

Engineering Management  
Field Project

**“Safe and Sound” – An Accelerated Bridge  
Improvement Program in Missouri –  
A Case Study**

By

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## **Executive Summary**

Predicted increases in the number of trucks and axle loads on the roads will continue to degrade the roads more rapidly. Deterioration of the bridges is expected, but it can be monitored and controlled through properly funded maintenance, rehabilitation, and replacement activities. Proper funding and a continued focus on bridges, such as the Missouri Department of Transportation's (MoDOT) Safe and Sound Bridge Improvement Program, is necessary to decrease the number of structurally deficient and functionally obsolete bridges in the country.

The innovative approach developed by KTU Constructors, a joint venture of Kiewit Western (a subsidiary of Kiewit Corporation), Traylor Brothers and United Contractors, along with HNTB Corporation and The LPA Group as design consultants provided MoDOT with a way to replace 554 of Missouri's ailing bridges at an accelerated pace. The complexity resulted from 554 scattered bridge sites in ten different MoDOT districts (then existing) with distinct hydraulic, geotechnical and environmental characteristics required advanced planning, streamlined design and plan production process and strategic construction timelines. An average of 45 days is allotted per bridge for reconstruction including demolition of the existing bridge. In order to meet this aggressive design and construction schedule, the project team developed the following approach:

- Early evaluation of all 554 bridges
- Standardization of proposed bridge spans, widths and skews
- Incorporation of various designs and details used by other State Department of Transportation that would help accelerate design and construction process
- Minimization of construction duration through the utilization of concrete precast components for superstructure and pile bents for substructure
- Standardization of the superstructure and substructure design and detailing processes

- Development and utilization of standard plan sheets

As the first successful program of its kind in the United States, the Safe and Sound Bridge Improvement Program now serves as a model for alternative project delivery. Many states are watching the outcome of the program and considering its applicability in their own states. MoDOT has proven with this unique design-build program that it is possible to accomplish a statewide logistics project under extreme budget limitations and time constraints.

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## Abbreviations

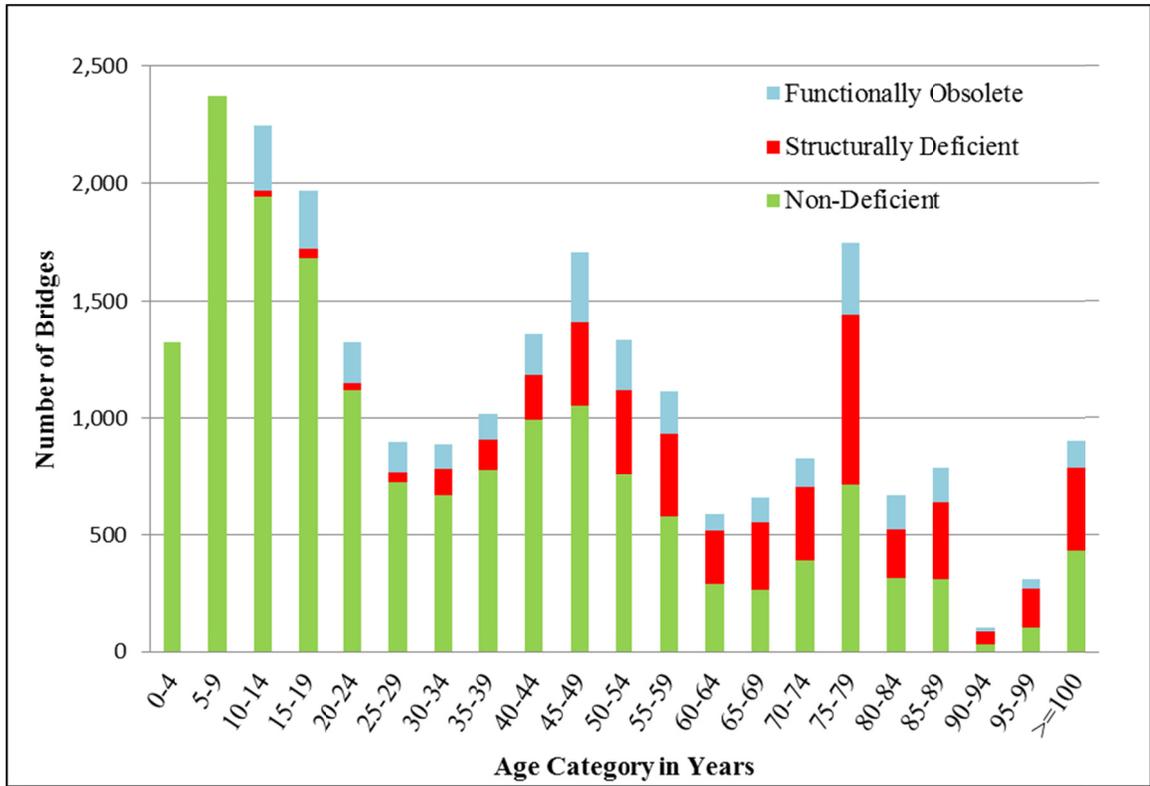
ABC	Accelerated Bridge Construction
ABB	Adjacent Box Beam
ACS	Adjacent Cored Slab
AAS	Alternate Applicable Standards
AASHTO	American Association of State Highway and Transportation Officials
AADT	Annual Average Daily Traffic
ADT	Average Daily Traffic
BAFO	Best and Final Offer
BHSR	Bridge Hydraulics & Scour Report
CADD	Computer Aided Drafting and Design
CMGC	Construction Manager General Contract
DBT	Design-Build Team
DBFM	Design-Build-Finance-Maintain
DBFOM	Design-Build-Finance-Operate-Maintain
DEM	Digital Elevation Model
GP&E	General Plan and Elevation
GIS	Geographic Information System
HOT	High Occupancy Toll
HOV	High Occupancy Vehicle
HEC-RAS	Hydrologic Engineering Center's River Analysis System
IDOT	Iowa Department of Transportation
LNTP	Limited Notice to Proceed
MOT	Maintenance of Traffic
MoDOT	Missouri Department of Transportation
MDBB	Modified-Design-Bid-Build
NBI	National Bridge Inventory
PBES	Prefabricated Bridge Elements and Systems
PPP	Public-Private-Partnerships
RFP	Request for Proposals
RFQ	Request for Qualifications
SPMT	Self-Propelled Modular Transports
SBB	Spread Box Beam
SCS	Spread Cored Slab
SEMA	State Emergency Management Agency
SHRP	Strategic Highway Research Program
TS&L	Type, Size and Location
UHPC	Ultra-high Performance Concrete
USGS	United States Geological Survey
UDOT	Utah Department of Transportation
VDOT	Virginia Department of Transportation

## **1. Introduction**

The Safe and Sound Bridge Improvement Project is a large-scale system improvement that is to replace Missouri's 554 ailing bridges in a short period of time using Accelerated Bridge Construction (ABC) techniques and under a unique design-build contract. The project goal is to replace bridges in poor or serious condition located on major and minor highways over relatively small streams throughout the state. Relatively few bridges are to be replaced over railroads or other roadways. In order to keep costs under control, Missouri Department of Transportation (MoDOT) expected and encouraged innovative methods while keeping public inconvenience to a minimum. The contract team is challenged with delivering quality bridges on a large scale in a short time at a good value. The complexity resulted from 554 scattered bridge sites in ten different MoDOT districts (then existing) with distinct hydraulic, geotechnical and environmental characteristics required advanced planning, streamlined design and plan production process and strategic construction timelines. An average of 45 days is allotted per bridge for reconstruction including demolition of the existing bridge.

Because of limited structural capacity, a structurally deficient bridge may be closed or restrict traffic in accordance with weight limits. These bridges are not unsafe, but must post limits for speed and weight. A functionally obsolete bridge has older design features and geometrics, and though not unsafe, cannot accommodate current traffic volumes, vehicle sizes, and weights.

In December 2009, of the 24,156 bridges across the state of Missouri, 4,289 (17.8%) were categorized as structurally deficient and 3,016 (12.5%) were categorized as functionally obsolete for a total of 7,305 (30.3%) deficient bridges. [U.S.DOT, FHWA, "Bridges by Owner"] Total percentage of deficient bridges in Missouri was higher than national average which was 24.8% as of December 2009. Figure 1.1 shows the total number of bridges and the number of structurally deficient and functionally obsolete bridges by age in Missouri.



**Figure 1.1: Distribution of Missouri Bridges by Age and Condition in 2009** [U.S.DOT, FHWA, “Bridges by Owner”]

Note: Bridges that are both structurally deficient and functionally obsolete are classified as structurally deficient.

## **2. Literature Review**

### **2.1 Importance of Infrastructure and Current State of Bridges in United States**

Bridges are an integral part of the United States highway network, providing links across natural barriers, passage over railroads and highways, and freeway connections. The reliable and efficient flow of people, commodities, and emergency services within our roadway system relies on the nation's bridge system. [ASCE, "Infrastructure Fact Sheet"] Extensive and efficient infrastructure is critical for ensuring the effective functioning of the economy, as it is an important factor determining the location of economic activity and the kinds of activities or sectors that can develop in a particular instance. A well-developed transportation and communications infrastructure network is a prerequisite for the access of less-developed communities to core economic activities and services. The United States has fallen sharply in the World Economic Forum's ranking of national infrastructure systems. In the forum's 2007-2008 report, American infrastructure was ranked 6<sup>th</sup> best in the world while under the latest report 2011-2012 was ranked 16<sup>th</sup>. [World Economic Forum, "Global Competitiveness"]

About 27 percent of the bridges in the United States were built between 1957 and 1971, reflecting increased bridge construction during the interstate construction era from the late 1950s through the early 1970s. However, a large number of bridges have been constructed in recent years; about 25 percent of the bridges are less than 20 years old. There are more than 11,800 bridges still in operation in the United States that are over 100 years old. [Memmott, "Bridges in U.S."]

According to the U.S. Department of Transportation, of the 604,493 bridges across the country as of December 2010, 69,223 (11.5%) were categorized as structurally deficient and 77,413 (12.8%) were categorized as functionally obsolete for a total of 146,636 (24.3%) deficient bridges. [U.S.DOT, FHWA, "Bridges by Owner"] These restrictions contribute to traffic congestion and causes major inconvenience to emergency vehicles and trucks to take lengthy detours.

American Association of State Highway and Transportation Officials (AASHTO) estimated in 2008 that it would cost roughly \$140 billion to repair every deficient bridge in the country. About \$48 billion to repair structurally deficient bridges and \$91 billion to improve functionally obsolete bridges. [ASCE, “Infrastructure Fact Sheet”] Simply maintaining the current overall level of bridge conditions that is, not allowing the backlog of deficient bridges to grow would require a combined investment from the public and private sectors of \$650 billion over 50 years, for an average annual investment level of \$13 billion. The cost of eliminating all existing bridge deficiencies as they arise over the next 50 years is estimated at \$850 billion in 2006 dollars, equating to an average annual investment of \$17 billion. [National Surface Transportation Policy and Revenue, “Transportation for Tomorrow”]

## **2.2 Accelerated Bridge Construction (ABC)**

U.S. Department of Transportation defines ABC as bridge construction that uses innovative planning, design, materials, and construction methods in a safe and cost-effective manner to reduce the onsite construction time that occurs when building new bridges or replacing and rehabilitating existing bridges. [U.S.DOT, FHWA, “Accelerated Bridge Construction”] The goal of ABC is to open a cost-effective, long-lasting bridge to traffic with increased safety and reduced traffic disruption in shortened construction duration. [Ralls, “Accelerated Bridge Construction”] Fundamental benefits of the ABC approach include improvement in safety, quality, durability, social costs and environmental impacts. ABC improves site constructability, total project delivery time, work-zone safety for the travelling public and reduces traffic impacts, onsite construction time and weather-related time delays.

Delivering projects quickly to improve safety and reduce congestion is now the priority on many of today’s bridge construction projects across the country. This trend is increasing. Improved safety is needed to avoid injury to construction crews in the work zone and to motorists as they

move through the growing number of work zones. Reduced congestion is needed to provide reliable travel times for motorists and emergency response teams and to avoid negative economic impact to surrounding businesses. Rapid delivery of both emergency and planned bridge construction projects ensures that people and goods are moved efficiently and effectively. [Ralls, “Accelerated Bridge Construction”] Oftentimes long detours, costly use of a temporary structure, remote site locations, and limited construction periods present opportunities where the use of ABC method can provide practical and economical solutions to those offered if conventional construction methods were used. [U.S.DOT, FHWA, “Accelerated Bridge Construction”] The ABC initiative is expected to move from innovation to standard practice because of the increasing age of the nation’s bridge inventory and the need to maintain traffic flow and economic vitality.

### **2.3 Prefabricated Bridge Elements and Systems (PBES)**

Prefabricated Bridge Elements and Systems (PBES) are structural components of a bridge that are built offsite, or near-site of a bridge, and include features that reduce the onsite construction time and mobility impact time which occurs when building new bridges or rehabilitating or replacing existing bridges relative to conventional construction. PBES includes innovations in design and high-performance materials and could be combined with “Fast Track Contracting” methods to further accelerate project schedule. Because PBES are built off the critical path and under controlled environmental conditions, improvements in safety, quality, and long-term durability can be better achieved. [U.S.DOT, FHWA, “PBES”]

### **2.4 Utah Department of Transportation (UDOT) ABC Approach**

The UDOT Structures Division has widely implemented the use of ABC. UDOT had started using different ABC methods since 2002 and have completed 217 bridges by the end of 2010. To date, UDOT has used precast deck panels, precast abutments, bent caps, precast voided slabs, precast approach slabs, precast sleeper slabs, precast columns, precast box culvert, and Self

Propelled Modular Transports (SPMT) on various bridges across the state. [Swanwick, “ABC: Research, Design and Practice”]

ABC is the standard practice for project delivery, efficiency and fast construction for UDOT. The department has recently adopted themes that are now used as the basis of all projects in Utah. The themes are as follows:

- Accelerate delivery – Design and Construction
- Decrease and minimize Maintenance of Traffic (MOT) to reduce user costs associated with delays
- Encourage innovation
- Get a good price

UDOT has identified eight measures of project constraints as being applicable to ABC decision process. These measures are average daily traffic, delay/detour time, bridge classification (importance), user costs, economy of scale, use of typical (standard) details, safety, environmental issues and rail road impacts. [UDOT, “ABC Decision Making Process”]

UDOT began its ABC implementation with the reconstruction of Interstate 15, in time for the 2002 Winter Olympics. UDOT worked with the contractor, Kiewit, as design-build project to complete the entire 17-mile corridor in just four and a half years, ahead of schedule. UDOT has continued to work with contractors and other industry partners since then to improve ABC methods and specifications and to speed up bridge replacement. [McMinimee and Ralls, “ABC: Designing for Contractors”]

UDOT’s ABC implementation has relied on industry collaboration to be successful. Obtaining contractor input in the early stages of ABC projects have led to more cost-effective, long-lasting bridges with early completions. Contracting methods such as Design-Build and Construction Manager General Contract (CMGC) have been used by UDOT to obtain this early input,

minimize risks, and improve schedule. [McMinimee and Ralls, “ABC: Designing for Contractors”]

## **2.5 Iowa Department of Transportation (IDOT) ABC Case Study** [LaViolette, Evans, Nelson and Sivakumar, “ABC Modular Bridge Demonstration”]

The Iowa Department of Transportation (IDOT) has significant experience in accelerated bridge construction including projects on both the primary and secondary road system. US 6 Bridge over Keg Creek was chosen for demonstration for the Strategic Highway Research Program’s (SHRP) comprehensive study in Innovative Bridge Design for Rapid Renewal lead by HNTB Corporation. The project team has designed a demonstration bridge that incorporates proven ABC bridge construction details with the innovative use of Ultra-high Performance Concrete (UHPC). This innovative ABC method shortened the normal bridge replacement period of six months down to only 2 weeks of traffic disruption.

This demonstration bridge features precast concrete semi-integral abutments, precast columns and pier caps connected with high-strength grouted couplers, and an innovative modular superstructure constructed using prefabricated concrete decked steel stringer units and field cast UHPC joints. In achieving the goals of this demonstration project, a series of innovative bridge details were used. These innovative bridge details used for the project have been proven through research, testing and application in projects around the US.

Prefabricated Bridge Elements and Systems (PBES) include the following:

- Modular precast concrete deck and steel hybrid superstructure.
- Superstructure units incorporating precast suspended back-wall elements to create semi-integral abutments at bridge ends.
- Precast concrete pier caps and abutment footings.
- Precast concrete bridge approach panels.

- UHPC in the joints between the modular superstructure units.

## **2.6 Innovative Contracts**

Since 1990, a number of transportation agencies (as owners, sponsors, or contracting agencies of highway projects) have been experimenting with a wide variety of innovative project delivery strategies aimed at lowering the costs and time to produce highway construction and rehabilitation projects, while maintaining or improving project quality. Many transportation agencies have discovered that traditional contracts and project methods do not meet current demands. Some of the problems faced with the traditional contracting are insufficient funds, little innovation, little value added services for the client and a general lack of integration between the phases of the project. Some of the widely used innovative contracts are discussed here.

### **2.6.1 Design-Build [Becker, “Adopting Design-Build”]**

Design-Build streamlines project delivery through a single contract between the owner and the design-build team (DBT). Single entity is held accountable for cost, schedule and performance, which streamlines communication and execution. According to the Design-Build Institute of America, this simple but fundamental difference transforms the sometimes adversarial relationship between designers and contractors to that of an alliance, fostering innovation, collaboration and teamwork. Combining the talents of designers and contractors at a project’s onset can work to the owner’s advantage, achieving speed and economies and allowing the design to be tailored to the contractor’s specific construction methods.

States that have embraced design-build are reporting impressive results. American Association of State Highway and Transportation officials are confident that with accelerated project delivery methods, such as design-build, state DOTs can cut schedules by as much as 50 percent. Typically, the cost of a design-build project is 6 percent lower than a traditionally delivered project. Procurement documents can be written so that design-builders are required to meet performance

standards, often resulting in innovations that deliver a better project than initially envisioned. The alternative technical concept process for design-build projects fosters innovation among DBT members, often yielding a higher performing asset at a lower cost.

### **2.6.2 Design-Build-Finance-Operate-Maintain (DBFOM)**

Public-Private-Partnerships (PPP) come in a variety of forms and no two PPP projects are exactly alike. With the Design-Build-Finance-Operate-Maintain (DBFOM) approach, the responsibilities for designing, building, financing, operating and maintaining are bundled together and transferred to private sector partners. There is a great deal of variety in DBFOM arrangements in the United States, and especially the degree to which financial responsibilities are actually transferred to the private sector. One commonality that cuts across all DBFOM projects is that they are either partly or wholly financed by debt leveraging revenue streams dedicated to the project. Direct user fees (tolls) are the most common revenue source. [NCPPP, “Public-Private-Partnerships”]

P3 projects can improve the efficiency of infrastructure provisions by bundling maintenance and operations with construction of the infrastructure project. Because the private partner builds, operates and maintains the project, the incentive for durable construction and efficient maintenance and operation are aligned. P3 projects can lower construction and operation costs. For example, the consortium proposed the I-495 Capital Beltway High Occupancy Toll (HOT) lanes in Virginia for one-third of the cost of the High Occupancy Vehicle (HOV) lanes then planned by the Virginia Department of Transportation (VDOT). [Engel, Fischer and Galetovic, “PPP to Revamp U.S. Infrastructure”]

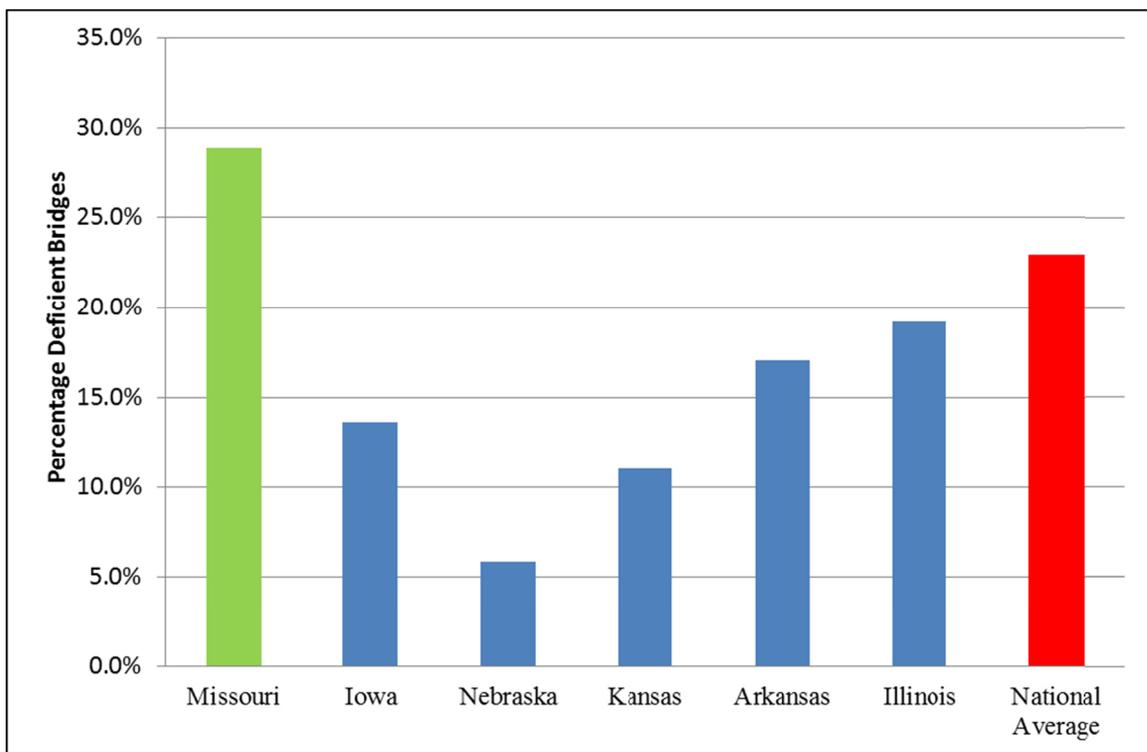
### **2.6.3 Construction Manger General Contract (CMGC)**

The Construction Manager General Contract (CMGC) project delivery method allows an owner to engage a construction manager during the design process to provide constructability input. The Construction Manager is generally selected on the basis of qualifications, past experience or a best-value basis. During the design phase, the construction manager provides input regarding scheduling, pricing, phasing and other input that helps the owner design a more constructible project. At approximately an average of 60% to 90% design completion, the owner and the construction manager negotiate a guaranteed maximum price for the construction of the project based on the defined scope and schedule. If this price is acceptable to both parties, they execute a contract for construction services, and the construction manager becomes the general contractor. [U.S.DOT, FHWA, “Construction Program Guide”]

### 3. Project Background

#### 3.1 Project Need

In December 2007, MoDOT had 10,189 structures on state inventory (7<sup>th</sup> largest nationwide), 1,608 (15.8%) were structurally deficient and 1,337 (13.1%) were functionally obsolete for a total of 2,945 (28.9%) deficient bridges. Figure 3.1 shows the comparison with neighboring states for total percentage deficient state DOT bridges and national average as of December 2007.



**Figure 3.1: Comparison with Neighboring States and National Average** [U.S.DOT, FHWA, “Bridges by Owner”]

As more and more bridges were becoming deficient a need for large-scale system improvement program was becoming more evident. To reduce the inventory of deficient bridges to the point where the projected bridge construction funding levels could address the remaining deficient bridges and keep up with the number of newly deficient bridges, MoDOT initiated the Safe &

Sound Bridge Improvement Program to replace 554 (5.4%) bridges and rehabilitate 248 (2.4%) of the worst bridges in the state. These bridges are dispersed in mostly rural locations in all 114 counties throughout the state, creating a mega project comprised of widespread, smaller projects.

Bridges for the project were selected based on the following criteria:

- No major river bridge (bridge on Missouri River or Mississippi River)
- No bridge greater than 1,000 feet in length
- Bridges on minor routes with National Bridge Inventory (NBI) rating of 3 or less
- Bridges on major routes with NBI rating of 4 or less
- No Bridges that may require significant roadway work or additional right of way

### **3.2 Project Contracting** [Desai, Gutknecht and McMillan, “Accelerated Bridge Improvement Program in Missouri”]

MoDOT announced the Safe and Sound Bridge Improvement project in fall 2006 structured under Design-Build-Finance-Maintain (DBFM) contract where contractor would replace or rehabilitate 802 bridges within five years and maintain them in fair or better condition for 25 years. The contractor was required to finance the entire construction cost and be repaid with annual payments over the 25 years maintenance period. Five teams responded to the Request for Qualifications (RFQ). Four teams were shortlisted to continue contract negotiations. Two teams withdrew from the bidding process during procurement. In the fall of 2007 the remaining two teams submitted bids. Both bids were determined to be unaffordable.

MoDOT entered into Best and Final Offer (BAFO) negotiations with the bidders to determine how the contract could be changed to reduce cost. The two bidders were invited to submit a BAFO in December 2007. Though both bids were determined to be unaffordable, a team was selected to negotiate a conforming contract that could possibly reduce costs. In July 2008, a

Limited Notice to Proceed (LNTP) was issued to the low bidder to begin preliminary engineering work while the terms of the contract were finalized.

Both bidders had planned to employ complex financial instruments, including synthetic fixed rated debt structures. In early 2008, when the housing crisis developed, some of these complex financial instruments became unavailable. The contract team was unable to obtain affordable financing, with the spread between public financing and private financing growing larger every day. In September 2008, MoDOT terminated contract negotiations.

Though the DBFM contract was terminated, the need to address the condition of Missouri bridges remained. In September 2008, MoDOT took 248 bridges from the DBFM project that the contractor had planned to rehabilitate, grouped them by location, type of work, and schedule and let them in small packages using a normal bid processes. This project was called the Modified-Design-Bid-Build (MDBB) program. The design work would be completed with in-house resources or by a consultant. This allowed a contract for a few MDBB bridges to be let within 30 days of termination of the DBFM project.

The remaining 554 bridges from the DBFM project were grouped into one Design Build project. These bridges were all scoped as complete bridge replacements in the DBFM contract by the apparent low bidder. The Design Build project differs from the original DBFM project in the following ways:

- No private financing or maintenance component
- Contractor will be paid for work as it is completed
- MoDOT does all construction inspection
- MoDOT coordinates utility relocations and ROW acquisition
- MoDOT coordinates traffic control for bridge closures
- MoDOT takes the lead for all Public Information

The goals for this project are:

- Deliver good bridges at a great value
- Minimize public inconvenience through increased construction speed and flexibility in schedule
- Complete construction no later than October 31, 2014

To ensure these goals were addressed, the contractor proposals were scored based upon bid price, the date they committed to completing the project, the average bridge closure duration and their willingness to shift construction dates to respond to MoDOT and the public's needs. Quality design standards were maintained by requiring the contractor to use current MoDOT bridge design standards or submit Alternate Applicable Standards (AAS) for approval prior to bid submittal.

Two teams submitted responsive bids. In May 2009, MoDOT awarded the Design Build contract for \$487 million to KTU Constructors, a joint venture of Kiewit Western (a subsidiary of Kiewit Corporation), Traylor Brothers and United Contractors along with HNTB Corporation and The LPA Group as design consultants.

### **3.3 Summary**

Design-Build-Finance-Maintain (DBFM) contract was proved unaffordable and was terminated in September 2008. However, the need to address the condition of Missouri bridges remained. In May 2009, MoDOT awarded the Design Build contract to replace 554 bridges to KTU Constructors for \$487 million. Design Build team was selected based on bid price, project schedule, bridge closure duration and compliance to the MoDOT's project goals. Detailed discussion on project's design and construction is discussed in the following chapter.

## **4. Project Design and Construction**

### **4.1 Project Design**

An average of 45 days per bridge is allotted for bridge reconstruction including demolition and disposal of the existing bridge components. To meet this aggressive schedule for construction utilization of Prefabricated Bridge Elements and Systems (PBES) was absolutely necessary. To minimize construction duration use of pre-cast components for superstructure and pile bents for substructure were selected. Rather than designing each span individually the approach was used to standardize bridge skew in 10-degree increments up to a 40-degree and span increments of five-foot.

#### **4.1.1 Pre-Award Phase**

During the pre-award phase, field inspections were carried out at all 554 bridge sites to study field conditions, access for construction, bridge size, height above approach fill and the channel. The field data was collected and stored in a database along with MoDOT required bridge widths, Average Daily Traffic (ADT) and other constraints. Based on this data, four major disciplines of bridge, roadway, geotechnical and hydraulics performed pre-design to determine a best approach to construct project bridges.

Taking the ideas/concepts from the disciplines along with the required site needs, the project team of designers and builders reviewed all 554 project bridges. During the review span arrangement, proposed foundations and potential road work was developed for all project bridge sites. This became the basis of the estimate phase. In addition to the project bridges, the preliminary maintenance of traffic (MOT) schemes were developed and used in the bid estimate.

#### **4.1.2 Post-Award Phase**

Once the contract with MoDOT was finalized, the design phase and construction phase of the project were reviewed. The preliminary construction schedule for all project bridges was developed. MoDOT preferred that KTU construct four bridges during 2009. This required a slight deviation from the original design and construction planning. Originally, 2009 was a year for the design team consisting of HNTB Corporation and The LPA Group to organize its design efforts and strategy, develop project standards and start design work for 2010 and for KTU, time to develop construction means, methods and schedules to achieve greater efficiencies to construct project bridges. Due to the early start bridges, both construction and design teams needed to complete a sizable amount of work ahead of schedule.

This innovative, accelerated design and construction approach included early evaluation of all 554 bridges and standardize spans, widths, and skews which helped finalize the superstructure and substructure configurations for all project bridges. This process enabled the design team to minimize the number of superstructure and substructure design analyses through standardization process. During the pre-award phase, several superstructure and substructure scenarios were evaluated based on preliminary design. These scenarios were grouped in categories that dictated number of design analyses to be performed. These “standardization” measures significantly reduced the design, fabrication and construction efforts.

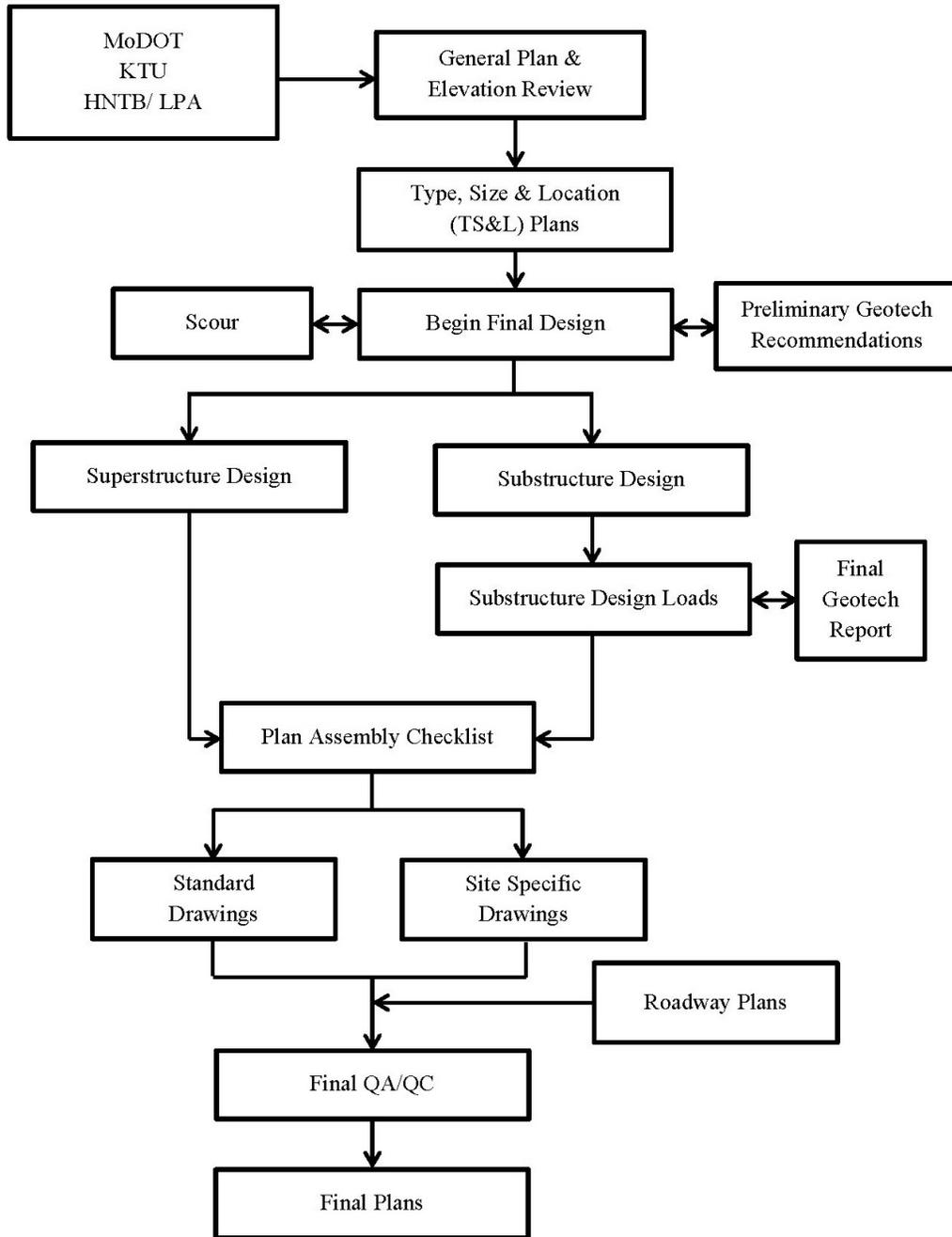
Since the design and plan production had to be performed in a most efficient manner due to the stringent time constraint, a standardized approach to tackling the design production was absolutely necessary. A three day long Standards Development workshop was conducted, which included participation of all design discipline task leaders, key technical staff members, along with construction managers. A Design Flowchart (simplified version) as shown in Figure 4.1 was developed. Since the first four 2009 bridges were already undergoing construction at this time,

the lessons learned were discussed. As a result, the design flow chart was modified to ensure proper sequencing of design process, adequate design level surveys, consistency in using Digital Terrain Models, implementation of appropriate Quality Assurance and Quality Control (QA/QC) procedures and coordination among different disciplines and design teams. The project Design Criteria document was reviewed for possible improvements to accommodate Additional Applicable Standards (AAS) that were approved or conditionally approved by MoDOT. Uniformity in computer aided drafting and design (CADD) standards were discussed and implemented for consistent appearance of plan set deliverables.

To enhance the plan development process, various bridge components were standardized. Approximately 600 standard plan sheets were created that were utilized for multiple bridges; these sheets were developed, checked once and then used multiple times.

#### **4.1.2.1 Design Flowchart**

The preliminary design drawings for General Plan and Elevation (GP&E) review included proposed bridge superimposed with existing bridge, limits of rock blankets with proposed ground contours, hydrological data in a consistent manner and adequate structural details depicting spans, widths, skews, foundation type and applicable loadings for which the structure under consideration was to be designed. These drawings were prepared by designers and were reviewed with MoDOT and KTU personal. Design and construction aspects of the bridge were discussed and bridge configuration was finalized. Once GP&E review is completed final Type, Size and Location (TS&L) plans were prepared along with preliminary geotechnical recommendations and Bridge Hydraulics & Scour Report (BHSR). TS&L plans are the starting point for the final bridge design and plan.



**Figure 4.1: Design Flowchart (Simplified Version)** [Safe and Sound, 2009]

The HNTB management team intended to divide project bridges between three groups. Each group would be responsible to complete assigned bridges from GP&E review to final plans. As the management team evaluated options, it was clear that the traditional project approach would not support the aggressive design schedule. To tackle the aggressive design schedule, the management team divided the design process into three phases; GP&E review, TS&L plans and final plans and assigned each group to these phases. Each group dedicated to do the same process created efficiencies in GP&E review, TS&L plans and final plans.

#### **4.1.2.2 Substructure**

Based on the preliminary geotechnical recommendations and Bridge Hydraulics & Scour Report (BHSR) substructure design was performed using the standard project specific design spreadsheet. Only pile cap bents, supported by HP piles or steel pipe piles; concrete filled up to frost depth; were considered as standard. HP 10, HP12 and HP 14 steel H-pile sections and 16 inch, 18 inch and 24 inch pipe piles sections were considered as part of standards. The starting capbeam width and depths were standardized as three foot minimum with possible higher width or depth in increments of six inches if dictated by design requirements. Final substructure design loads were incorporated in the geotechnical recommendations and final geotech report was completed.

#### **4.1.2.3 Superstructure**

For most project bridges, four types of pre-cast concrete superstructure were selected. These four types are Adjacent Cored Slab (ACS) Units, Adjacent Box Beam (ABB) Units, Spread Cored Slab (SCS) Units and Spread Box Beam (SBB) Units. Table 4.1 shows the beam depths and respective design span lengths for typical superstructure types.

**Table 4.1 Beam Depths and Span Lengths for Typical Superstructure [Safe and Sound 2009]**

ACS		ABB		SCS		SBB	
Beam Depth (Inches)	Span Length (Feet)						
21	30-60	27	75-90	21	30-45	27	65
24	60-75	33	95-105	24	50-60	33	70-90
---	---	39	110-120	---	---	---	---

For ACS and ABB units, four foot wide and three foot wide precast units were specified. Combination of four foot wide and three foot wide units were specified to derive the exact bridge width required without overbuilding. In order to minimize number of design combinations only four foot wide units were designated as exterior units. Figures 4.2 and Figure 4.3 shows typical section of ACS units and ABB units respectively.

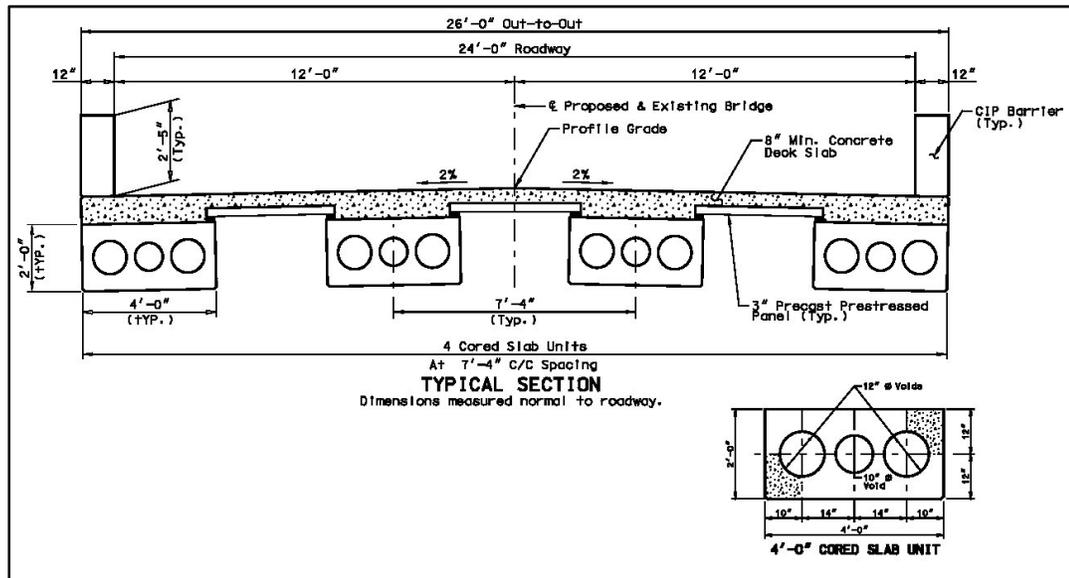
The spans were specified in increments of five feet in order to keep the number of design analyses to a minimum. The bridges with Average Daily Traffic (ADT) count of less than 1,000 were specified to receive two inch minimum asphalt overlay over precast units. In some rare situations, ACS and ABB bridges carrying more than 1,000 ADT were specified to maintain reduced structure depth to meet free board criteria as dictated by hydraulic analysis. In such instances a minimum of six inch thick concrete overlay was specified over precast units to comply with the design criteria.

For the bridges with asphalt overlay, 0.6 inch diameter high strength post-tensioning strands were provided in transverse direction to bridge all precast units together so that they act as a unit for load carrying purpose. These strands were sheathed with a non-corrosive sleeve. For adjacent precast units with concrete overlay, one inch diameter Grade A36 tie rods were specified for transverse post-tensioning with a design torque of 200 foot-pounds.

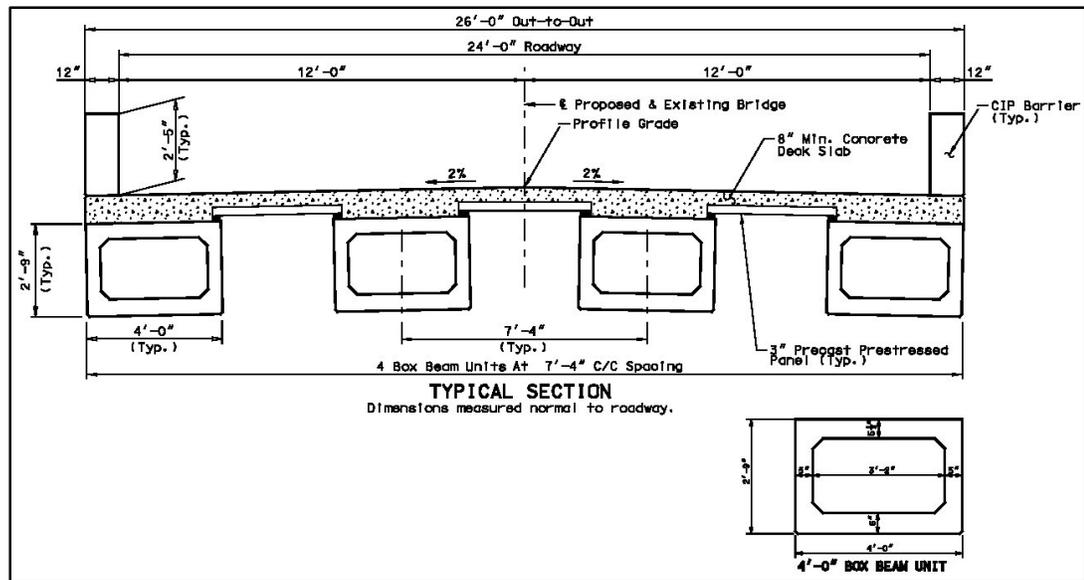


During standardization process, an attempt was made to select spread configuration for bridges with ADT exceeding 1000. Since these bridges with relatively higher ADT were required to have at least six inches of concrete overlay, it was preferred to spread them apart eliminating a few precast units and provide eight inch thick concrete deck to achieve economy. With spread configuration, all SCS units and SBB units were four feet wide and spread no further than four feet (clear) apart. Figures 4.4 and Figure 4.5 shows typical section of SCS units and SBB units respectively.

To reduce the construction time three inch precast deck panels supported on preformed fiber expansion joint material (or extruded/expanded polystyrene bedding material) with one inch minimum thickness were used in place of deck forms. The cast-in-place portion of the deck consisted of five inch thickness with one layer of epoxy coated reinforcement.



**Figure 4.4: Typical Section Showing Spread Cored Slab (SCS) Units [Safe and Sound 2009]**



**Figure 4.5: Typical Section Showing Spread Box Beam (SBB) Units [Safe and Sound 2009]**

#### 4.1.2.4 Plan Assembly Checklist and Final Plans

The Plan Assembly Checklist was created as an Excel file and used to automatically identify which of the standard drawings were applicable to a specific bridge. Approximately 600 standard plan sheets were created that were utilized for multiple bridges. These sheets were developed, checked once and then used multiple times. Standard details in these sheets were developed with assigned variables. These variables were calculated with use of standard superstructure and substructure variable spreadsheets. These variables were tabulated to create site specific drawings. Site specific drawings allowed standard drawings to use non-dimensional details and gave the contractor all the information they needed to construct the bridge on a specific bridge site. The Plan Assembly Checklist was a significant time saving tool for the plan production process. This checklist also ensured that the correct drawings were used for a specific bridge.

Once Superstructure and Substructure designs were completed for a bridge, general information about the bridge was entered on the first tab of the Plan Assembly Checklist: bridge width, skew angle, skew direction and design loading. Specific information about the spans and substructure

was also input into the spreadsheet: span length, number of beams, beam widths, beam types and size of piles for substructure. From this short page of input the remaining tabs on the spreadsheet referenced the input information using “if/then” equations to determine which standard drawings were applicable to a specific bridge. A check box would automatically be filled in by the equations in the spreadsheet for each of the standard drawings that were required for the specific bridge. QA/QC was performed on the site specific drawings and the roadway drawings. These drawings were combined with standard drawings to produce final plans.

#### **4.1.3 Bridge Load Rating**

All the project bridges were load rated in accordance with Load Rating for Design Build Bridges memorandum. All project bridges were load rated by VIRTIS Software for axle configurations identified in the memorandum.

#### **4.1.4 Geotechnical Design**

Geotechnical design team’s primary focus was to develop pile lengths using existing subsurface information during the pre-award phase of the project. Additional boring requirements for about 100 bridge sites were also identified during the pre-award phase. Pile lengths estimated from the preliminary design served as the basis of the construction price proposal for all the bridges’ foundation. Additional geotechnical borings and laboratory testing for project bridge sites were typically completed prior to final TS&L plans. Only pile cap bents, supported by HP piles or steel pipe piles; concrete filled up to frost depth; were considered as standard. HP 10, HP12 and HP 14 steel H-pile sections and 16 inch, 18 inch and 24 inch pipe piles sections were considered as part of standards. Pile supported footings, spread footings or drilled shaft foundation were specified at limited bridge sites.

#### **4.1.5 Hydraulic Design**

Hydraulic design is a critical component of the project since most of the project bridges are over small streams. The Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS) was used to develop water surface profile models for the hydraulic analysis of project bridges. Hydraulic design was performed to assess floodplain and regulatory floodway impacts based on Federal and State of Missouri regulations. The Floodplain Development Permits were obtained from the State Emergency Management Agency (SEMA) for construction within areas of identified flood hazard prior to proceeding with construction.

To meet the aggressive design schedule, Hydraulic Design team's primary focus was to collect as much information as possible during the pre-award phase and remaining date at the early stage of the final design phase. Data collected for the hydraulic design were Digital Elevation Model (DEM) data from the United States Geological Survey (USGS) mapping of the entire state, existing bridge and roadway plans, individual surveys of the structure and surrounding terrain at each site, existing bridge and surrounding terrain photos, field measurements of flow area through the bridge and stream width, ordinary high water elevation for permitting, and estimates of roughness coefficients for the hydraulic modeling. Geographic Information System (GIS) was utilized to acquire aerial photography, highway boundaries and municipal boundaries for all bridge sites.

#### **4.1.6 Roadway Design**

The roadway design team primarily relied on the existing roadway plans and as-built plans to evaluate elements of existing horizontal and vertical geometry of the proposed bridge sites. The design-build team was provided fairly extensive database during the pre-award by MoDOT. The data base contained information regarding existing bridge as well as proposed roadway width, bridge width, design loading and other roadway design related elements.

During the post-award phase of the project the roadway design team obtained site-specific survey information at every single bridge location from KTU. Site-specific roadway design plans were prepared to show proposed bridge plan, profile, and typical roadway sections. Consistency in the collected survey data was important for this project involving 554 bridge sites. Based on the Annual Average Daily Traffic (AADT) new pavement consisted of asphaltic concrete, cold mix, hot mix, or Portland cement concrete pavement.

KTU was responsible to develop, install, maintain and remove temporary traffic control for project bridges on divided highways, constructed with staged construction or constructed using a bypass. For all the remaining project bridges, MoDOT was responsible for maintenance of traffic (MOT).

#### **4.2 Construction**

KTU Constructors divided the state into five construction regions to facilitate construction. Through the standardized bidding process, the selected local bridge contractors were let to build project bridges. The project bridges were divided into 15 bid lettings that were further subdivided into 72 bid packages. KTU managed the responsibility to provide Pre-cast beams, bearing pads and piles for foundations to the local contractors.

KTU had two biggest challenges during early planning for the project. The first challenge was the production of pre-cast beams to meet the high demand for the project bridges. For the production of the pre-cast beams, three pre-cast companies were selected to tackle production speed, quality and logistics. To minimize duration of construction and fabrication, standardized bridge skew in 10-degree increments up to a 40-degree and span increments of five-foot were utilized. This standardization allowed pre-cast companies to mass produce the pre-cast beams and deck panels that helped reduce costs and time. The second challenge was the logistics of getting the beams to the bridge sites. A strategic construction sequence was the key to prioritize bridges in such a way

that deteriorated load-posted bridge on the same route would not be utilized during construction. The construction sequencing prioritized the bridges in the vicinity of major highways, and then progressed away along each route allowing for closures and traffic detours. This approach also allowed the use of reconstructed bridges to haul material and construction equipment. Delivery of pre-cast beams to the construction site required a lot of coordination between multiple entities including KTU, the subcontractor, the pre-caster, the road permitting offices and escorts on certain loads.

Pre-construction reviews were carried out for each project bridge two weeks prior to the construction. The intent of the review was to have the subcontractor, KTU and MoDOT personnel discuss all aspects in the construction of the bridge to ensure that the subcontractor was ready to start construction. Including design, standardization and initial construction planning, to date KTU Constructors have completed over 400 project bridges in less than two and a half years, averaging 42 days per bridge for reconstruction including demolition of the existing bridge.

#### **4.3 Public Involvement**

Safe and Sound strategic communication plan was developed to help MoDOT Community Relations managers, the KTU Constructors public involvement team and KTU subcontractors, communicate effectively with stakeholders throughout the Safe and Sound Bridge Improvement Program. The intent of the strategic communication plan was to deploy many effective strategies and tactics for educating and engaging the public as following.

- Communicate directly with key audiences regarding the need and benefits of the Safe and Sound bridge improvement program.
- Coordinate alternate routes and schedules as needed with school districts and other public transportation providers.
- Hold public briefing 30 days prior to scheduled start of construction for each project bridge.

- Maximize use of existing MoDOT communication tools such as state and district web sites, roadside signs and newsletters to tell the Safe and Sound bridge improvement program story broadly and effectively.
- Leverage social media as appropriate to inform and engage the public, specific stakeholders and the news media in a positive partnership focused on the program's successful completion.
- Execute proactive media relations program at both the statewide and district levels to build recognition of MoDOT's responsiveness to its customers and their needs, as well as its effectiveness as a manager of complex, large-scale transportation programs.

Public involvement was critical to the success of the project. KTU developed plan to keep MoDOT Community Relations managers informed about the schedule changes for the Safe and Sound bridges. This communication was important as Community Relations managers were responsible for scheduling public briefings, notifying public officials of closures and sending press releases to the media. This ongoing communication between KTU and MoDOT helped prepare the public for closures, organize press releases and schedule appropriate community outreach activities.

## 5. Summary

KTU Constructors along with HNTB Corporation and The LPA Group as design consultants created special design approach to meet the owner's expectations for innovation and speed. In order to meet the aggressive design and construction schedule, the project team developed the following approach:

- Early evaluation of all 554 bridges
- Standardization of proposed bridge spans, widths and skews
- Incorporation of various designs and details used by other State Department of Transportation that would help accelerate design and construction process
- Minimization of construction duration through the utilization of concrete precast components for superstructure and pile bents for substructure
- Standardization of the superstructure and substructure design and detailing processes
- Development and utilization of standard plan sheets

Once the contract with MoDOT was finalized, the survey team and the drilling team collected the site specific survey information and geotechnical data from each bridge site as needed. From the collected information and preliminary design, General Plan and Elevation (GP&E) reviews were conducted with all design disciplines, KTU Constructors and MoDOT. Once GP&E review was completed final Type, Size and Location (TS&L) plans were prepared along with preliminary geotechnical recommendations and Bridge Hydraulics & Scour Report (BHSR). These plans became the basis for the final design.

The design build team created guidelines and standards for key bridge components. Accelerated delivery of bridge designs and construction resulted from the development of standardized beams and substructure components. Standardization allowed the designers to select bridge components

that were ready to be incorporation into the final design. It also allowed fabricators and suppliers to mass produce beams and deck panels resulted in reduced costs and time.

As the first successful program of its kind in the United States, the Safe and Sound Bridge Improvement Program now serves as a model for alternative project delivery. Many states are watching the outcome of the program and considering its applicability in their own states. Lessons learned from this project could be applied to future similar projects. The following chapter highlights lessons learned during the pre-award, early processes, standard development, final design and construction.

## **6. Lessons Learned and Conclusion**

### **6.1 Lessons Learned**

#### **6.1.1 Pre-Award and Early Processes**

The Additional Applicable Standards (AAS) used with Federal Highway Administration's approval during the procurement gave MoDOT more design options that would help accelerate the project's schedule.

Stringent considerations should be given to the long-term maintenance aspects of the project bridges. This could be accomplished by specific performance requirements in the project's Request for Proposals (RFP).

To outline the design intent, project specific design manual should be prepared in accordance with the performance requirements. Detailed design criteria should be developed and approved by the owner during the pre-bid phase of the project.

To accomplish aggressive project goals, colocation of the owner, the contractor and the designer is essential. Colocation with the owner during the standard development and initial design phase is critical to finalize the complete project deliverables.

Colocation of all the design team is a must for this multi discipline project which requires close coordination between the disciplines.

#### **6.1.2 Standard Development and Final Design**

The first four project bridges built prior to the standardization process streamlined the overall design and construction for the remainder of the project bridges. These bridges served as prototypes and helped improve the design details and the constructability of the project bridges.

At the early stage of the standard development process, strategy to tackle the design detail changes to the standard plan sheets is needed to easily incorporate the revisions to already designed project bridges.

Utilization of standard plan sheets, project specific design spreadsheets and efficiencies gained from the specialized design groups allowed to complete bridge designs and final plans in 39 days, on average.

During the standard development phase of the project, enormous challenges for the roadway design team was to develop roadway standards that would consistently work for all the project bridges. Lessons learned from the first few project bridges were used to develop final set of roadway standards.

Standard operating procedures were established on the storage, transfer, distribution, communication and display of data. All the activities were managed and tracked at every stage, the incoming, in process and outgoing data. The real time tracking spreadsheet allowed managing every piece of data and focusing on areas of possible delay.

### **6.1.3 Construction**

KTU's subcontractors were constructing about 35 to 40 bridges at any time during the construction period. To achieve project's aggressive construction schedule, assigning work to the local bridge contractors was the key.

Consistency and accuracy in the survey data was crucial to keep the project on schedule. Each bridge needed specific survey criteria depending on hydraulics and roadway design requirements.

Construction experience in the type of design greatly benefits the final product.

For first few project bridges, it is quiet beneficial to perform mock design and construction along with various project deliverables with the owner involvement.

## **6.2 Conclusion**

As the first successful program of its kind in the United States, MoDOT's Safe and Sound Bridge Improvement Program now serves as a model for alternative project delivery. Public inconvenience was minimized through accelerated bridge construction techniques which limited bridge closures to 42 days, on average.

KTU Constructors will be completing all the project bridges by August 2012, almost two years ahead of schedule. By accelerating the replacement of all deficient project bridges, Safe and Sound Bridge Improvement Program helped MoDOT save prolonged deficient bridge maintenance costs.

At an accelerated pace, increasing deficient bridge inventory could be reduced by state Department of Transportation (DOT) around the country by implementation of similar bridge improvement programs in their state. Bridge structure types could be selected based on the criteria for bridge selection, the performance requirements and the expected project goals established by individual state DOT.

### **6.3 Suggestions for Further Studies**

MoDOT's Safe and Sound Bridge improvement program had identified replacement of 554 worst bridges in the state. Further investigation is required to comprehend the optimum project size be selected for future projects.

Further investigation could be done to identify and compare different approaches used by State Department of Transportation around the country to address deficient bridges in their states.

As inventory of deficient bridges is growing, a need for a strategic plan is evident to address deficient bridges in many states around the country.

Study on alternate project delivery methods could be conducted to compare with the Design Build approach used by MoDOT.

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