on similar subsequent projects. In addition to huge savings in user costs and significantly improved safety, this bridge was also completed under budget.



The MD Route 24 Bridge over Deer Creek near Rock State Park in Harford County in northeastern Maryland is a 122.5-ft long, 33-ft wide single-span 2-lane historic through-truss bridge built in 1934 and eligible for inclusion in the National Register of Historic Places. In 2001 the deck was deteriorated and required a replacement that maintained the historic characteristics of the bridge. The rehabilitation project was also a challenge because the bridge was on a school bus route and could only be closed for rehabilitation a maximum of 10 weeks in the summer. Replacing the deck with one that would last longer than the typical maximum 40 years due to the harsh climate was another challenge. In addition, replacing the deck with one that did not further reduce the live-load capacity of this weight-restricted bridge was a challenge. Other challenges were the low 24.5-ft vertical clearance that restricted crane use and the 56-degree skew.

In 2001 the Maryland State Highway Administration (SHA) decided to address these challenges with fiber-reinforced polymer (FRP) deck panels. Following removal of the existing deck, steel angles were welded to the girders and the panels were installed in just 3 days. The rapid installation possible with these panels allowed the bridge to be rehabilitated during the summer and opened prior to the start of school. The corrosion resistance of the panels is anticipated to almost double the deck's service life, to at least 70 years. In addition, the significantly lighter weight of the FRP panels allowed easier placement and increased the live-load capacity of the bridge.

The project was completed in 10 weeks. Deck replacement with FRP panels was done in 1/3 the time required for a conventional concrete deck.

The bridge consists of two warren trusses each with five 24.5-ft long panels connected to overhead members. The trusses are supported by eight steel girders at 4-ft spacing. The FRP panels, which were manufactured by the protrusion method, are E-glass fiberglass strands and fabric coated with an isophthalic polyester resin.

Because of limited vertical clearance, the most efficient deck installation method is with a forklift to place the panels, and the use of a forklift was possible because of FRP's light weight. The FRP deck system that was selected allowed immediate construction loads without the full grouting required for some FRP deck systems. This enabled the forklift to immediately move onto the newly-placed panel to position the next panel as it progressed from one end of the bridge. The panels were installed perpendicular to the girders and act as a continuous beam across the girder supports.

The method used to attach the panels to the girders was similar to the method used in the region to construct reinforced concrete decks on steel girders. Steel angles were welded to the sides of the girders to form a haunch, the panels were placed on the angles, shear studs were installed in prefabricated pockets in the panels, and the shear stud pockets were filled with non-shrink grout. An asphalt overlay was then placed to provide the required skid resistance, to form the roadway crown, and to protect the FRP from ultraviolet radiation. While a polymer overlay is typically used in Maryland, the asphalt overlay was allowed because the FRP panels will not corrode.

Once the existing deck was removed and the existing girders cleaned, it took only 15 working days for the bridge to be opened to traffic.

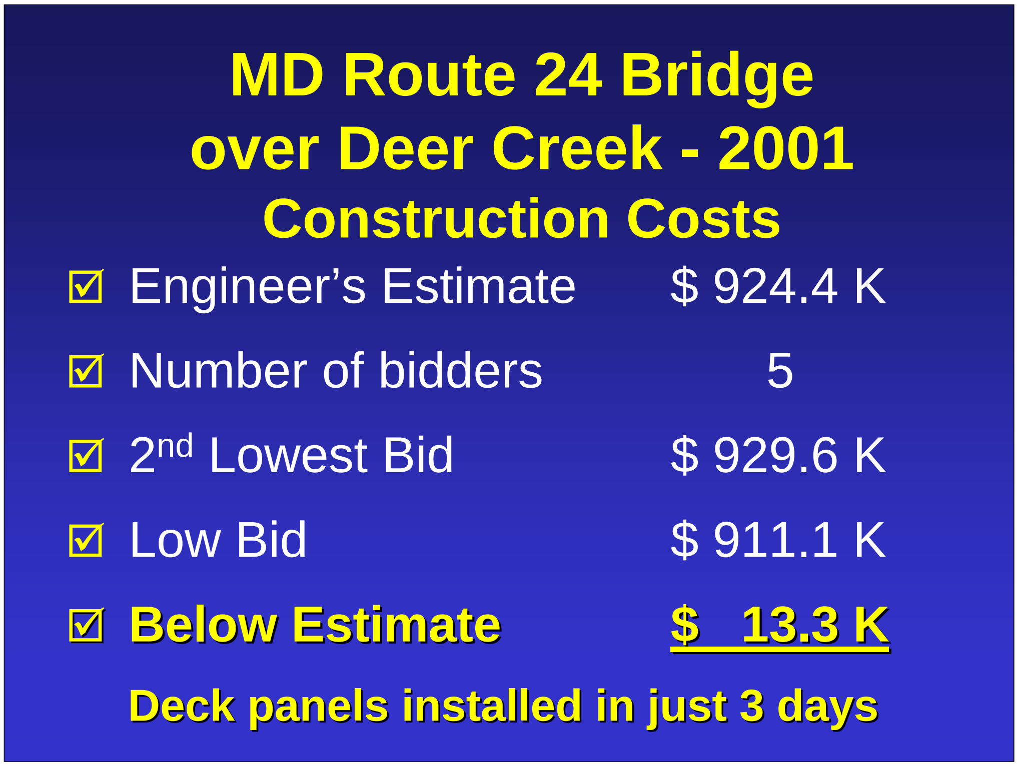
MD Route 24 Bridge over Deer Creek
Contract Requirements

- ☑ Maximum 10 weeks of closure
- ☑ Disincentive of $4,700 per day past 10 weeks

The low traffic volume of 3,700 ADT (in 2000) allowed the bridge to be closed during a 10-week period in the summer when school was out. Traffic was diverted to a 21-mile detour during this time.

A penalty for time violations was included in the contract. For every day beyond the 10-week closure period that the detour was in place, the contractor would be fined $4,700. No incentives or other accelerated construction strategies were included in the contract.

In addition to replacing the deck, the contract included cleaning and painting the truss members. During construction several steel members were found to be deteriorated and required repair. These repairs increased the time it took the contractor to complete the work, but it was still within 10 weeks. No penalties were assessed.



The engineer's estimate for this project was $ 924.4K. The low bid of $911.1K was slightly below the engineer's estimate. Five contractors bid on the project, and the 2nd lowest bid was only slightly higher than the low bid.

The deteriorated deck was replaced with a deck that is anticipated to last at least 70 years compared to 40 years for typical concrete decks in the region. The FRP deck, connections and grout weigh just 25 pounds per square foot (lbs/sq ft). Adding the 45 lbs/sq ft for the asphalt overlay results in a total deck weight of just 70 lbs/sq ft compared to 115 lbs/sq ft for a traditional reinforced concrete deck. This 40% reduction in deck weight increased the live load capacity of this historic bridge. In addition, the accelerated construction made possible using FRP panels allowed the bridge to be completely rehabilitated within the available 10-week period.

This project was the Maryland State Highway Administration's first use of FRP bridge decks. The FRP deck cost $88/sq ft compared to $35/sq ft average cost for a traditional concrete deck replacement in 2001. Costs for replacements with FRP deck panels are anticipated to go down with subsequent projects.

Use of FRP on this historic bridge helped the State Highway Administration maintain the heritage of the region. They partnered with the University of Maryland and received an FHWA Innovative Bridge Research and Construction Program grant that covered part of the cost to install and monitor the FRP deck. A recent inspection in 2006 found the deck still looking new, with no signs of problems. The Maryland SHA is planning rehabilitation with FRP deck panels for similar historic through-truss bridges in their State, although future availability of multiple suppliers of FRP deck panels is an concern.

Mill Street Bridge over Lamprey River, New Hampshire – 2004

Totally Prefabricated Bridge, erected in just 8 day!

In 2003 the town of Epping’s existing 28-ft wide 2-lane Mill Street Bridge over the Lamprey River consisted of two 30-ft long spans separated by a 60-ft long center pier causeway. The spans were deteriorated and required replacement. The low traffic volume crossing the bridge in combination with a short half-mile detour allowed complete closure of this bridge during its replacement. The site was selected for the New Hampshire Department of Transportation’s first use of totally prefabricated cantilevered substructure construction. The location minimized the overall risk of using the precast abutment system that was newly developed by a team with members from the NHDOT, FHWA, University of New Hampshire, Precast/Prestressed Concrete Institute’s Northeast Region Technical Committee, and local general bridge contractors and precasters.

In August 2004 the existing bridge was replaced with a 115-ft long and 28-ft wide 2-lane single-span pretensioned concrete adjacent box beam superstructure on full-height cantilevered precast concrete abutments founded on precast concrete spread footings. Thirty-two precast concrete segments were used to construct the bridge.

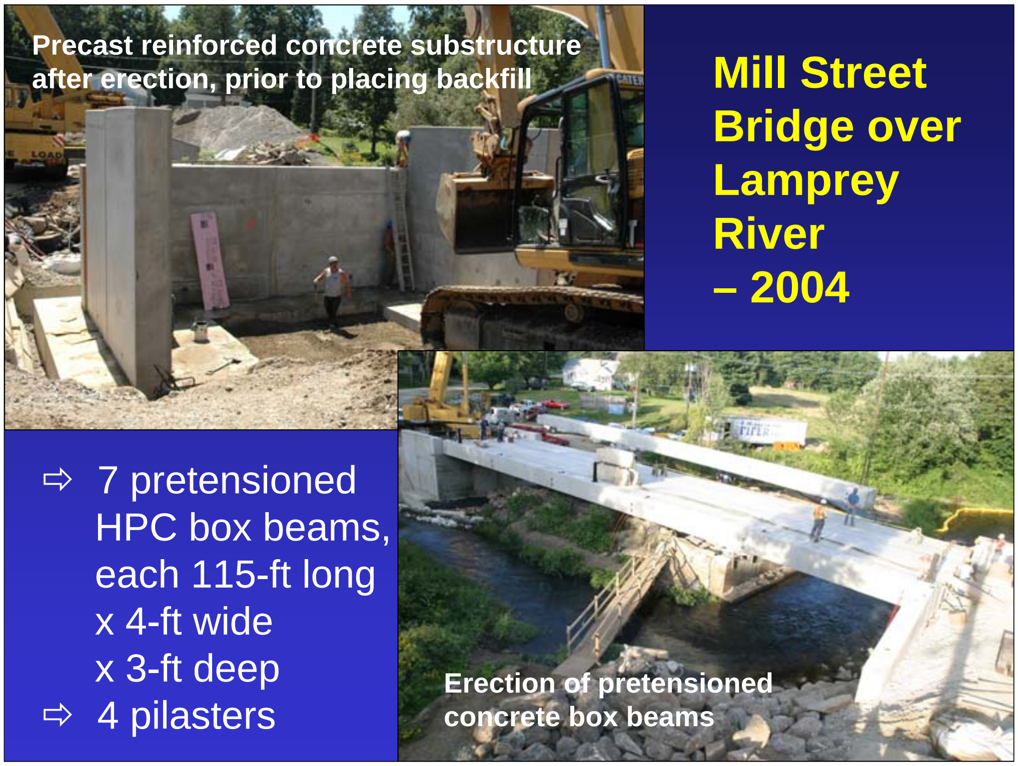
The erection of the bridge, from start of footing placement to opening to traffic, required 8 days. The bridge was closed to traffic for a total of 2 months, compared to 5 months that would have been required for conventional construction.

The 32.4-ft wide 5,000 psi precast reinforced high performance self-consolidating concrete abutments consist of 10 spread footing segments and 11 abutment wall and wingwall segments. All precast segments were fabricated at the J. P. Carrara & Sons plant in Middlebury, Vermont and shipped 170 miles to the jobsite.

Spread footings provide significant speed and simplicity to bridge construction when soil conditions permit their use as in this project and in many other New Hampshire bridge projects. The spread footings and other substructure components were fabricated in segments as determined by the contractor and precaster to facilitate shipping and handling, and were standardized to reduce fabrication costs. The precaster used a template in the plant fabrication to ensure adequate tolerances between the abutments, wingwalls, and footing segments. The contractor developed the assembly plan.

Following placement of the footings, a minimum 3-inch thick flowable grout bed was injected through grout tubes in the footings to provide a sound bearing surface for the roughened bottom surfaces of the footings. Proper grading was assured by using leveling screws cast in the corners of each footing segment. The abutment walls and wingwalls had splice sleeve connections to accommodate the reinforcing bars protruding from the tops of the footings. The walls were lowered into place, and the splice sleeves were then grouted to complete the bar splices. All horizontal joints are full-moment connections with grouted reinforcing bars, and vertical joints have grouted shear keys.

The erection of the abutments took 2 days, plus a 3rd day to cure the grout and prepare for the backfill. Similar conventional cast-in-place abutments would have required 6 separate concrete placements and two months to construct.



The 115-ft long and 28-ft wide superstructure consists of seven 4-ft wide adjacent box beams. The beams are made of 8,000 psi high performance pretensioned concrete. The use of HPC in combination with 0.6-inch diameter pretensioning strands stretched the 3-ft deep box beams to 115 ft, allowing the use of a single span. Following erection of the beams, a precast concrete pilaster was set along the top of the stem wall on each side of the outside box beams to provide lateral load transfer between the superstructure and substructure and to also provide a more finished look. Full-depth shear keys were then cast between each box beam, and the span was transversely post-tensioned in 6 locations to complete the connection between beams. A 3-bar aluminum railing was then installed. A waterproofing membrane was applied to the top surfaces of the box beams, followed by an asphalt overlay.

In spring 2006, the Lamprey River crested 1 to 2 ft above the bridge deck after heavy rains. Although the area has a significant flooding history, this level was the highest seen by Epping residents. The inundation battle-tested the bridge in its second year of existence, with no ill effects. The bridge is expected to see a service life of at least 75 years due to the use of HPC, the quality of its prefabricated construction, the attention given to connection details, and an aggressive NHDOT maintenance and preservation program.

Mill Street Bridge over Lamprey River

Original Contract Requirements

- ☑ 30-day bridge closure
- ☑ Assembly of bridge in 14 days
- ☑ Incentives/disincentives:
  - ☑ $1,500 per day less/more than 30-day
  - ☑ $5,000 per day less/more than 14-day

Because the focus of this project was to develop project details and processes that will reduce the onsite bridge construction timeline and improve safety on future projects, the project was originally bid with a maximum 30-day bridge closure and a maximum 14-day bridge assembly. The 30-day bridge closure compared to a 5-month closure for conventional construction. The 14-day assembly limitation started with lifting the first footing and ended with opening to traffic. The limitation on assembly time allowed the NHDOT to evaluate the effectiveness of this new bridge substructure system by removing the site-specific conditions; the 14-day clock would start after the site was prepared.

Two separate incentive/disincentive clauses were also included in the project that was originally bid. The first was an incentive of $1,500 per day for completion before the 30-day closure limit and a disincentive of the same amount per day for completion after the 30-day closure limit. The second was an incentive of $5,000 per day for completion before the 14-day bridge assembly limit and a disincentive of the same amount per day for completion after the 14-day bridge assembly limit.

The low bid for the original project was $1.4M, which was 40% higher than the $1.0M budgeted for the project. The bid was not awarded.

Mill Street Bridge over Lamprey River

Final Contract Requirements

- ☑ Assembly of bridge in 14 days
- ☑ $5,000 per day:
  - ☑ Incentive if less than 14 days
  - ☑ Disincentive if more than 14 days

The NHDOT modified the contract to eliminate the 30-day closure window and the incentive/disincentive related to the closure limit. The 14-day assembly limit and its incentive/disincentive clauses remained in the contract. The project was re-advertised 3 months later.

Mill Street Bridge over Lamprey River – 2004 Construction Costs

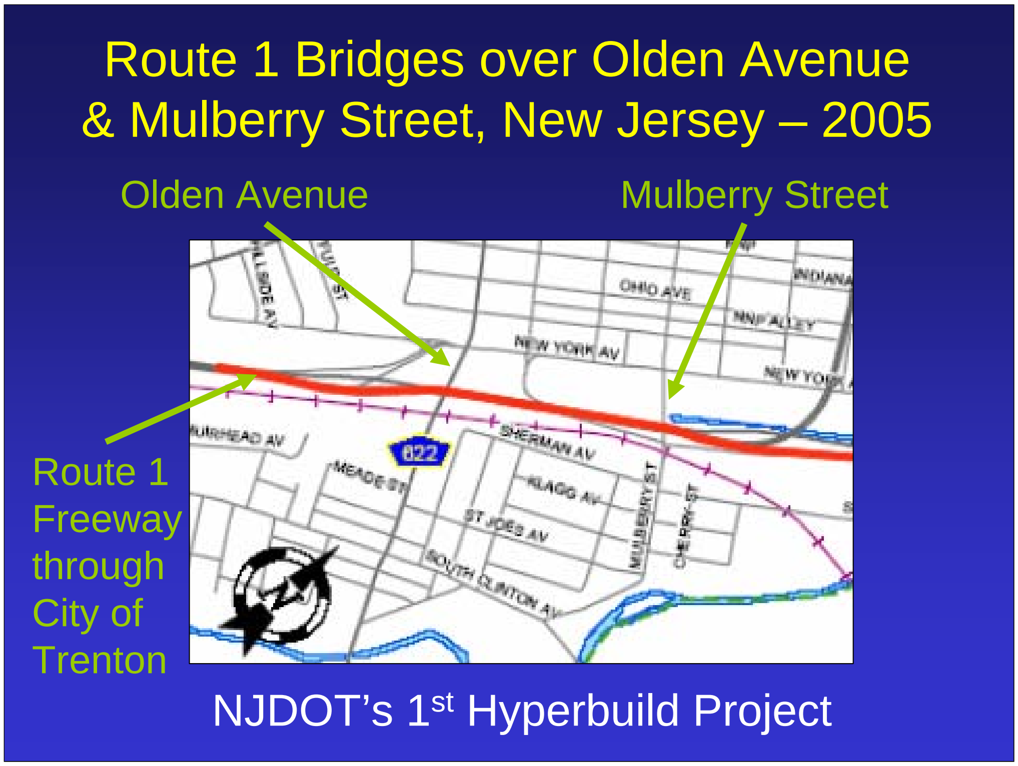
☑ Engineer's Estimate	$ 0.95 M
☑ Number of bidders	6
☑ 2nd Lowest Bid	$ 1.20 M
☑ Low Bid	$ 1.05 M

Erection of bridge in 8 days

The engineer's estimate for the re-advertised project was $ 0.95M. The low bid of $1.05M from R. M. Piper Construction was 10% or $97,000 more than the engineer's estimate. Since there were 6 bidders for the project and the second low bid was $152,000 or 15% above the low bid, the NHDOT awarded the contract. Partial funding was received from the FHWA Innovative Bridge Research and Construction Program.

The bridge assembly was completed in just 8 days. This was 6 days ahead of the 14-day limit in the contract. At $5,000 per day, the contractor received an incentive of $30,000.

The NHDOT plans to use the knowledge gained from this demonstration project to design and construct future bridges with their new precast abutment system. They are developing a plan to provide standard detail sheets for prefabricated elements that could be substituted for cast-in-place concrete designs at the contractor's option at bid, as they now do for partial-depth precast deck panels. The standard sheets in the contract plans will include prefabricated full-depth panels, multi-column bents, cantilevered abutments, and stub abutments. The contractor will be required to submit an assembly plan to pull the components together if he chooses the prefabricated standards option.



Each day the New Jersey Department of Transportation's Route 1 carries more than 50,000 vehicles through the city of Trenton in Mercer County on the western edge of New Jersey. Route 1 is a vital link to adjacent Pennsylvania as well as locations within New Jersey. Three bridge decks on the Route 1 Freeway through the capital city, one at the Olden Avenue Connector and two at Mulberry Street, were deteriorated and in need of constant maintenance. In 2005 the replacement of these three bridges was the NJDOT's first Hyperbuild project.

The term "Hyperbuild" was coined in 2004 by NJDOT Commissioner Jack Lettiere. Hyperbuild projects were initiated to shave years off road construction projects and save millions of dollars in design, construction, and road user costs. To qualify for Hyperbuild status, a project should have a well-defined scope and, if possible, require limited right-of-way acquisition, utility relocations and environmental impacts.

All three bridges in this project were replaced with no impact to rush-hour traffic. The Route 1 bridge over the Olden Avenue Connector was replaced during a weekend closure in August 2005. The Route 1 Southbound bridge over Mulberry Street was replaced during a weekend closure in September 2005, followed by the Route 1 Northbound bridge over Mulberry Street during a weekend closure in October 2005. Design and construction would have taken 22 months using conventional methods.

The 2-lane 86.8-ft long, 35.0-ft wide single-span Route 1 bridge over the Olden Avenue Connector is a highly-skewed steel girder bridge with concrete deck. Its deck was in very poor condition and required constant maintenance.

The 4-lane 60.0-ft long, 82.2-ft wide single-span Route 1 bridge over Mulberry Street consists of two bridges with a median barrier separating each direction of traffic. The decks of these steel girder bridges were also in very poor condition.

The Route 1 bridge over the Olden Avenue Connector was closed at 7 p.m. on a Friday in August 2005, and traffic was rerouted onto a 5-mile detour. The bridge was demolished in place using conventional methods. The existing abutments were repaired and new bearing seats constructed. The prefabricated superstructure was then erected. The longitudinal joints between superstructure segments were then sealed, and the expansion joints at the ends of the span were completed. The cast-in-place parapets were connected to the outside segments with bars in threaded inserts.

The Route 1 Southbound and Northbound bridges over Mulberry Street were closed at 7 p.m. on a Friday in September and October 2005, respectively, and traffic was rerouted onto a 5-mile detour for Southbound Mulberry, while off- and on-ramps were used for Northbound Mulberry. The construction methods and time required to replace these bridges were similar to the bridge over the Olden Avenue Connector. Parapets and median barriers were cast-in-place concrete.

Each superstructure span consists of 5 full-length segments of varying width, each with two Grade 50W steel girders and a 9-inch thick composite concrete deck (Inverset) system. The 86.8-ft long bridge span over Olden Avenue required W36x182 girders, and the 60-ft long bridge spans over Mulberry Street required W30x99 girders. The 15 segments were designed and fabricated at The Fort Miller plant in Schuylerville, New York, assembled at the plant to verify field tolerances, and trucked to an airport parking lot near the bridge. The segments were required to be onsite 24 hours prior to the start of demolition of the existing bridge. The contract specified high performance concrete for all concrete on the job.

Each bridge is expected to see a 75-100 year service life due to the quality of its prefabricated superstructure, the use of high performance concrete, and the attention given to connection details. Conventionally constructed bridges have an average minimum 50-year life in New Jersey.

Route 1 Bridges over Olden Avenue & Mulberry Street

Contract Requirements

- ☑ For each bridge, maximum 57 hours from complete closure to 2 lanes open
- ☑ Lane Occupancy Charge up to $10K/da
- ☑ Substantial Completion by November 16, 2005
- ☑ All work completed by January 13, 2006

Each of the 3 bridges was allowed a 57-hour window from complete closure to re-opening of both lanes. If this window was exceeded, a Lane Occupancy Charge would be assessed, up to $10,000 per day. In addition, Substantial Completion of all 3 bridges was required by November 16, 2005, and all work was to be completed by January 13, 2006.

Route 1 Bridges over Olden Avenue & Mulberry Street

Incentives

- If less than 57 hours:
  - Bridge over Olden Avenue
    - $1,500 per hour
    - Cap of $27,000
  - Each bridge over Mulberry Street
    - $2,000 per hour
    - Cap of $36,000

Incentives were also included on this project to encourage the contractor to minimize onsite construction time even further than 57 hours per bridge.

For the bridge over the Olden Avenue Connector, an incentive of $1,500 per hour was specified if the work was completed in less than 57 hours, not to exceed a maximum of $27,000.

For each bridge over Mulberry Street, an incentive of $2,000 per hour was specified if the work was completed early, not to exceed $36,000.

Route 1 Bridges over Olden Avenue & Mulberry Street

Liquidated Damages

- If more than 57 hours:
  - Bridge over Olden Avenue
    - $1,500 per hour
  - Each bridge over Mulberry Street
    - $2,000 per hour
- If after Nov. 16 – $4,200 per day
- If all work not completed by Jan. 13 – additional $900 per day

Liquidated damages were also specified. The contractor would be charged $1,500 per hour if he took longer than 57 hours to open the bridge over the Olden Avenue Connector to traffic, and $2,000 per hour if he took longer than 57 hours to open either of the bridges over Mulberry Street.

Also, the contractor would be charged $4,200 per day if the bridges weren't substantially completed by November 16, 2005, and an additional $900 per day if all work was not completed by January 13, 2006.

Route 1 Bridges over Olden Avenue & Mulberry Street - 2005 Construction Costs

☑ Engineer's Estimate	$ 3.8 M
☑ Number of bidders	5
☑ 2nd Lowest Bid	$ 3.8 M
☑ Low Bid	$ 3.5 M
☑ **Savings – 8 %** =	**$ 0.3 M**

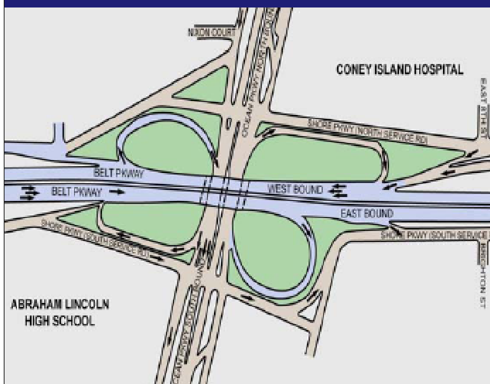
3 bridges replaced in 3 weekends

The engineer's estimate for this project was $ 3.8M. The low bid of $3.5M from Neshaminy Constructors, Inc., was 8% or $297,000 less than the engineer's estimate. There were 5 bidders on this project. The second lowest bid was 10% higher than the low bid.

All three bridges were opened in less than the required 57 hours. The bridge over the Olden Avenue Connector was opened in 56 hours, the bridge over Southbound Mulberry was opened in 51 hours, and the bridge over Northbound Mulberry was opened in 54.5 hours. With all three bridges opened well before Monday morning rush hour, the contractor earned an $18,500 incentive.

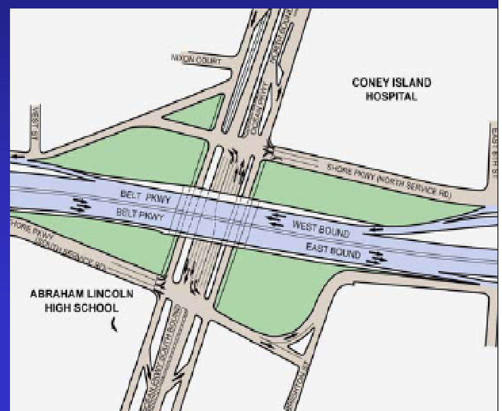
Each of the 3 bridges in the New Jersey DOT's first Hyperbuild project was replaced in a weekend, during a total of 6 days over 3 consecutive months. The replacements were completed in significantly less than the 22 months required for conventional design and construction, and they were completed under budget. The design and construction savings, including delay-related user costs, are in excess of $2M.

Belt Parkway Bridge over Ocean Parkway, New York City (Brooklyn) – 2004



Existing Interchange

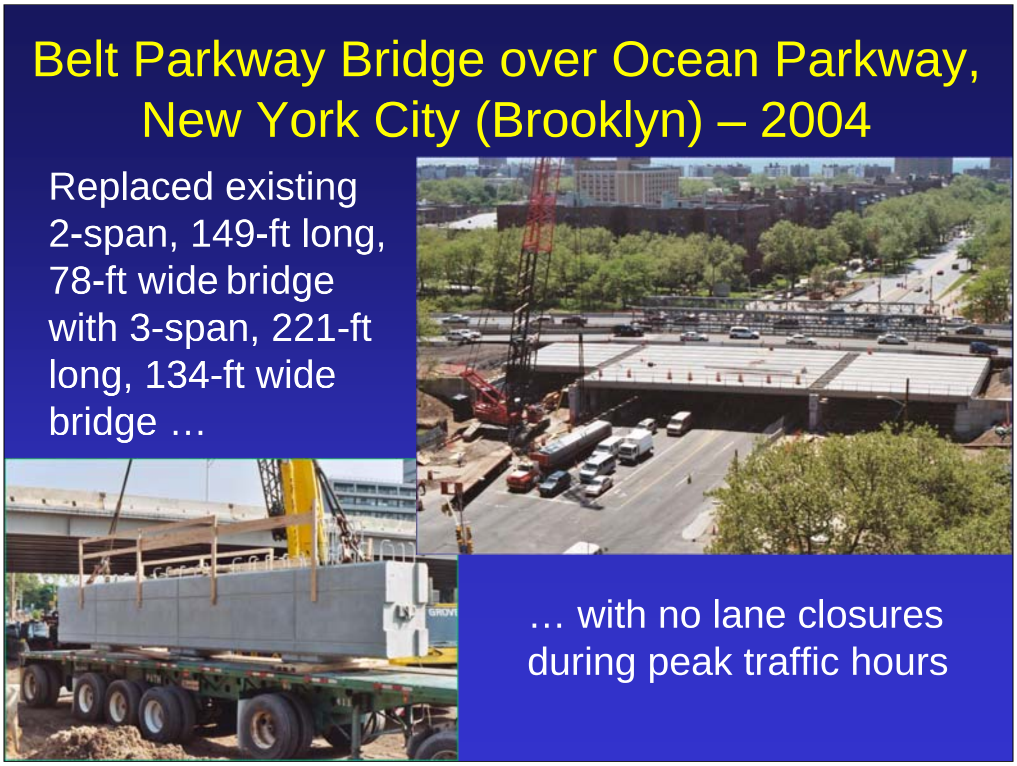
Reconstructed Interchange



The New York City Department of Transportation's Belt Parkway Bridge over Ocean Parkway in south Brooklyn was deteriorated and required complete replacement. The entire design-build project included replacing the existing bridge with a longer and wider bridge, reconfiguring the existing outdated cloverleaf interchange into a modified tight diamond interchange, and other rehabilitation and upgrade work to the Parkways.

The selected design-build team of Granite Halmar/Gannett Fleming specified extensive use of prefabricated bridge components to achieve an accelerated onsite construction timeline. The rapid construction was required to minimize disruption to the 166,000 average daily traffic volume that used the Belt Parkway, a major artery through Brooklyn that also had a large hospital and two schools fronting on the project limits.

Onsite installation of each half of the new bridge took only a few nights in each of two weeks. The entire design-build project was completed in 14 months, including a 3-month winter shutdown. Construction would have taken 3 to 4 years using conventional methods.



The old 2-span 149-ft long, 78-ft wide Belt Parkway Bridge was lengthened and widened to a 3-span 221-ft long, 134-ft wide bridge with span configuration of 49 ft - 107 ft - 65 ft. The width was increased to add shoulders and acceleration/deceleration lanes at the entrance and exit points, in addition to the existing 3 lanes in each direction.

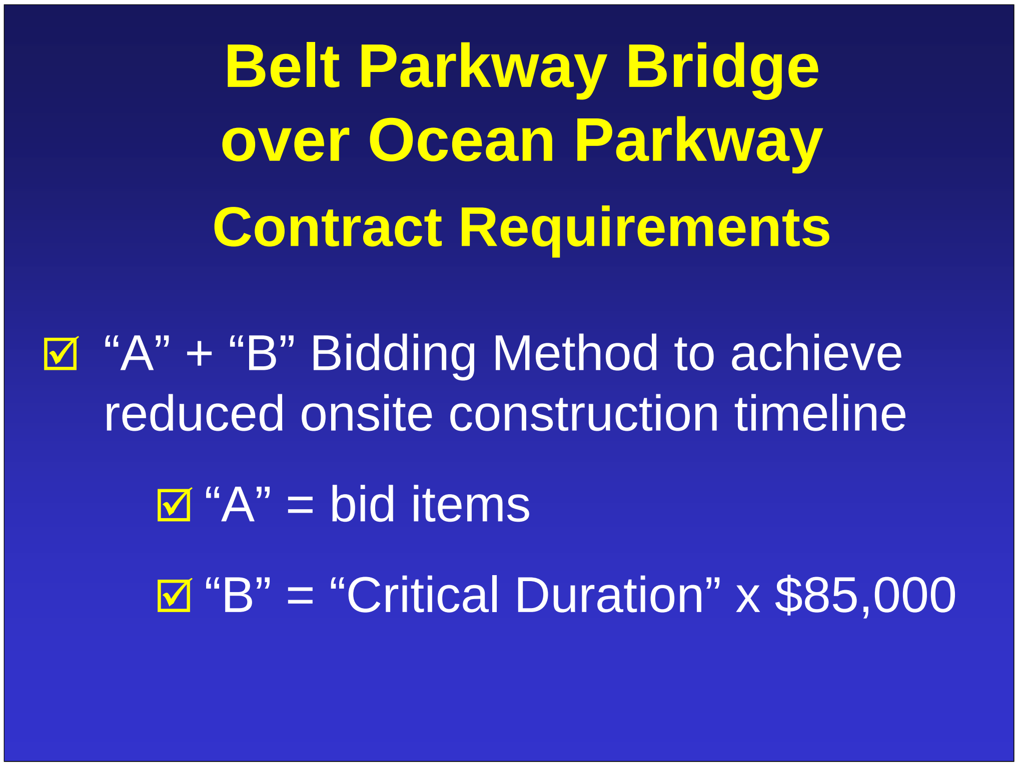
Throughout the project, six lanes of traffic remained open during rush hour, with limited lane closures as needed during off-peak hours. A temporary bridge was erected adjacent to the south side of the existing bridge to maintain the existing number of lanes on Belt Parkway during the bridge reconstruction. Traffic was diverted onto the temporary bridge and the south portion of the existing bridge while the north portion of the existing bridge was demolished and reconstructed. Traffic was then rerouted to the six lanes, three in each direction, on the new north portion of the bridge which was overbuilt to accommodate the six lanes. The south portion of the existing bridge was then demolished and reconstructed.

To minimize traffic disruption, prefabricated components were used extensively. Prefabricated components included concrete-filled steel pipe piles, precast T-walls, precast post-tensioned cap beams, prefabricated superstructure segments, precast bridge parapets, median barriers, and approach slabs. High performance concrete with 4000 psi compressive strength was specified for all precast components. Stainless steel reinforcement was specified for the precast decks, parapets, and median barriers. While the stainless steel reinforcement increased the cost of the bridge by approximately one percent, the bridge is anticipated to last twice as long as the 45-year-old bridge it replaced.

The 51 span-length prefabricated superstructure segments, as well as the other precast concrete components, were fabricated at the Fort Miller plant in upstate New York and shipped 200 miles to the jobsite. Each (Inverset) superstructure segment consisted of two steel girders and a composite deck.

Various processes were adjusted to maximize onsite construction speed. For example, the mini-piles were installed with limited headroom while the existing bridge remained in use. Another example is pre-erection of the superstructure segments in the plant to ensure adequate tolerances for field erection.

The bridge is expected to see a 75-100 year service life due to the quality of its prefabricated components and the attention given to connection details, including the loop-on-loop closure joints connecting the deck segments.



The NYCDOT utilized a modified "A" + "B" bidding method, where "A" equals the bid items and "B" equals a "Critical Duration" (number of days specified by the contractor) times $85,000 to translate the duration into a delay-related user cost. "Critical Duration" was defined as the period of time from when the design-build team permanently impacted the roadways for construction until the time that all new roadways were in their final completed configuration.

Belt Parkway Bridge over Ocean Parkway

Incentives/Disincentives

- ☑ Incentive for completion before "Critical Duration":
  - ☑ $85,000 per day
  - ☑ Cap of $2,000,000
- ☑ Disincentive for completion after "Critical Duration":
  - ☑ $85,000 per day
  - ☑ No dollar limit

Incentive/disincentive and liquidated damages clauses were included in the contract to help ensure early completion of critical activities to minimize traffic disruption. The contract specified an incentive of $85,000 per day for completion before the "Critical Duration," with a cap of $2M. Also specified was a disincentive of $85,000 per day for completion after the "Critical Duration," with no dollar limit.

Belt Parkway Bridge over Ocean Parkway Construction Costs

- ☑ Engineer's Estimate — $ 60.0 M
- ☑ Number of bidders — 5
- ☑ Low Bid — $ 47.9 M
- ☑ Awarded Bid * — $ 55.5 M
- ☑ **Savings – 8 % = $ 4.5 M**

*** Best Value: only 285 "Critical Duration" days**

The engineer's estimate for this project was $ 60.0M. The awarded bid of $55.5M from Granite Halmar Construction Co., Inc., was 8% or $4.5M less than the engineer's estimate. There were 5 bidders on this project. The awarded bid proposed a "Critical Duration" of only 285 days, which was 300 "Critical Duration" days shorter than the low bid. Therefore, at $85,000 per day, the awarded bid was the best value, with a delay-related user cost that was $25M lower than the low bid.

The 14-month construction schedule began September 2003 and included a 3-month winter shutdown. "Critical Duration" work began in March 2004 and was completed in November 2004, in one construction season. The bridge was completed 29 days ahead of the "Critical Duration" of 285 consecutive calendar days that was bid in the contract. The actual number of "Critical Duration" days was just 256 days, with no lane closures during peak traffic hours. The contractor received the maximum $2M incentive.

The bridge work on this design-build project was approximately a third of the total project cost. The project replaced the existing high-traffic-volume bridge with a longer and wider bridge, reconfigured the interchange, and completed other rehabilitation and upgrade work in significantly less time than conventional construction, and it was completed under budget.

The State of Ohio has the second largest number of bridges in the United States and the seventh largest highway system. Like many states, portions of the system are outdated, overburdened and in need of repair. Many areas of the Buckeye State are becoming highly populated and developed, resulting in increased traffic volumes. The additional motorists on the roadways necessitate adding lanes on many of the routes. To accomplish this task, road crews have to close or restrict lanes during the construction process. Such closures and restrictions negatively impact motorists in terms of lost time, higher fuel costs, and lost revenues. The Ohio Department of Transportation (ODOT) is committed to the continuous movement of traffic through all work zones by the elimination or reduction of delays.

ODOT's U.S. Route 22 Bridge over the Scioto River, in Pickaway County 30 miles south of Columbus, provides access for the 12,900 vehicles that cross it each day. It is a vital link for the local school district, the local trucking industry transporting harvest crops to mills, and emergency response services. The existing 45-year old concrete slab and steel girder bridge, built in 1957, had deteriorated girders and a roadway width that was too narrow for the local farm equipment. A 2003 design-build project replaced the deteriorated superstructure with a wider bridge, in one of ODOT's first accelerated construction projects under its Fast Track Bridge Program strategic initiative to build bridges faster, smarter, and better.

Adjacent site constraints required that the new superstructure be constructed in the same location as the existing bridge. The design-build team of Ruhlin Construction Company and E.L. Robinson Engineering Company developed a new superstructure consisting of high performance steel girders and high performance concrete deck, and a galvanized steel pier cap replacement for the rehabilitated and widened substructure, in combination with other innovations to achieve the required accelerated onsite construction timeline. The bridge was completely closed during construction, which began when school closed in mid-June 2003, and it was required to be back in service in 60 days, by the beginning of the fall harvest in August. Traffic was maintained on a 20-mile detour during the closure.

The U.S. Route 22 Bridge was completed in just 48 days, despite heavy rain and flooding. Construction would have taken 18 months using conventional methods.

The existing 6-span 634-ft long, 35.4-ft wide U.S. Route 22 Bridge superstructure was replaced and widened to 44.2 feet to upgrade the 2-lane bridge by increasing the two shoulders from 3 ft to 4 ft, and by adding an 8-ft sidewalk.

While much of this bridge replacement project used conventional design and construction methods, adjustments were made to maximize onsite construction speed. The five new girders per span were made of high performance steel and fabricated by Stupp Bridge Company in Kentucky. They were designed to be simply supported to streamline erection, and made continuous with integral concrete diaphragms over the piers. The integral abutments on this bridge make it ODOT's longest bridge without expansion joints. Galvanized permanent metal deck forms provided a stay-in-place deck forming system instead of the traditional wooden deck forms that would have to be removed.

The widening of the substructure was also designed and constructed to shorten the onsite construction time. The existing piers were saw-cut below the pier-stem construction joint and replaced with galvanized steel plate girder bent caps that extended to groups of four concrete-capped galvanized steel 18-inch diameter pipe piles under the widened portion of the bridge. Pipe piles for several of the piers under the widening were driven before the bridge was closed to further shorten the bridge closure time.

Other details to speed onsite construction included demolition of the existing deck beginning at the middle of the bridge and simultaneously working toward the abutments because environmental restrictions prevented river access. Other details included beginning the retrofit work on each pier as soon as the existing girders were removed, shipping and erecting the new girders as soon as the pier retrofits were completed, and using two concrete pumps to avoid delays during the deck pour.

The bridge is expected to see a 75-year service life due to the use of high performance concrete in the deck, high performance steel girders, galvanized steel plate girder bent caps, galvanized steel pipe piles, and good construction practices. ODOT has partnered with the University of Cincinnati to evaluate the piloted features of the contract.

U.S. 22 Bridge over Scioto River

Contract Requirements

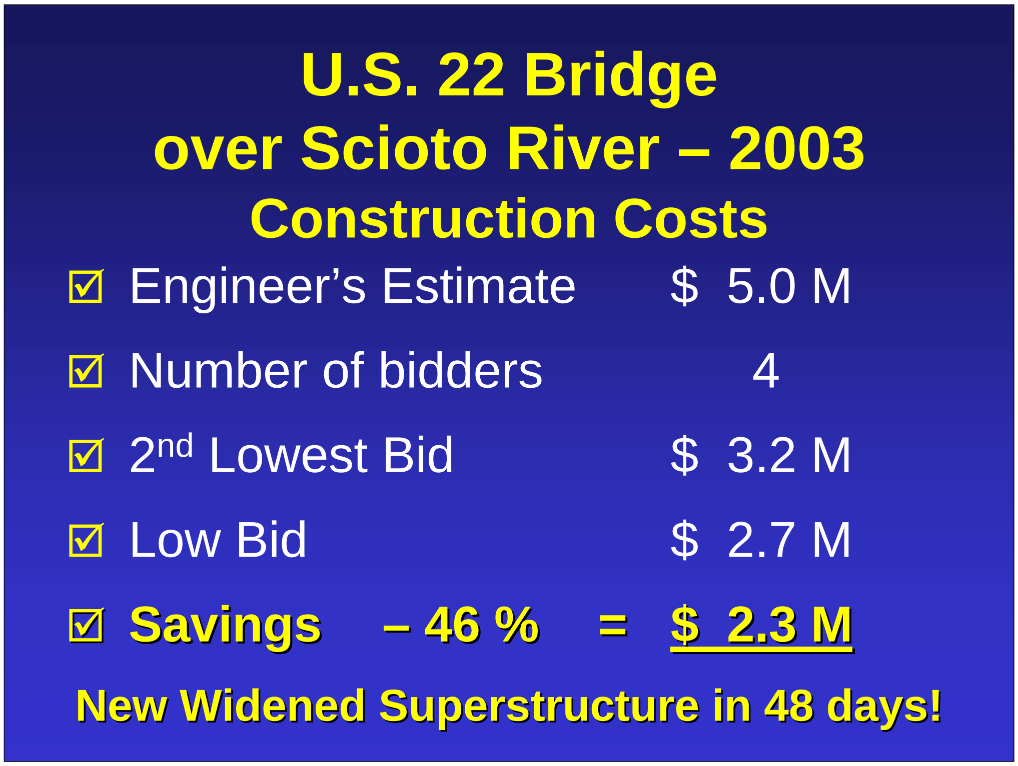
- ☑ Maximum 60 days of closure
- ☑ Liquidated savings for early completion:
  - ☑ $50,000 per day
- ☑ Liquidated damages for late completion:
  - ☑ $20,000 per day for 61-65 days
  - ☑ $30,000 per day for 66-70 days
  - ☑ $40,000 per day for 71-75 days
  - ☑ $50,000 per day for 76 or more days

The Ohio DOT awarded this design-build project based on responses to a bid package that included a Scope of Services and a set of the existing bridge plans from 45 year ago. The Scope of Services required that the bridge be closed a maximum of 60 days.

In addition, incentive/disincentive clauses were included in the contract to help ensure completion of critical activities to open the bridge on the accelerated schedule.

The contract specified Liquidated Savings of $50,000 for each day that all necessary work was completed prior to the maximum 60-day closure requirement, with maximum Liquidated Savings of $500,000.

The contract also specified Liquidated Damages for completion after the specified maximum 60-day closure. The Liquidated Damages were assessed at $20,000 per day for opening the bridge in 61-65 days, $30,000 per day for 66-70 days, $40,000 per day for 71-75 days, and $50,000 per day if the bridge remained closed for 76 or more days.



The engineer's estimate for this project was $ 5.0M. The low bid of $2.7M from Ruhlin Construction Company was 46% or $2.3M less than the engineer's estimate. There were 4 bidders on this project, with the 2nd lowest bidder 19% or $500,000 higher than the low bid.

The bridge was completed in 48 days, 12 days ahead of schedule and without a single lost-time injury. The contractor received the maximum $500,000 incentive.

This Ohio DOT Fast Track design-build project replaced the existing deteriorated bridge with a wider superstructure in significantly less time than conventional construction, and it was completed significantly under budget. It demonstrates quite effectively that cost-effective, long-lasting accelerated bridge construction projects can be built through the innovative use of conventional construction in combination with high performance materials and good contracting strategies. ODOT has continued their Fast Track Bridge Program with subsequent accelerated bridge construction projects.

In 2000 the Texas Department of Transportation's State Highway 66 over Lake Ray Hubbard in Rockwall County northeast of Dallas was a narrow, congested, 40-year-old 2-lane bridge. It was replaced with a pair of bridges, completed in early 2003. The new 4,360-ft long, 40-ft wide eastbound bridge has two traffic lanes and shoulders, and precast bent caps as part of its substructure due to a contractor-initiated field change.

Precasting 43 identical caps resulted in a time savings of 5 to 7 days per cap, at least 215 days of effort. Forming, concrete placement, and curing for conventional bent caps would have required 7 days of critical path activity per cap. This represented a total potential delay of 9 months for the 43 bent caps, a delay that would have required additional overhead costs and slower project delivery.

First the new westbound bridge was built adjacent to the existing bridge using conventional construction. Traffic was then moved to the new bridge, the old bridge was demolished, and the eastbound bridge was built approximately on the bridge's original alignment.

The contractor fabricated the 43 identical caps adjacent to one end of the bridge. The precast reinforced concrete caps are 37.5-ft long with beveled ends and a 3.25-ft square cross section. Each cap is supported by three 3-ft diameter cast-in-place columns, and provides the bearing for five AASHTO Type IV beams per typical 100-ft span. TxDOT designed grouted-duct connections between the precast caps and the cast-in-place columns based on previous research at the University of Texas at Austin. Seismic design was not required.

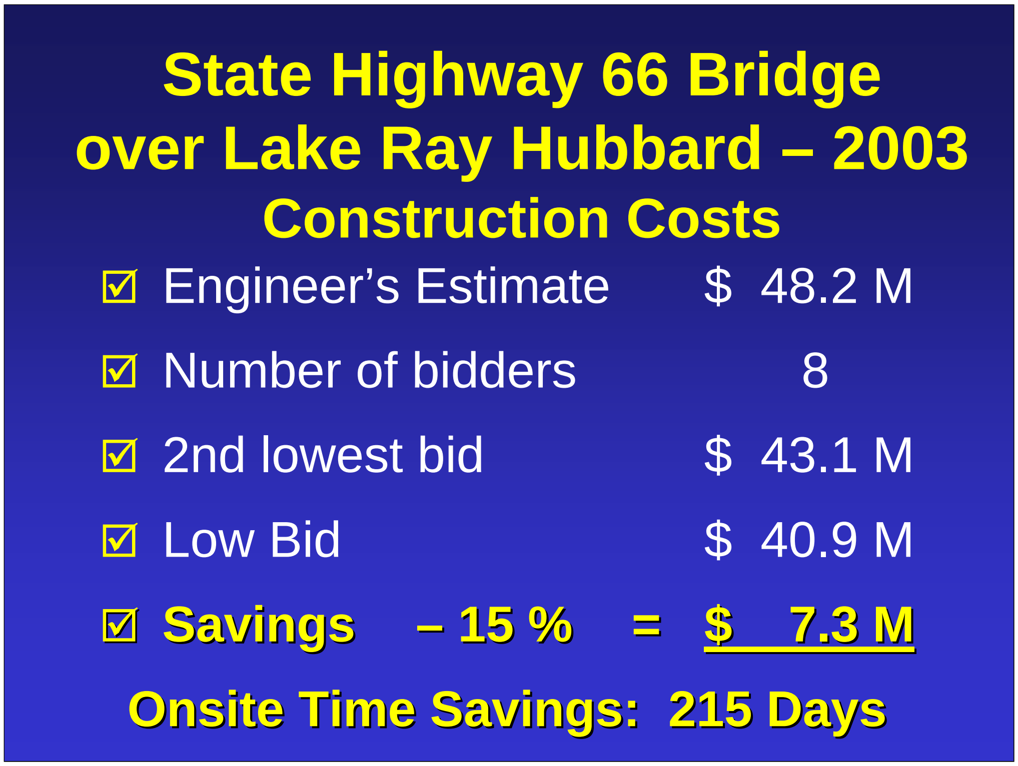
In addition to speeding onsite construction, fabricating the bent caps off the critical path allowed the use of a normal-strength high performance concrete mix design that results in greater durability but with a slower strength gain due to the 35 percent replacement of cement with ground-granulated blast-furnace slag.

State Highway 66 Bridge over Lake Ray Hubbard Contract Requirements

- ☑ Contract specified cast-in-place concrete bent caps
- ☑ Contractor proposed field change to precast concrete bent caps for eastbound bridge
- ☑ TxDOT accepted proposed field change, with no change in funding

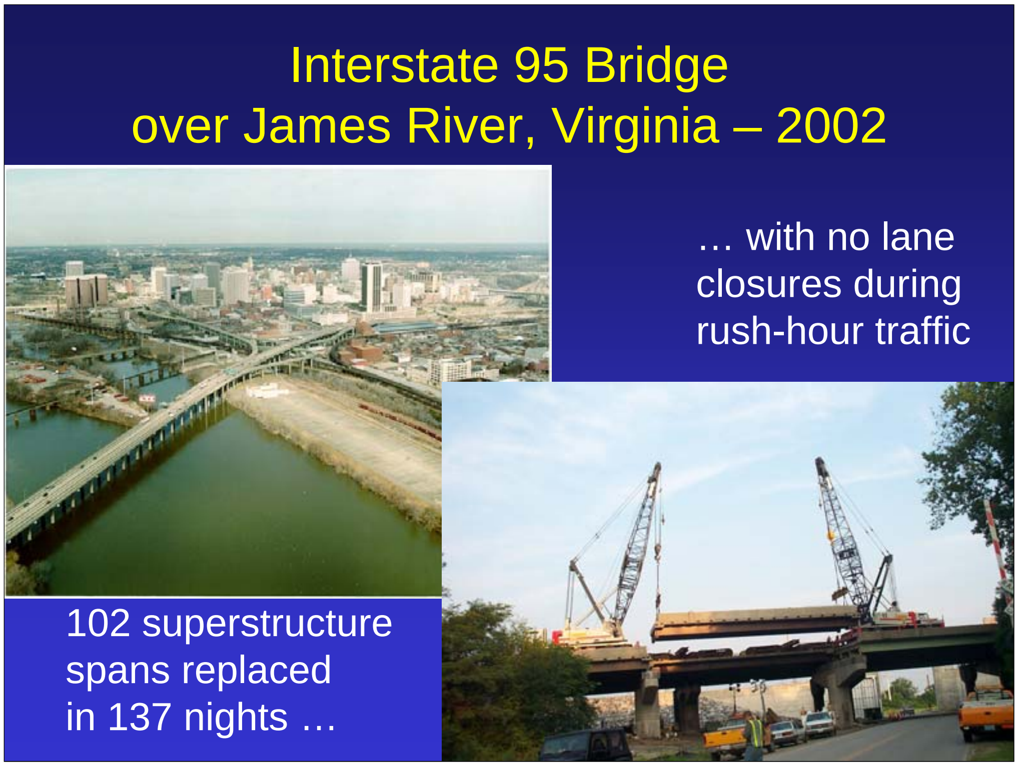
The contract specified conventional cast-in-place construction for the substructures. Early in the project the contractor, Traylor Bros., Inc., proposed a field change to precast reinforced concrete bent caps as a way to speed construction of the eastbound bridge, to avoid the difficulties in handling formwork and materials over water, and to minimize the construction workers' exposure to high-voltage transmission lines running adjacent to the bridge. TxDOT approved the contractor's proposal with no change in funding.

The contract did not include incentives or disincentives.



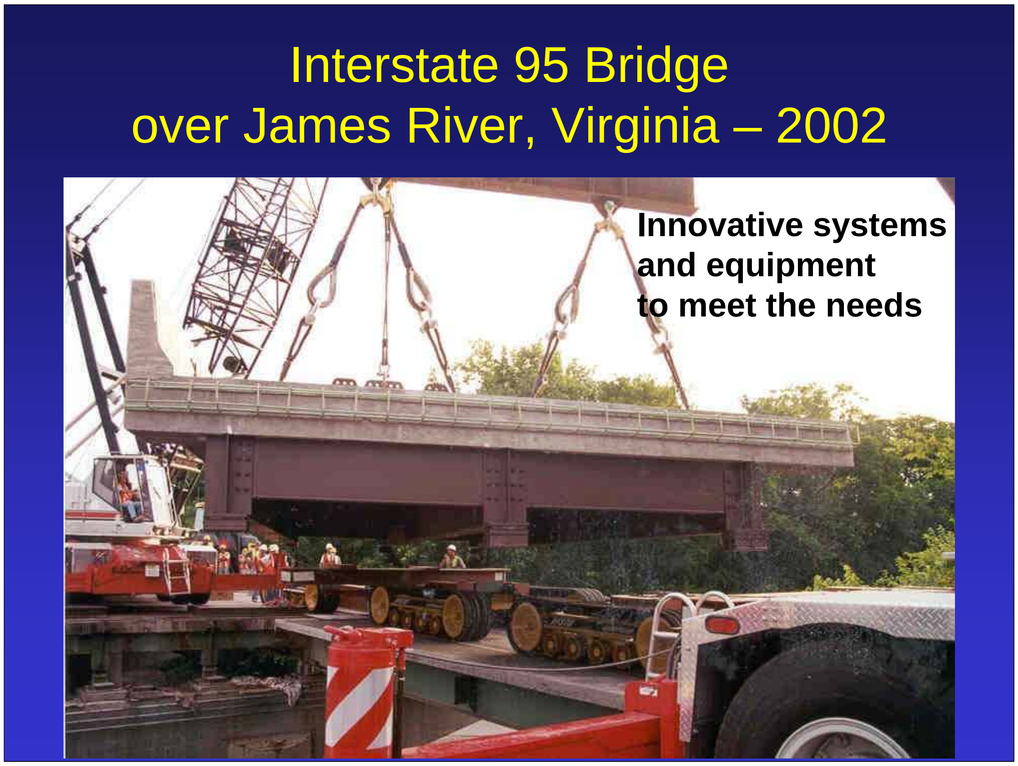
The engineer's estimate for this project was $48.2M. The low bid of $40.9M was 15% or $7.3M less than the engineer's estimate. There were 8 bidders on this project, with the 2nd lowest bid about 5% or $2.2M more than the awarded low bid.

Using the 43 precast bent caps reduced onsite construction time by 215 days. TxDOT obtained the bridge ahead of schedule and under budget.



Interstate 95 over the James River in the City of Richmond, Virginia, consists of twin 4,185-ft long bridges with 3 lanes in each direction and a total width of 90 ft. In 1997 the bridges carried 110,000 vehicles daily. Nearly 50 years old, the superstructures had significant structural deterioration and needed to be replaced.

In 2002 the Virginia Department of Transportation completed replacement of the superstructure and rehabilitation of the substructure. The 102 superstructure spans were replaced in just 137 nights during 17 months, with no impact to rush-hour traffic. Conventional construction would have required 24 to 36 months and significant impact to traffic.



Public participation was solicited at the beginning of plan development to limit the impact to motorists. A community advisory group was given several construction options for the replacement. Their preferred option, which VDOT used, was night construction with all three lanes open in each direction during the day. Construction took place from 7 p.m. to 6 a.m. only. During the night work, traffic was shifted to one of the bridges, with one lane in each direction remaining open.

The bridges are composed of multiple steel plate girder simple spans ranging from 44 ft to 114 ft in length, and a 243-ft truss span. The typical steel plate girder span was replaced with 2 full-span-length prefabricated superstructure segments. Each prefabricated segment consisted of 3 steel plate girders with an 8.75-inch deck, complete with bridge railing, and weighed approximately 100 tons. The segments were fabricated by the contractor at a nearby casting yard.

During the night, the existing superstructure was cut longitudinally at every other girder. The old segments were removed using high-capacity cranes and conventional flatbed trailers. The cranes then installed the new prefabricated superstructure segments. After the two segments were in place, the span was transversely post-tensioned and connected longitudinally with bars running through pockets cast into the ends of the segments. The deck of the truss span was replaced with a filled-grid deck system because mechanical and geometrical requirements precluded the use of the prefabricated superstructure segments. The substructure was also rehabilitated as needed.

Interstate 95 Bridge over James River Contract Requirements

- ☑ "A" + "B" Bidding Method
  - ☑ "A" = bid items
  - ☑ "B" = calendar days to replace superstructure
- ☑ VDOT considered bids to be non-responsive if days > 240 days

VDOT utilized the "A" + "B" bidding method, where "A" equals the bid items and "B" equals the number of calendar days with nighttime lane closures for the superstructure replacement and rehabilitation.

The Department considered bids greater than 240 days to be non-responsive.

Interstate 95 Bridge over James River Incentives / Disincentives

- ☑ Incentive for early completion:
  - ☑ $30,000 per day
  - ☑ Cap of $2,000,000
- ☑ Disincentive for late completion:
  - ☑ $30,000 per day
  - ☑ No dollar limit

The contract included an incentive of $30,000 for each day the work was completed ahead of the time that was bid in the contract, not to exceed $2.0M. The contract also included a disincentive of $30,000 for each day the work was completed past the bid time, with no dollar limit.

Interstate 95 Bridge over James River Additional Disincentive

Failure to Restore All Traffic Lanes by	Amount	Cumulative Amount
6:00 A.M.	$ 5,000	$ 5,000
6:15 A.M.	$10,000	$ 15,000
6:30 A.M.	$35,000	$ 50,000
6:45 A.M.	$40,000	$ 90,000
7:00 A.M.	$25,000	$115,000
7:15 A.M.	$10,000	$125,000
7:30 A.M.	$10,000	$135,000
7:45 A.M.	$10,000	$145,000
8:00 A.M.	$ 5,000	$150,000
8:30 A.M.	$ 5,000	$155,000

VDOT wanted all lanes open to traffic from 6 a.m. to 7 p.m. To achieve this, an additional disincentive was included for not having all lanes of the bridge open to traffic on time.

Interstate 95 Bridge over James River

Additional Disincentive, continued

Failure to Restore All Traffic Lanes by	Amount	Cumulative Amount
9:00 A.M.	$ 5,000	$160,000
10:00 A.M.	$ 5,000	$165,000
11:00 A.M.	$ 5,000	$170,000
12:00 Noon	$ 5,000	$175,000
1:00 P.M.	$ 5,000	$180,000
2:00 P.M.	$ 5,000	$185,000
3:00 P.M.	$15,000	$200,000
4:00 P.M.	$20,000	$220,000
5:00 P.M.	$20,000	$240,000
6:00 P.M.	$10,000	$250,000

This additional disincentive accumulated up to $250,000 per day. Disincentives of this magnitude help ensure the contractor's buy-in to the owner's accelerated construction schedule and encourage the contractor to innovate.

Interstate 95 Bridge over James River – 2002 Construction Costs

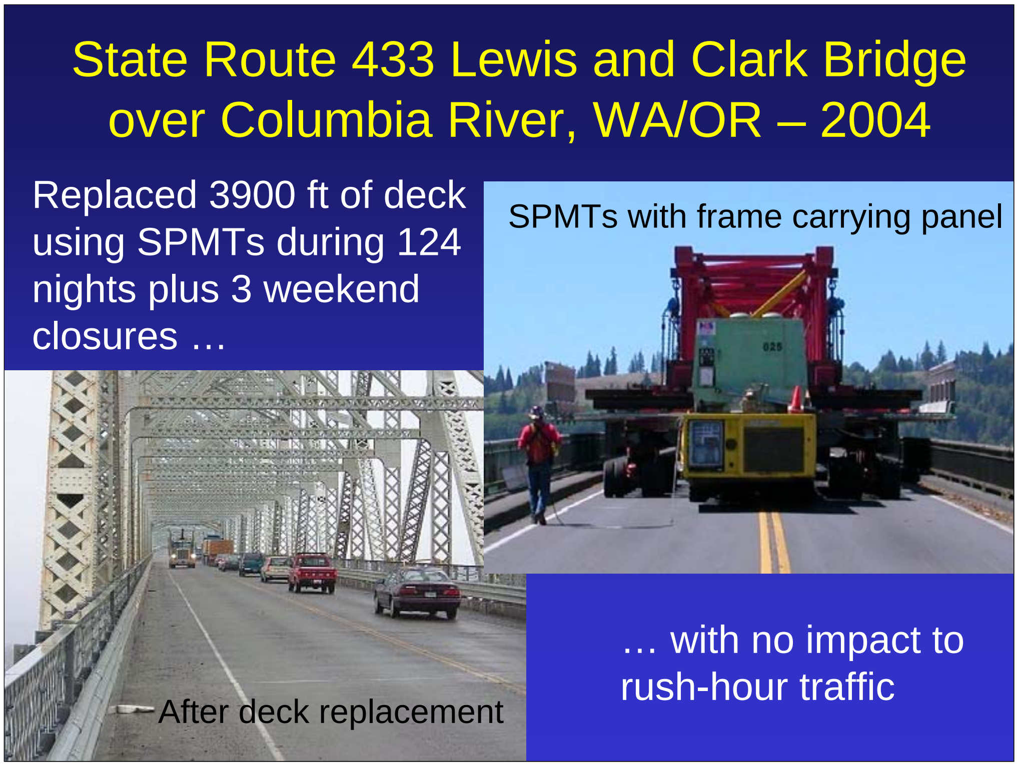
- ☑ Engineer's Estimate $ 48.5 M
- ☑ Number of bidders 5
- ☑ 2nd lowest bid $ 44.9 M
- ☑ Low Bid $ 43.4 M
- ☑ **Savings – 11 % = <u>$ 5.1 M</u>**

Closures: Only 137 nights

The engineer's estimate for this project was $48.5M. The low bid by Archer-Western Contractors, Ltd., was $43.4M and 179 days calendar days with nighttime lane closures. The low bid was 11% or $5.1M less than the engineer's estimate. There were 5 bidders on this project, with the 2nd lowest bid about 3% or $1.5M more than the awarded low bid.

The contract specified that the contractor would receive $30,000 per day for early completion. The contractor replaced the 102 superstructure spans during only 137 night closures of half the roadway width. He received $30,000 for each of 42 nights, for a $1.3M incentive.

VDOT obtained a new superstructure ahead of schedule with less impact to the traveling public and with improved safety, and obtained it under budget.

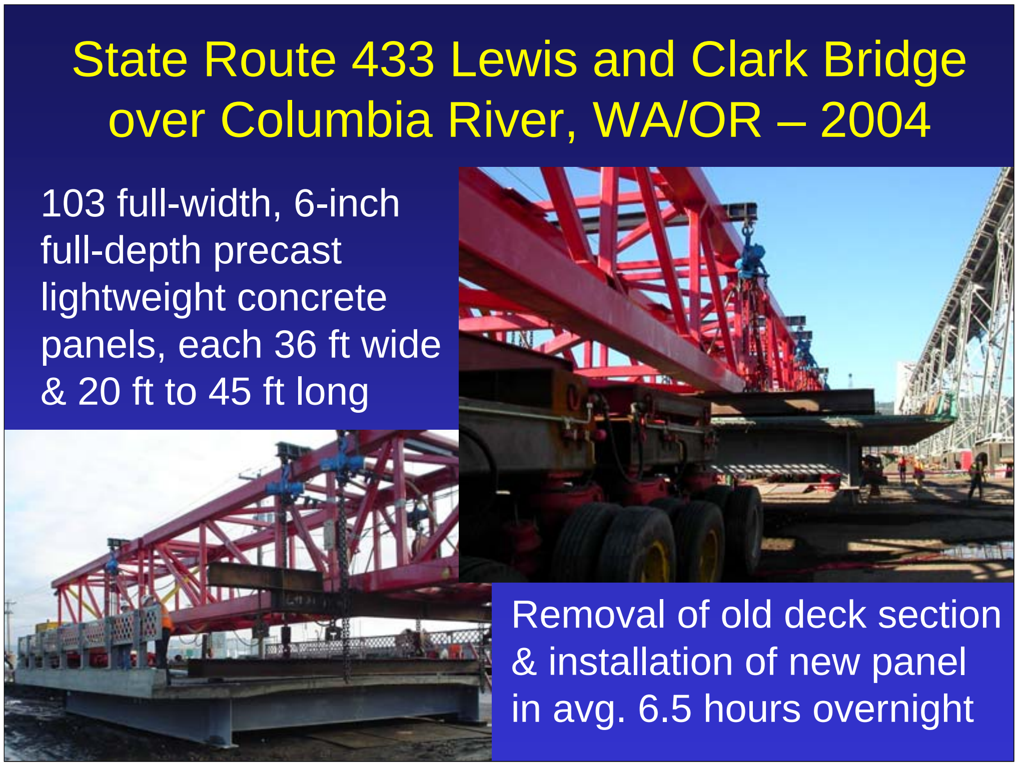


The Lewis and Clark Bridge on State Route 433 over the Columbia River spans the state line between Longview, Washington and Rainier, Oregon and is jointly owned by the Washington State Department of Transportation and the Oregon Department of Transportation. The 1929 steel through-truss bridge was designed by the famed engineer Joseph B. Strauss and is listed in the National Register of Historic Places. It provides access across state lines for 18,000 vehicles each day.

In early 2000 its deck was severely deteriorated and required replacement. Accelerated onsite construction was needed to limit the impact to emergency services and to avoid extended use of a 40-mile detour west to the town of Cathlamet that included a ferry ride or an 80-mile detour south to Portland.

In 2004 WSDOT completed replacement of the bridge deck on this mile-long bridge with no impact to rush-hour traffic. Self-propelled modular transporters (SPMTs) were used to replace 3,900 ft of deck during 124 night closures plus 3 weekend closures. A helicopter with landing pad was provided on the south side of the river for emergency crossings during the closures. Construction using conventional cast-in-place methods would have required 4 years.

The deck replacement extended the life of the bridge another 25 years.



In the contract plans, the Washington State DOT had designed prefabricated full-width full-depth deck panels and a placement procedure to accommodate the required rapid construction schedule. One contractor, Max J. Kuney Company of Spokane, partnered with an SPMT supplier in the development of his bid, assuming a revised placement procedure that used SPMTs in combination with a specially-designed steel truss frame for lifting and transporting. Their bid was considerably lower than the other bidders. Kuney was awarded the contract, and WSDOT accepted their proposed system.

The 5,478-ft long bridge included 3 deck-truss spans at 168 ft, 337 ft, and 337 ft; 3 through-truss spans at 760 ft, 1200 ft, and 760 ft; plus approach spans. Of this total length, 3900 ft of the deck was replaced with 103 prefabricated deck panels that were 36 ft wide and 20 ft to 45 ft long (20 at 45 ft, 45 at 40 ft, 20 at 35 ft, 14 at 30 ft, and 4 at 20 ft). The lightweight concrete panels were 6-in. thick plus 1-in. thick overlay. Each panel was supported on two longitudinal steel support beams and had a maximum panel weight of 96 tons. The new deck eliminated the existing 3-ft-wide raised sidewalks, providing 5-ft shoulders at road level for bicyclists and pedestrians as well as additional room for traffic to maneuver around disabled vehicles.

The bridge was closed on Sunday through Thursday nights from 9:30 p.m. to 5:30 a.m. The SPMTs with truss frame moved a new panel to the top of the bridge, lifted the old panel out, and then lowered the new panel into place before taking the old panel off the bridge. Each panel movement took an average 6.5 hours. Use of this prefabricated deck system in combination with the innovative SPMT equipment reduced construction workers' exposure to traffic during construction, improved the constructability of the bridge, and allowed the bridge to remain open for normal weekday operations.

SR 433 Lewis and Clark Bridge over Columbia River
Contract Requirements

- ☑ "A" + "B" + "C" Bidding Method to determine lowest responsible bidder
  - ☑ "A" = bid items
  - ☑ "B" = bridge closures @ $8,000
  - ☑ "C" = single lane closures @ $2,000

WSDOT utilized an "A" + "B" + "C" bidding method to determine the lowest responsible bidder, where "A" equals the bid items, "B" equals the total number of bridge closures established by the bidder to complete the work times the Total Bridge Rental Closure Cost of $8,000, and "C" equals the total number of single lane closures established by the bidder to complete the work times the Bridge Single Lane Rental Cost of $2,000. The "B" and "C" parts of the bid were only used to determine the lowest responsible bidder, not to determine final payment to the contractor.

SR 433 Lewis and Clark Bridge over Columbia River

Incentives for Early Completion

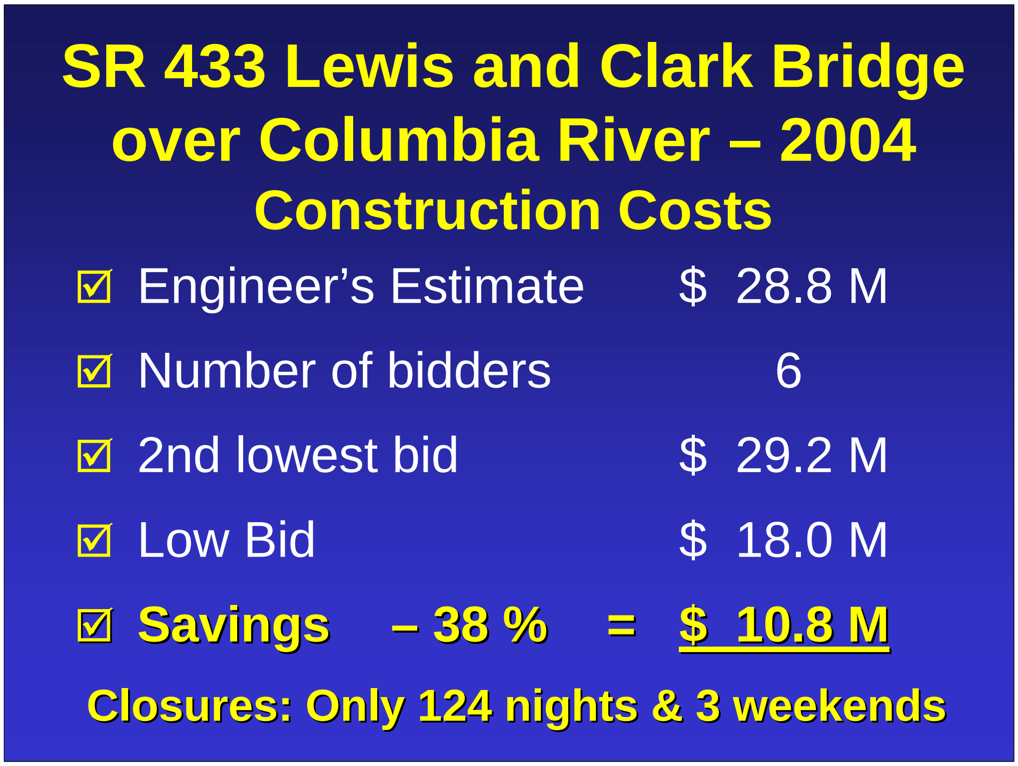
- ☑ $100,000 for completion by April 2004
- ☑ $55,000 per Weekend Bridge Closure less than 4
- ☑ $4,000 per Total Bridge Closure less than number bid
- ☑ $1,000 per Single Lane Closure less than number bid

The contract included several incentives for early completion. If the contractor finished all work requiring Weekend or Total Bridge Closures by April 30, 2004, he would receive $100,000. In addition, for each Weekend Bridge Closure less than 4, the contractor would receive $55,000. For each Total Bridge Closure less than the number bid in the contract, the contractor would receive $4,000. For each Single Lane Closure less than the number bid in the contract, the contractor would receive $1,000.

SR 433 Lewis and Clark Bridge over Columbia River
Liquidated Damages

- ☑ $16,000 per Total Bridge Closure more than number bid
- ☑ $4,000 per Single Lane Closure (SLC) more than number bid
- ☑ $1,700 per 15-min period beyond times specified for Weekend or Total Closure
- ☑ $900 per 15-min period beyond SLC

The contract also included liquidated damages for not meeting the time constraints for accelerated construction. This included a penalty of $16,000 per Total Bridge Closure more than the number that was bid, and a penalty of $4,000 per Single Lane Closure more than the number that was bid. In addition, penalties would be assessed for any late opening of closures. A $1,700 penalty per 15-minute period would be assessed for time beyond that specified for Weekend Closure or Total Bridge Closure, and a $900 penalty per 15-minute period would be assessed for time beyond that specified for Single Lane Closure.



The engineer's estimate for this project was $ 28.8M. The low bid of $18.0M was 38% or $10.8M less than the engineer's estimate. There were 6 bidders on this project, with the 2nd lowest bid about 62% or $11.2M more than the awarded low bid.

The contractor completed all work requiring Weekend or Total Bridge Closures by the end of April 2004 and, therefore, received the $100,000 incentive. He also received an incentive of $55,000 for using 3 instead of 4 Weekend Bridge Closures, and an additional $30,000 for having 30 fewer Single Lane Closures than the 173 allowed. The contractor received a total incentive of $185,000. No liquidated damages were assessed.

3900 linear feet of deck were replaced during only 124 nights plus 3 weekend closures, with no impact to rush-hour traffic. The Washington State DOT not only obtained the new deck ahead of time with less impact to the traveling public and with increased safety, but also obtained it significantly under budget.

The details for these nine projects clearly show that prefabrication in combination with effective contracting strategies can result in the completion of bridge replacement projects on an accelerated timeline and under budget. The projects included various prefabricated bridge elements and systems that provide quality, long-lasting bridges. The projects also included bidding methods and incentives/disincentives that provided an economic reason for the contractor to innovate and to buy in to the owner's accelerated onsite construction timeline.

Prefabrication and effective contracting strategies result in cost-effective rapid bridge construction projects. Their use helps the owner accomplish its mission of efficiently moving people and goods.

Thank you for your attention.