STANDARDS FOR SINGLE SPAN PREFABRICATED BRIDGES

Phase I - CONCEPT DEVELOPMENT

FINAL REPORT

July 2014

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Project TR-663

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Background

In coordination with a Technical Advisory Committee (TAC) consisting of County Engineers and Iowa DOT representatives, the Iowa DOT has proposed to develop a set of standards for a single span prefabricated bridge system for use on the local road system. The purpose of the bridge system is to improve bridge construction, accelerate project delivery, improve worker safety, be cost effective, reduce impacts to the travelling public by reducing traffic disruptions and the duration of detours, and allow local forces to construct the bridges.

HDR Inc. was selected by the Iowa DOT to perform the initial concept screening of the bridge system. This Final Report summarizes the initial conceptual effort to investigate potential systems, make recommendations for a preferred system and propose initial details to be tested in the laboratory in Phase 2 of the project.

The prefabricated bridge components were to be based on the following preliminary criteria set forth by the TAC. The criteria were to be verified and/ or modified as part of the conceptual development.

- 24' and 30' roadway widths
- Skews of 0^o, 15^o, and 30^o
- Span lengths of 30' – 70' in 10' increments using precast concrete beams
- Voided box beams could be considered
- Limit precast element weight to 45,000 pounds for movement and placement of beams
- Beams could be joined transversely with threaded rods
- Abutment concepts may included precast as well as an option for cast-in-place abutments with pile foundations

In addition to the above criteria, there was an interest to use a single-width prefabricated bridge component to simplify fabrication as well as a desire to utilize non-prestressed concrete systems where possible to allow for precasting of the beam modules by local forces or local precast plants. The SL-1 modular steel bridge rail was identified for use with this single span prefabricated bridge system.

Investigation of Current or New Systems

As an initial step, HDR performed an internet search to determine what similar systems are being used by State DOT's and also polled HDR's office nationwide to gain insight on systems predominantly used by their DOT clients. Also, results of a previous scanning tour to other countries by various State DOT bridge officials was reviewed to determine if there are other viable international systems.

The predominant short span prefabricated bridge systems identified through the above queries were:

- Precast voided slabs
- Precast voided box beams
- Precast Bulb T beams
- Precast Double T beams (or updated NEXT beam precast double T beams)
- Inverted T beams

A comparison matrix for the above systems is shown in Figure 1.

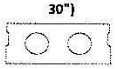
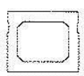
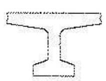
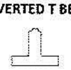
Construction Considerations

The internet search also identified a number of construction considerations that should be considered when selecting a preferred prefabricated short span bridge system. Some of these considerations and applicable discussions of these considerations are presented below:

- **Differential Camber** – If pretensioning is used in prefabricated concrete superstructure members, the potential for differential camber between adjacent members should be considered. Differential camber can cause rideability issues as well as safety issues if a vehicle’s tire catches on the edge of a beam member that is cambered slightly lower than an adjacent beam. Adding a wearing surface, cast-in-place topping or granular surface over the prefabricated elements are all potential remedies for this issue.
- **Transverse Connection of Prefabricated Elements** – A common concern with bridges using prefabricated elements such as adjacent precast concrete box beams or voided slabs is the tendency to see reflective cracking along the longitudinal joints between the elements. This cracking has been attributed to any of a number of factors that may include: the configuration of the shear key between the elements, the amount of transverse post tensioning in the diaphragms connecting the adjacent members, the height of the transverse post tensioning with respect to the neutral axis, and temperature shrinkage between adjacent members.
- **Barrier Rail Connections** – An assumption for this project was that the standard SL-1 steel barrier rail would be used for these county standards. This standard utilizes embedded bolts or reinforcing steel within the side of the

prefabricated elements for the connection of the rail to the superstructure. For prefabricated systems such as a Bulb-T beam or Double T beam, which have a thin top flange, an alternative connection may need to be investigated to provide a bolt-through connection to the top flange or a thickened edge may be needed along the outside flange of the exterior beam to allow for the standard connection.

- **Accommodation of Roadway Cross-slope** - To provide drainage to the bridge deck, the deck surface is typically sloped at a minimum rate of 2% from the centerline of roadway. This becomes troublesome for beam elements that are post-tensioned together transversely if the orientation of the post tensioning follows the roadway crown and thus introduces a vertical component. Also, to accommodate this cross slope, the abutment cap beams must also be sloped at a 2% rate so that prefabricated elements can be placed at the proper slope.
- **Skew Effects** – The proposed county standards are to accommodate skews of 0^o, 15^o and 30^o. Prefabricated members must be detailed to address skew effects, particularly at end blocks over the abutment supports and at intermediate diaphragm locations where elements are potentially post-tensioned together.
- **Width of Prefabricated Units** – Many states utilizes two standard widths of prefabricated units (3’ and 4’) so that various combinations of the units can be used side-by-side to add up to the required overall bridge width. Having two separate widths requires separate forms for the prefabricated members, which translates into added costs. Conversely, if only one width is used, a bridge might need to be built wider than needed, which also adds costs.
- **Prefabricated Substructure Units** – The size and length of prefabricated abutments that may be needed could exceed the preferred maximum weight limit of 45,000 lbs. If wingwalls are prefabricated monolithically with the abutment barrel, wingwalls oriented parallel to the abutment centerline vs. u-shaped wingwalls would be easier to fabricated and ship. However, this type of wingwall orientation contrasts with Iowa DOT current standards for flooded backfill details.

COMPARATIVE MATRIX FOR SHORT SPAN PRECAST SIDE BY SIDE SUPERSTRUCTURE SYSTEMS								
SUPERSTRUCTURE TYPE	RELATIVE COST	CONSTRUCTABILITY BY LOCAL FORCES	INSPECTABILITY	SPAN RANGES vs Depth and Weight (Assuming Prestressed)			PROS	CONS
				Depth and Weight of Precast Section	Span Range	Maximum Span Assuming 45k Limit on Weight (If Weight Limit Controls)		
SLAB BEAMS (With Voids for 15", 18", 21", 26", and 30") 	1	Good	Good	12" (153psf) 15" (151psf) 18" (167psf) 21" (187psf) 26" (229psf) 30" (252psf)	15' to 30' 23' to 40' 29' to 47' 31' to 55' 40' to 68' 57' to 83'	ok ok ok ok 51' (4' Wide); 68' (3' Wide) 46' (4' Wide); 61' (3' Wide)	1. Formwork is simple.	1. For shallower sections, may have difficulty in attaching railing to side of beam. This can be solved by either bolting through the slab or casting a deepened end section along the edge.
BOX BEAMS 	0.9 to 1.3	Good	Difficult to Access Inside	33" (204psf) 39" (221psf) 42" (229psf) 48" (246psf)	54' to 86' 62' to 96' 68' to 102' 83' to 116'	57' (4' Wide); 76' (3' Wide) 53' (4' Wide); 71' (3 Wide) 51' (4' Wide); 68' (3' Wide) 48' (4' Wide); 64' (3' Wide)		1. Some fabricators pour the bottom slab as a separate pour, which takes more time to fabricate.
DECK BULB T BEAMS 	0.6 to 1.2	Moderate	Good	35" (188psf for 4' Wide Section to 134psf for 8' Wide Section.)	85'	62'		1. Difficulty in attaching railing to side of top flange. This can be solved by either bolting trough the top flange or casting a deepened end section along the edge.
DOUBLE T BEAMS 	0.9 to 1.2	Good	Good	32" (190psf for 8' Wide Section)	90'	34'		1. Difficulty in attaching railing to side of top flange. This can be solved by either bolting trough the top flange or casting a deepened end section along the edge.
INVERTED T BEAM 	1.7 to 2.4	Difficult (Requires CIP Deck)	Can Not Inspect Bottom of CIP Deck	13" (93psf) 17" (107psf) 21" (120psf)	45' 60' 70'	ok ok ok	Sections are light	Requires CIP deck. (Could a precast deck be utilized?)

Assumptions:

1. CIP slab topping not required.
2. Use of wearing surface or gravel surface can be used, but not required.
3. Span range data for Slab Beams taken from the Oregon DOT's standards for a 4' wide section.
4. Span range data for Box Beams taken from the Oregon DOT's standards for a 4' wide section.
5. Span range data for Deck Bulb T Beams taken from the PCI Bridge Design Manual (for a 6' top flange width).
6. Span range data for Double T Beams taken from the PCI Bridge Design Manual.
7. Relative costs based on cross sectional area for Voided Slabs, Box Beams, Deck Bulb T and Double T. Relative cost for Inverted T is higher since a cast in place slab is required.

Figure 1

Accelerated Bridge Construction Workshop

On May 1-2, 2014, a 1 1/2 day Accelerated Bridge Construction (ABC) Workshop was held at the InTrans office in Ames, IA. Several State DOT's, FHWA, Iowa State University, various county engineers, Iowa DOT staff, industry representatives and HDR were all represented.

The first day of the workshop included presentations on two bridge projects either constructed or planned by the Iowa DOT using ABC techniques (Keg Creek and Silver Creek). There were also presentations by the South Dakota DOT and the Indiana DOT on their current practices for integral abutment bridges. Ben Graybeal (FHWA), Kyle Nachuk (LaFarge North America) and Matthew Royce (New York DOT) all made presentations on the use of Ultra High Performance Concrete (UHPC) for joints joining superstructure elements together.

For the ½-day session on the second day of the workshop, discussion was focused primarily on applying ABC techniques to the Iowa DOT proposed single span standards for prefabricated bridges. There was a presentation on current ISU research for prescast concrete box beam bridges, including discussion of keyway performance, grout material in the keyway, the keyway configuration, the keyway location, and ideas such as using an expansive grout to induce a precompressed state into the keyway between box beams. There was also discussion of what county engineers are looking for relative to prefabricated bridge systems. This included discussion of currently available commercially produced precast concrete slab beams (Oden Enterprises from Nebraska), the merits of UHPC concrete in joints vs. high performance grout, the merits of potentially using the New England NEXT beam system and the merits of using high strength reinforcing steel for conventionally reinforced precast concrete bridge components.

From the workshop discussions and presentations, the Phase 1 recommendations were modified to include the following recommendations for the Phase 3 implementation:

- Consider no post-tensioning between precast superstructure components and instead utilize:
    - Short lapped reinforcing steel (5'- 6" lap) with UHPC in the joints between the beam components
    - Nested and hooked reinforcing steel with high performance grout in the joints between the beam components
- Consider voided slab beams, voided box beams and NEXT double T beams
- Consider the use of high strength reinforcing steel to extend the span capabilities of non-pretensioned beam components
- Assume each beam element supporting a single wheel line of live load

Recommendations for Phase 3 Implementation

The initial effort to develop the concepts for the short span prefabricated standards occurred in the fall 2013 when HDR made recommendations to the TAC to define the final design parameters for a single span prefabricated bridge system. Additional recommendations came out of the ABC Workshop held from May 1-2, 2014. The following parameters were agreed upon:

- Precast reinforced concrete beam components would be used for the shorter span ranges. It was decided to use a concrete strength with f'c = 5,000 psi. It was additionally discussed to use Grade 60 reinforcing steel. However, as a result of the ABC Workshop on May 1-2, 2014, it was suggested to also investigate high strength reinforcing steel.
- For longer span ranges where conventional reinforced sections are not economical, pretensioned/ precast beam components will be utilized with 0.6-inch diameter, low relaxation strand and a concrete strength with f'c = 6,000 psi.
- Standards will be developed for span ranges in five foot increments ranging from 30-foot spans to 70-foot spans and for skews of 0^o, 15^o (left ahead), 30^o (left ahead), 15^o (right ahead) and 30^o (right ahead).
- Abutment details will be developed assuming wing walls oriented parallel to the centerline of abutment. Precast concrete abutment details will be developed utilizing voided pile pockets, and it is assumed the Office of Bridges and Structures will provide sample details for precast abutments previously used for the Accelerated Bridge Construction project in Boone County. The standards will also provide cast-in-place concrete abutment alternatives.
- Assume HP 10 x 42 piles for abutments as per BDM Section 6.2.1.1. Assume a minimum of 4 piles per abutment based on BDM Section 6.2.1.3 to achieve a redundant pile group. Assume a minimum pile spacing of 2 ½ feet and a maximum pile spacing of 8 feet based on BDM Section 6.2.4.1 but assume the BDM requirement for one pile to support each beam does not apply. Assume the standard plans will provide pile spacing for abutments but the site specific required pile lengths will need to be determined by a geotechnical engineer as necessary to achieve the required geotechnical resistance at the strength limit state.
- The slab beam, box beam and/or NEXT beam standards would be designed with no structural topping or future wearing surface. Provision for an optional ¾" epoxy topping to improve rideability and account for differential camber between beams will be optional.
- A shear key is assumed between beam elements located near the top flange. As per the ABC Workshop, the shear key will either utilize short (5" – 6") lapped straight reinforcing steel bar extensions with Ultra High Performance Concrete

(UHPC) in the shear key or the shear key configuration will use nested and hooked bar extensions with high performance grout in the shear keys.

- As per the recommendations of the ABC Workshop, beam elements will not be post-tensioned together transversely, but instead will rely on the shear key connections. The rational for this decision was based on the high post-tensioning force required to meet code recommendations, the lack of local post-tensioning expertise and equipment, at the inability to achieve a uniform compressive force along the interface between beam elements.
- Bridge standards shall be developed in packages for either 24' clear or 30' clear roadway widths. For slab and box beam standards, only nominal 3' (+) wide slab or box beams shall be used to develop the 24' and 30' clear roadway widths. (Beams may be slightly wider than 3' to account for the distance that steel barrier rails may intrude into the clear roadway width.) Further investigation of the module width is required if NEXT beams are used but it is anticipated that a 6' wide module would likely be used in order to work with the proposed 24' and 30' roadway widths.
- The single-span bridge standards shall utilize either the Iowa SL-1 steel barrier rail or the steel barrier rail recently developed by the University of Nebraska Midwest Roadside Safety Facility.
- Initial discussions in the fall of 2013 indicated the bridge cross section would not be crowned for drainage. Instead, bridges would be sloped 2% in one direction only for drainage to alleviate vertical load component issues associated with transverse post-tensioning on a crowned bridge section. Additionally, no provision for drain scuppers would be incorporated in the design since open steel barrier rails are proposed. However, with the direction from the ABC Workshop to eliminate transverse post-tensioning, the option for crowning the bridge deck can be reconsidered.
- Assume that beams will be conservatively designed to support a single wheel line without transverse post tensioning; therefore assume no improvement to the wheel line distribution factor to account for shared load between beams.
- The Phase 3 effort will include a parametric study to determine the cut-off point for span lengths using reinforced concrete beams and pretensioned concrete beams. Factors to be considered in the study include: structure type (voided slab, box beams, NEXT beams), structure depth, weight of precast units (with goal of limiting weights to less than 45,000 pounds), serviceability limits (size of reinforcing steel with respect to crack control criteria), use of high strength reinforcing steel, shear steel requirements, and cost. The study would develop recommendations for beam type and depth at each span length. It would also include consultation with with Iowa AGC to price precast slab beams, pretensioned box beams and NEXT beams. The results of the parametric study

would be presented to the Iowa DOT and the TAC with the recommendations for the reinforced concrete / pretensioned concrete span cut-off point and the structure type(s).