

Final Report

Prefabricated/Precast Bridge Elements and Systems (PBES) for Off-System Bridges

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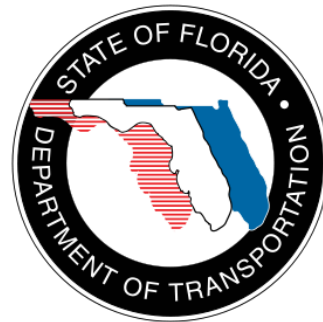
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Approximate conversion to SI units

Symbol	When you know	Multiply by	To find	Symbol
Length				
in.	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
Area				
in ²	square inches	645.2	square millimeters	mm ²
ft ²	square feet	0.093	square meters	m ²
yd ²	square yard	0.836	square meters	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	square kilometers	km ²
Volume				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
Mass				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
Temperature				
°F	Fahrenheit	$\frac{5}{9}(F - 32)$	Celsius	°C
Illumination				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$\frac{\text{candela}}{\text{m}^2}$	$\frac{\text{cd}}{\text{m}^2}$
Stress/Pressure				
lbf	poundforce	4.45	newtons	N
$\frac{\text{lbf}}{\text{in}^2}$ (or psi)	$\frac{\text{poundforce}}{\text{square inch}}$	6.89	kilopascals	kPa

Approximate conversion to imperial units

Symbol	When you know	Multiply by	To find	Symbol
Length				
mm	millimeters	0.039	inches	in.
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
Area				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
Volume				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
Mass				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lb)	T
Temperature				
°C	Celsius	$\frac{9}{5}C + 32$	Fahrenheit	°F
Illumination				
lx	lux	0.0929	foot-candles	fc
$\frac{cd}{m^2}$	$\frac{candela}{m^2}$	0.2919	foot-Lamberts	fl
Stress/Pressure				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	$\frac{\text{poundforce}}{\text{square inch}}$	$\frac{\text{lbf}}{\text{in}^2}$ (or psi)

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16. Abstract <p>The Federal Highway Administration's (FHWA) "Every Day Counts" initiative aims to shorten the overall project delivery time, enhance safety, and protect the environment both on and around construction projects. Using innovative planning, design, and construction methods, Accelerated Bridge Construction (ABC) techniques reduce on-site construction time for new or replacement bridges. One aspect of ABC is Prefabricated Bridge Elements and Systems (PBES), where bridge components are fabricated off site to reduce on-site construction activities.</p> <p>Many state departments of transportation (DOTs) are currently making efforts to implement PBES for construction of their off-system bridges. The purpose of this research project was to investigate other states' standards and to evaluate them for possible implementation in Florida. An exhaustive search was made, and new literature was reviewed, to learn about current DOT standards and practices. The search revealed that the states with the most prefabricated bridge standards or activities are as follows: Utah, Alabama, Texas, Minnesota, and a collaboration of Northeastern states. These standards were reviewed for details such as the presence of post-tensioning, joint types, design load, and inspectability.</p> <p>The two standard bridge types that show the most promise for adoption by Florida Department of Transportation (FDOT) are Minnesota's Inverted-tee Beam, and PCI's "Northeastern Extreme Tee" (NEXT) Beam. A summary of the findings, including advantages and disadvantages of the bridge systems, is included in this report. Also included is a comprehensive list of Web links to standard drawings from all state DOTs, as well as more information on ABC and PBES, which could also be helpful to expedite other research that involves standards and bridge construction/design practices.</p>					
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EXECUTIVE SUMMARY

The Federal Highway Administration’s (FHWA) “Every Day Counts” initiative aims to shorten the overall project delivery time, enhance safety, and protect the environment both on and around construction projects. Using innovative planning, design, and construction methods, Accelerated Bridge Construction (ABC) techniques reduce on-site construction time for new or replacement bridges. One aspect of ABC is Prefabricated Bridge Elements and Systems (PBES), where bridge components are fabricated off site to reduce on-site construction activities.

Many state departments of transportation (DOTs) are currently making efforts to implement PBES for construction of their off-system bridges. The purpose of this research project was to investigate other states’ standards and to evaluate them for possible implementation in Florida. An exhaustive search was made, and new literature was reviewed, to learn about current DOT standards and practices. The search revealed that the states with the most prefabricated bridge standards or activities are as follows: Utah, Alabama, Texas, Minnesota, and a collaboration of Northeastern states. These standards were reviewed for details such as the presence of post-tensioning, joint types, design load, and inspectability.

The two standard bridge types that show the most promise for adoption by Florida Department of Transportation (FDOT) are Minnesota’s Inverted-tee Beam, and PCI’s “Northeastern Extreme Tee” (NEXT) Beam. A summary of the findings, including advantages and disadvantages of the bridge systems, is included in this report. Also included is a comprehensive list of Web links to standard drawings from all state DOTs, as well as more information on ABC and PBES, which could also be helpful to expedite other research that involves standards and bridge construction/design practices.

TABLE OF CONTENTS

Disclaimer	ii
Acknowledgements	vi
Executive Summary	vii
List of Tables	x
List of Figures	xi
1 Introduction	1
1.1 Background	1
1.2 Scope	4
2 Literature Review	6
2.1 Review of Prefabricated Elements and Systems	6
2.2 Prefabricated Decks	7
2.2.1 Deck Panels	7
2.2.2 Full-Depth Deck Panels	9
2.2.3 Partial Depth Deck Panels	12
2.2.4 Open Grid Decks	14
2.2.5 Concrete/Steel Hybrid Decks	14
2.2.6 Fiber Reinforced Polymer (FRP) Decks	17
2.2.7 Timber Decks	18
2.3 Beams and Girders	19
2.4 Bent Caps	21
2.5 Abutment and Wall Elements	24

2.6	Columns and Piers	25
3	Prefabricated Superstructure Systems	27
3.1	Introduction	27
3.2	Precast Slab/Deck Beams	28
3.3	Precast Adjacent Box Beam	29
3.4	Poutre Dalle System (Inverted-tee Beams)	30
3.5	Precast Adjacent Concrete Tee Beams	31
3.6	Precast Prestressed Concrete Deck Bulb-tee Systems	32
3.7	Precast Concrete Deck on Steel Stringers	34
4	Top PBES Candidates	35
4.1	Alabama	35
4.2	Minnesota	37
4.3	PCI Northeast NEXT Beam	40
4.4	Texas Box Beam	46
4.5	Florida Prestressed Slab Unit	49
5	Conclusions	52
5.1	Summary	52
5.2	Recommendations	53
	References	56
	Appendices	58
	Appendix A	59
A.1	FHWA Weblinks for EDC, ABC, AND PBES	60
A.2	State Departments of Transportation Weblinks for Standard Drawings and Specifications	61
	Appendix B	71
B.1	Links to State Departments of Transportation Standard Drawings for PBES	72
B.2	Selected Prefabricated/Precast Bridge Elements and Systems	84
B.3	Selected Case Studies on Total Precast Concrete Bridges	85

LIST OF TABLES

2.1	Summary of Deck Systems and Their Minimum Installation Times	8
4.1	Summary of Pros and Cons of Alabama DOT Precast Slab System	37
4.2	Summary of Pros and Cons of Minnesota’s Inverted-tee System	39
4.3	Summary of Pros and Cons of NEXT Beam	45
4.4	Summary of Pros and Cons of Texas Box Beam	47
4.5	Summary of Pros and Cons of Florida Prestressed Slab Unit .	51
5.1	Summary of Attributes of Top PBES Candidates	54

LIST OF FIGURES

1.1	Elements of Accelerated Bridge Construction	2
1.2	Mitchell Gulch Bridge Replacement	4
1.3	Typical Construction Site	5
2.1	Full-depth Deck Panel	9
2.2	Male-to-Female Connection	11
2.3	Shear Pocket Connection for Deck Panels	12
2.4	Leveling Bolt	13
2.5	Partial Depth Deck Panel	13
2.6	Open Grid Deck	15
2.7	Exodermic Deck Installation	16
2.8	Exodermic Deck	16
2.9	Fiber Reinforced Polymer Deck Placement	17
2.10	Glulam Deck Panel Placement	19
2.11	Standard AASHTO Girders	20
2.12	Placement of Precast Bent for Redfish Bay Bridge	21
2.13	Precast Bent Detail Sheet for Redfish Bay Bridge	22
2.14	Inverted-tee Bent	23
2.15	Cap-to-Column Connection using Grouted Sleeve	24
2.16	Total Precast Abutment	25
2.17	Precast Concrete Columns	26
3.1	Adjacent Beam Bridge Span Ranges	28
3.2	Precast Adjacent Box Beam Bridge	29
3.3	Poutre Dalle Beam	30
3.4	Double-tee Bridge Profile	31

3.5	Decked Bulb-tee Cross section	33
3.6	Roadway Profile Using Decked Bulb Tees	33
4.1	Alabama Precast Superstructure System	36
4.2	MnDOT Inverted-tee Beam Cross Section	38
4.3	Center City Bridge Under Construction	40
4.4	NEXT Beam Cross Section	41
4.5	NEXT Beam Precast Railing Option	42
4.6	NEXT Beam Fabrication	44
4.7	Full-depth Top Flange NEXT Beam	45
4.8	Texas Adjacent Box Beam	47
4.9	X-Beam Bridge Profile	49
4.10	Cross Section of Florida Prestressed Slab Unit, 12 in. x 48 in.	50
4.11	Keyway Detail for Florida Prestressed Slab Unit	51

CHAPTER 1

INTRODUCTION

1.1 Background

The Federal Highway Administration (FHWA) has an initiative called the “Every Day Counts” (EDC) program, which is aimed at shortening the overall project delivery time, enhancing safety, and protecting the environment both on and around construction projects. A major focus of the Every Day Counts program is called Accelerated Bridge Construction (ABC). The FHWA defines ABC as bridge construction that uses innovative planning, design, materials, and construction methods in a safe and cost-effective manner to reduce the on-site construction time that occurs when building new bridges or replacing and rehabilitating existing bridges. Figure 1.1 shows that there are many facets to Accelerated Bridge Construction, including: right-of-way procurement, handling of utilities, contracting methods, geotechnical solutions, and Prefabricated Bridge Elements and Systems (PBES).

PBES, which is the focus of this report, means that most or all of the bridge components are fabricated off site in a controlled environment, where extra care can be taken to ensure high quality and increased durability of the individual bridge elements. The most common reason to use ABC is to decrease the impact of construction on the traveling public. This is due to the delicate flow of the transportation network, and on-site construction related activities directly impact those who use it. With most of the bridges in the scope of this project located in rural areas on roads with low Average Daily Traffic (ADT), some equally practical reasons for accelerating construction could be to minimize lengthy detours, negate the use of a temporary struc-

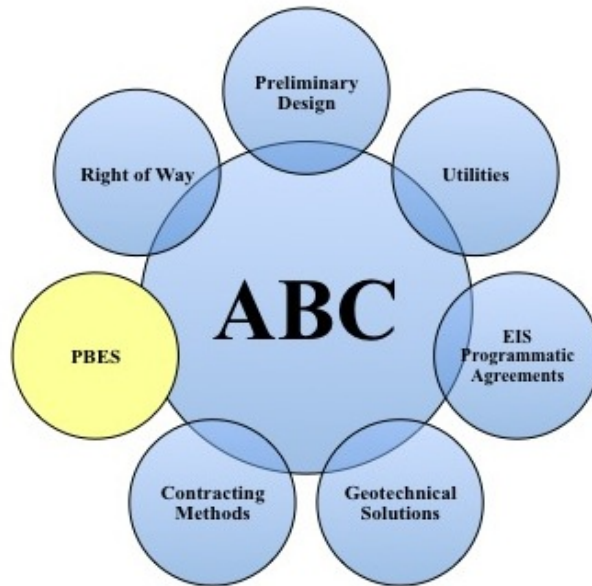


Figure 1.1: Elements of Accelerated Bridge Construction
 (www.fhwa.dot.gov/everydaycounts/technology/bridges/pbeswebinartraining/s1_m1.cfm)

ture, and reduce impact on the environment. With this being said, moving the fabrication of the bridge parts off the traveled path has many benefits, including time savings, cost savings, safety advantages, and convenience for travelers (FHWA, 2011). Appendix A.1 provides several Web links to FHWA reports and presentations on ABC and PBES technologies.

To fully understand the time savings of PBES, one must first look at how bridges are currently being built with no accelerated technologies being used. Bridges are built from the bottom up, so the first step is to construct the foundation. This requires forms to be constructed, rebar to be placed, and concrete to be placed and cured before the piers or columns can be built. Concrete must gain strength before loads can be applied, which lengthens the time needed for construction. A similar process is needed to construct not only the columns but also the pier caps, which are located on top of the columns, and the superstructure. In Florida, it is common to use precast prestressed concrete girders with a cast-in-place deck, but this is not considered accelerated bridge construction because no innovative methods are used to decrease the project time.

With PBES, the components can be fabricated at the same time, so that the elements are ready to be shipped before they are needed at the site. Because the elements are usually constructed in a controlled environment, weather delays are less frequent and only have the possibility to occur on the portion of the work done on site. This alone can have a great impact on bridge construction in Florida due to its tropical climate.

The popular adage “Time is Money” applies to bridge construction: reducing a project’s construction time may also decrease the total cost of the project. According to a cost study conducted by the FHWA, the combined use of PBES and effective contracting strategies saved 30 million dollars on just nine bridge replacement projects across the country. Some PBES projects had no delay at all during peak hour traffic; by closing only one or two lanes, traffic does not have to stop completely or be rerouted. On other projects, it may be more beneficial to work while there is little to no traffic such as late at night and on the weekends.

In a PBES case study from Colorado, the 40-ft-long, two-span, 26-ft-wide State Highway 86 Bridge over Mitchell Gulch was replaced with a new 40-ft single span, 43-ft-wide bridge in only 46 hours. The original bridge had two 11-ft lanes and 1.5-ft shoulders; the new bridge was designed to have two 12-ft lanes and 8-ft shoulders. The road was closed at 7PM on Friday, where demolition was started immediately, and opened at 5PM on Sunday, 13 hours ahead of schedule. Had this bridge been built using conventional methods, it would have taken two to three months; where ABC was implemented, it took only a weekend and had no impact on weekly rush-hour traffic. Drivers who traveled over the bridge on the way home from work on Friday and then back to work on Monday never experienced a construction-related delay or detour. The engineer’s estimate on the replacement project was \$394,200, and the Lawrence Construction Company had the lowest bid at \$365,200, with a total of \$29,000 in savings or 7% of the engineer’s estimate (FHWA, 2006). This was the first bridge of its kind that the contractor built, and they anticipate that another 50 percent of the time can be saved on similar bridge projects. Figure 1.2 shows the first and last beams being placed. Notably, the parapet is precast with the beam; this reduces construction time by eliminating the need for cast-in-place concrete.



(a) First Beam Being Placed

(b) Last Beam Being Placed

Figure 1.2: Mitchell Gulch Bridge Replacement
(www.fhwa.dot.gov/bridge/prefab/successstories/091104/index.cfm)

Some states are promoting the use of PBES as standard practice. Fully implementing PBES, however, would require education and training for engineers and contractors who are used to conventional construction, more widespread use of special fabrication and construction methods to handle large loads, creation of design and construction standards and specifications, and research on long-term durability – particularly of connection details for the bridge elements. Even so, PBES may not be necessary for all bridge construction projects, for example: if there is no need for quick bridge construction; long detours are not required; road user mobility is not affected by construction; and environmental concerns are minimal. Furthermore, to evaluate if PBES is advantageous for a particular project, the schedule for construction of the *entire* project must be considered. PBES may not be beneficial, for example, on a project that involves extensive roadway work where the bridge is not on the critical path for construction.

1.2 Scope

The purpose of this project is to research what other states are currently using for PBES construction of off-system bridges. The use of PBES can minimize the commotion caused by construction to commuters and other travelers. Shorter construction time means shorter roadway closures, which means that traffic patterns return to normal more quickly. Another benefit of using prefabricated bridge elements is the increase in worker safety. Blinking lights,

cones, and unique looking machinery located on and around construction sites easily distract drivers, especially during peak hours (Figure 1.3).



Figure 1.3: Typical Construction Site
(www.ci.fridley.mn.us/street-projects/)

By using PBES and shortening the construction time, driver exposure to these hazards can also be reduced, thereby lowering the possibility for a motorist to miss or fail to notice a lane shift or closure. Other hazards around bridge construction sites in Florida include bodies of water. For bridges over water, the use of prefabricated pier caps and prefabricated superstructure elements will limit the amount of time that workers need to function over the water. Construction around water creates another problem other than worker safety: sensitive ecosystems can be destroyed by the heavy machinery needed for bridge construction. This can be reduced with the use of prefabricated elements and systems. Because the components are constructed off site, heavy cranes are typically needed to erect them; however, the equipment is needed on site for less time than for conventional construction. Careful scheduling of projects can also reduce the impact on the environment by not working during periods of high animal activity and plant growth (FHWA, 2011).

CHAPTER 2

LITERATURE REVIEW

2.1 Review of Prefabricated Elements and Systems

To prefabricate is to manufacture sections, especially in a factory-like setting, so that they can be easily transported to and rapidly assembled on a construction site. For this research, a prefabricated *element* is a single structural unit that has been constructed off site. A prefabricated *system* is a combination of elements that can be joined together to make up an entire bridge. Precast elements, generally made of concrete, can have many different shapes and sizes; among these are precast abutments, piles, piers, bent caps, columns, girders, and deck panels. In a total prefabricated bridge system, every element is made ahead of time and transported to the site as deemed necessary by the project schedule.

Superstructure systems can also be constructed by combining prefabricated girders and deck elements into modular sections that can be moved and placed simultaneously, thus eliminating the need to move and place multiple individual elements (Culmo, 2009). Likewise, substructures can also be constructed into systems with combinations of spread footings to columns to bent caps, or precast abutments with precast wingwalls. In certain circumstances, prefabricated elements can also be combined with traditional cast-in-place construction to accelerate bridge construction. All of these different elements and systems will be discussed in the following section.

2.2 Prefabricated Decks

2.2.1 Deck Panels

As stated earlier, the most conventional method of constructing a bridge deck is by using time consuming and labor intensive cast-in-place concrete. One benefit of this method is that a smooth riding surface is ensured because the concrete can be worked and leveled out to the appropriate elevation and profile. Unfortunately, this method requires temporary formwork or stay-in-place formwork to be constructed to hold the wet concrete. Once the formwork is in place, reinforcement must be tied, and concrete is placed in the forms. The concrete must then be allowed to cure until a specified strength is achieved, before traffic is allowed on the bridge. This method can be very time consuming and labor intensive, due to the preparation of the forms and having to wait for the concrete to gain the necessary strength. By using prefabricated precast deck elements, these constraints can be avoided.

There are two main types of precast concrete deck panels: partial depth and full-depth. Some other examples of prefabricated deck panels are open grid deck, concrete/steel hybrid deck, fiber-reinforced polymer deck, and timber deck panels. Both types of concrete deck panels can be manufactured off site in a casting yard, allowed to cure, and transported to the site when needed. After arriving on site, the deck panels can be lifted and placed directly onto precast concrete girders and connected in a variety of ways (Medlock et al., 2002). A summary of these deck systems, including their minimum installation times, is provided in Table 2.1.

Table 2.1: Summary of Deck Systems and Their Minimum Installation Times

System	Time <i>$\frac{Days}{Span}$</i>	Comments
Full-depth Precast Concrete Deck Panels	2	This includes longitudinal post-tensioning and closure pours. Deck replacements have been completed during a single weekend closure.
Open Grid Decks	1	The lack of post-tensioning needs for these systems can lead to very fast installations.
Concrete/Steel Hybrid Decks	2	Some of these systems are similar to full-depth precast decks. They require grouting in order to make the connection to the beam framing.
FRP Deck Panels	2	Adhesive connections and grouting are the major installation tasks.
Partial Depth Precast Deck Panels	7	The panels install quickly (1 day); however, replacement of the top mat of reinforcement and concrete is needed to complete the deck.
Timber Deck Panels	1	This system is simple and requires no grouting or post-tensioning.

(After www.fhwa.dot.gov/bridge/prefab/if09010/02.cfm#a6)

2.2.2 Full-Depth Deck Panels

Full-depth precast deck panels accelerate bridge construction by totally eliminating the need for formwork, casting/curing time on the critical path of the bridge project, and cast-in-place concrete. Full-depth precast concrete deck panels can be used both transversely and longitudinally, as well as vary in shape and size. Figure 2.1 shows the placement of a precast full-depth deck panel. Most commonly, the elements are constructed with transverse joints



Figure 2.1: Full-depth Deck Panel
(www.fhwa.dot.gov/everydaycounts/technology/bridges/pbeswebinartraining/s2_m5.cfm)

along the bridge, and each element spans the entire width of the road. Because these elements are precast in a yard, they can be easily prestressed and are commonly post-tensioned longitudinally after placement. This post-tensioning ensures that the panels are securely tightened together to create a continuous deck.

There are several cases where full-depth precast concrete decks have been

used and have been in service for over ten years. In the 1980s, the deck of the Woodrow Wilson Bridge that crosses the Potomac River near Washington D.C. was replaced using full-depth precast lightweight concrete panels. Maryland Department of Transportation (DOT) noted that the deck had performed very well under very severe environmental conditions until it was replaced by the Outer Loop Bridge in the summer of 2006. Transverse strands were sheathed in plastic with a grease coating, and longitudinal tendons were grouted. The multilayered corrosion protection methods used for the transverse and longitudinal post-tensioning tendons were very successful (Dymond et al., 2009). This system was used to re-deck several bridges in Connecticut in the 1990s; the bridges are still in service and are in excellent condition (FHWA, 2011).

There are many different ways of connecting these panels both to each other and to their supports. The most common connection between panels is a grouted shear key type of joint. There are different types of shear keys including female-female, male-female (Figure 2.2), and match-cast connections that are post-tensioned, bolted, welded or passively reinforced. Cracking of the joints between panels is perhaps the most problematic aspect of using a panels system; this leads to water leakage and deterioration.

Unfortunately, *post-tensioned* joints are the most complicated of the connection types, but they provide the best performance. By introducing a compressive force on the joints, the concrete has a lesser probability of cracking from service loads. A *passively* reinforced joint is one that utilizes a closure pour. Reinforcement is placed so that it extends out of the precast shape into the joint. Once the elements are placed, the void is filled with concrete. The downside to passively reinforced joints is there is still a need for formwork to be erected, and time is needed for the concrete to cure.

Welded connections are made by careful placement of steel plates in the element prior to it being cast. The location of the plates is in conjunction with other elements such as steel H piles, so when they are placed, the plates line up and are welded together to ensure load transfer. Welded connections are beneficial for ABC because they do not take long to complete. Unlike concrete, they do not take days or weeks to gain full strength; once the metal is cool, the connection is complete. Some disadvantages to welded connections can be a lack of certified field welders, difficulties with welding in cold environments,



Figure 2.2: Male-to-Female Connection
(www.fhwa.dot.gov/pavement/concrete/pubs/if06010/ch5.cfm)

and quality of field welds.

Another type of connection commonly used with full-depth deck panels is called a block-out or shear pocket (Figure 2.3), which is precast into the element. This type of connection also requires that studs protrude up from supporting members into these shear pockets, and when the deck panel is in place, non-shrink grout is used to fill the shear key and complete the connection.

Because these panels are full depth, they have the potential to have very heavy lifting weights; this problem can be addressed with the use of lightweight concrete or fiber-reinforced polymer reinforcement. These materials may be preferred when it is necessary to reduce the loads from the superstructure, or when there are space concerns where smaller erection equipment is needed to place the deck panels (FHWA, 2011).

Another issue with using precast deck panels is leveling. If the design calls for full-depth panels to be used, then an irregularity in either the panel or the supporting members may cause a difference in elevation of adjacent panels.



Figure 2.3: Shear Pocket Connection for Deck Panels
(www.fhwa.dot.gov/bridge/prefab/if09010/02a.cfm)

This can cause a rough riding surface and may cause dynamic vibrations that can be detrimental to the longevity of the bridge. Therefore, leveling devices are needed to ensure that there is a smooth transition from panel to panel. A common solution to this problem is to cast a threaded socket in each corner of every panel (see Figure 2.4). A bolt is threaded through the socket, and a wrench is used to adjust the panels until the proper elevation is achieved. These bolts are supported by the flanges of the supporting girders until grout is placed to hold the weight of the panels. Once the grout is supporting the panel, the bolts are removed, and the bolt hole is also filled with grout. Leveling shims are another way to ensure proper deck elevations prior to grouting (Culmo, 2009).

2.2.3 Partial Depth Deck Panels

Many different states have used partial depth deck panels; for example, 85% of all bridges built in Texas use this forming method. Unlike full-depth deck panels, partial depth panels act as a stay-in-place form when used for bridge construction, and a topping slab or overlay is applied once the panels are in place (Figure 2.5). These panels are generally 3.5 in. to 4 in. thick and are placed on top of the beams on interior spans. Using partial depth precast deck panels accelerates construction by eliminating the need to construct formwork,

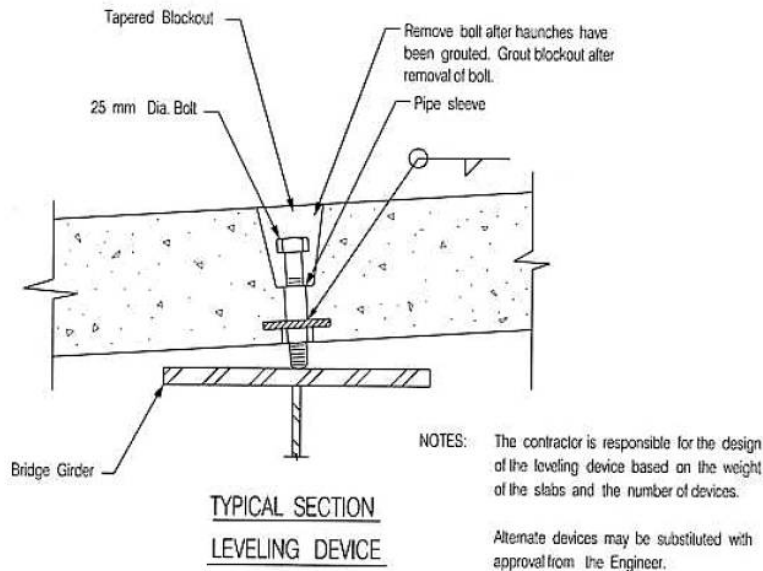


Figure 2.4: Leveling Bolt
(www.fhwa.dot.gov/bridge/prefab/if09010/02a.cfm)

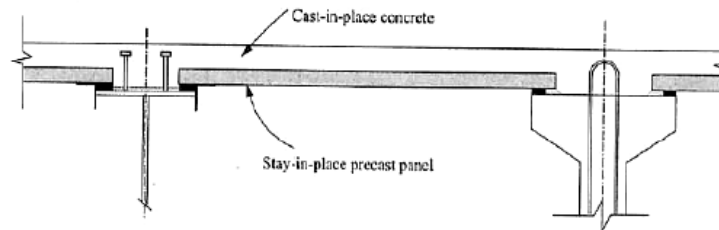


Figure 2.5: Partial Depth Deck Panel
(www.fhwa.dot.gov/bridge/prefab/if09010/02a.cfm)

although overhangs are usually constructed with conventional forming methods because of future widening concerns. One disadvantage is the possibility of cracks in the topping slab located at the joints of the precast panels. Washington DOT only allows the use of partial-depth panels in the positive moment region of the deck because, in this area, the top of the slab is in compression.

Texas DOT has sponsored a great deal of research on precast partial depth deck panels, including laboratory studies, field verification, strength tests, and cyclic live load tests. It is preferred to use prestressing as the main reinforcement in partial depth panels. Due to their shallow depth, it is important to use a minimum amount of prestressing force and a small strand diameter

to decrease the probability of edge cracking during the development of the strands.

The panels are made composite with steel or concrete beams by using welded stud shear connectors or standard shear reinforcement, respectively, in the gap between adjacent panels. When the topping concrete is placed, this gap is filled. For this system, it is important to provide a concrete bedding between the panels and beams, so that the panels are continuously supported to resist live loads; otherwise, the riding surface can be poor, and joints may spall. With regard to ensuring that the panels and topping concrete act as a single unit to resist loads, research has shown that composite action between the panels and topping is possible without using horizontal shear reinforcement (Whittemore et al., 2006) (Buth et al., 1972); intentionally roughening the top surface of the panel, after removing laitance or other contaminants, can provide the needed bond between the CIP concrete and precast panel.

2.2.4 Open Grid Decks

Open grid decks have been used for many years on bridges where lightweight decks are required, such as for moveable bridges and suspension bridges. One concern of the open grid deck is long-term durability of elements below the open grid. Grid decks act as miniature steel framing systems, usually consisting of main rail members that span between supporting beams in the strength direction, along with transverse cross bars to resist loads running parallel to the supporting beams (Figure 2.6) (FHWA, 2011). Open grid decks can be connected with the use of bolts or field welding. If the panels are painted prior to placement, there shall be no paint where the welds are located. More information on open grid decks is available from the Bridge Grid Flooring Manufacturers Association (www.bgfma.org).

2.2.5 Concrete/Steel Hybrid Decks

These types of systems consist of a combination of steel and concrete components. There are two common types of hybrid decks: partially filled grid decks and exodermic decks. The partially filled grid decks include a steel grid deck, in which the upper portion of the deck is filled with concrete after placement.



Figure 2.6: Open Grid Deck

(<http://i733.photobucket.com/albums/ww340/emmons1315/ehbridge026.jpg>)

The concrete is filled over the top of the grid to improve performance. An exodermic deck is similar to a partially filled grid deck, with the exception that the concrete is primarily placed above the grid. The connection of exodermic decks is similar to that of the precast full-depth deck systems (see Figure 2.7), in that headed shear studs are installed on girders, and grout is poured into voids to achieve the connection between the beams and the deck system. Figure 2.8 shows the details for an exodermic deck.



Figure 2.7: Exodermic Deck Installation
(www.fhwa.dot.gov/bridge/prefab/if09010/02.cfm)

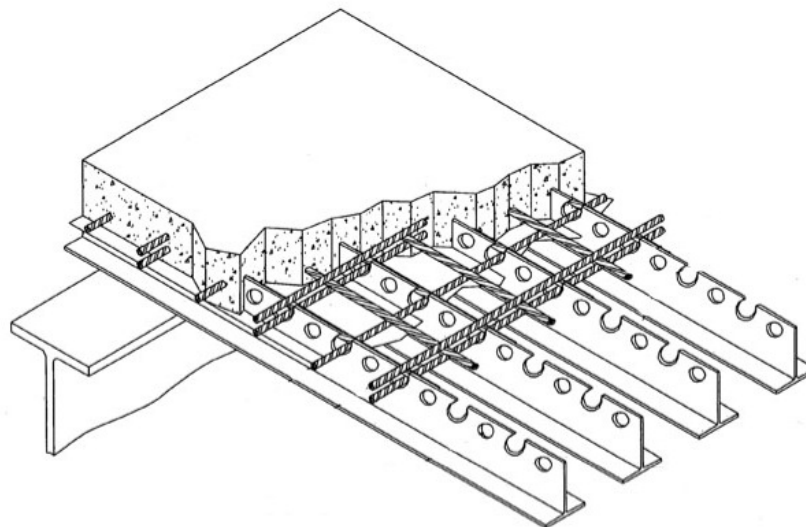


Figure 2.8: Exodermic Deck
(www.freepatentsonline.com/7197854.html)

2.2.6 Fiber Reinforced Polymer (FRP) Decks

Fiber reinforced polymers (FRP) were first used in the aerospace industry and have just recently made their way into the bridge construction industry. FRP composites can be made using several different types of fibers and can be formed into many different shapes. (For example, glass fiber and carbon fiber are the most widely used FRP products to be used as reinforcement in concrete members.) There are many advantages of using FRP products over other structural materials: they have high strength, are lightweight, have high stiffness-to-weight ratios, and are corrosion resistant. They have a low modulus of elasticity, which limits their use as beams and girders, but this is not a factor with decks because the structural spans of elements are very short. Figure 2.9 shows the placement of an FRP deck replacement.



Figure 2.9: Fiber Reinforced Polymer Deck Placement
(www.fhwa.dot.gov/bridge/prefab/successstories/091104/01.cfm)

The process of making FRP panels allows for development of complex

shapes and joint configurations. Interlocking panels and male-female shear keys have been used, and high quality epoxy adhesives are used to join panels together. FRP panels can be made composite with the bridge framing. Typically, pockets are formed over the beams, to allow for the installation of welded stud shear connectors and non-shrink grout. Bolts have also been used to connect the panels to the framing (Culmo, 2009). According to the FHWA Connection Details Manual, no FRP products have been standardized, and each project has been a totally unique design (Culmo, 2009).

2.2.7 Timber Decks

The United States Department of Agriculture (USDA) Forest Products Laboratory (FPL) has developed standard details for prefabricated timber panels and beams. Most timber bridges are used on low-volume roads, but with the development of these standards, they may be applicable to higher volume roads. Prefabricated timber beams and panels are normally manufactured using the glue laminating process, where multiple pieces of nominally dimensioned lumber are glued together side-by-side to create a solid glulam timber panel. For beams, the wide dimension of the laminations is horizontal, and for panels, the longer dimension of the laminations is vertical. Because these bridges are constructed where they will be exposed to weather, proper measures must be taken to ensure that the wood does not rot. Pressure treated wood is used for glulam members and can be either pressure treated before or after the pieces have been laminated together. Waterproof glue is also required for glulam members exposed to weather. Figure 2.10 is a picture of glulam deck panels being placed on steel girders (Culmo, 2009). There is a significant amount of information on timber bridges at the USDA FPL website (www.fpl.fs.fed.us), as well as in Section 2.1.6 of the FHWA Connection Details Manual (Culmo, 2009).



Figure 2.10: Glulam Deck Panel Placement
(www.westernstructures.com/WS_Site/News_Blog.html)

2.3 Beams and Girders

Currently, the most widely used prefabricated element for bridge construction is the precast prestressed concrete girder. The first use of this girder type in the United States was in 1949 on the Walnut Lane Bridge in Philadelphia, Pennsylvania. In the late 1950s, the American Association of State Highway and Transportation Officials (AASHTO) and the Precast/Prestressed Concrete Institute (PCI) developed a set of standardized girder sections (Figure 2.11) (PCI, 2001). Although the I-girders are the most common shape used, other shapes can be used such as the U-beam, Single- and Double-tee beams, rectangular box beam, flat slab, and voided slab girders. Each type of superstructure type will be explained in the next chapter on prefabricated superstructure systems.

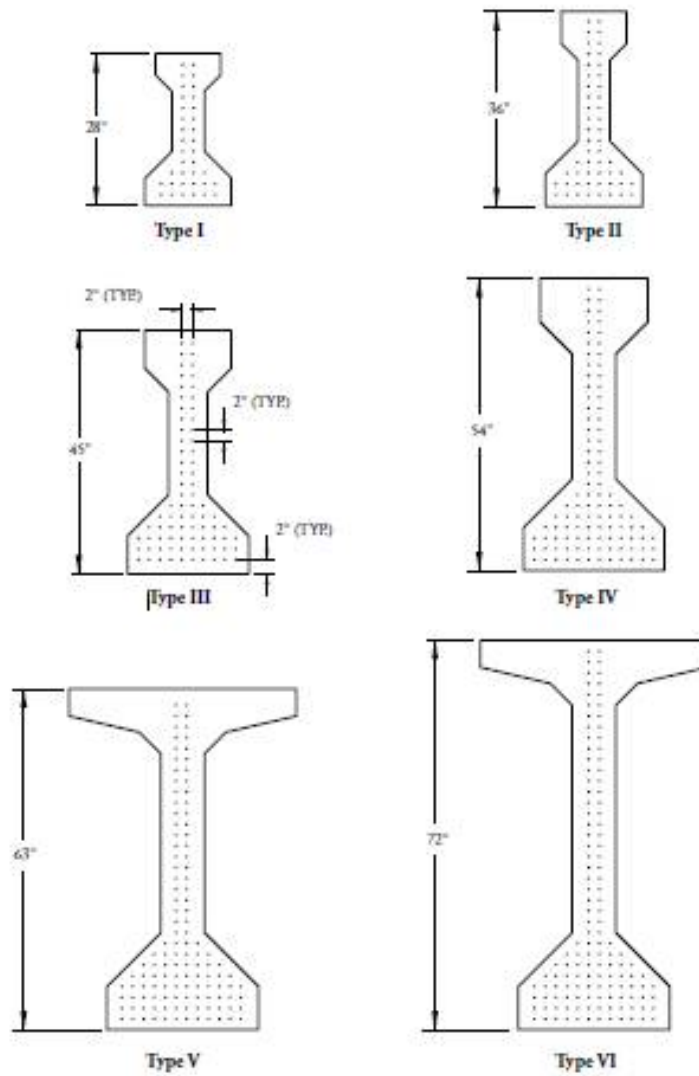


Figure 2.11: Standard AASHTO Girders (PCI, 2001)

2.4 Bent Caps

The most commonly used prefabricated substructure element to date is the precast bent cap. With the use of precast bent caps, construction times can be accelerated in the same fashion as using precast deck elements and prefabricated girders, by moving the forming and curing of the elements off the critical path of the bridge project. Texas was the first state to use prefabricated bent caps in the United States. In 1994, Texas used precast bents on the Redfish Bay Bridge and Morris Cummings Cut Bridge (Figures 2.12 and 2.13), and the use of these prefabricated elements reduced the total project length by six months (Medlock et al., 2002).



Figure 2.12: Placement of Precast Bent for Redfish Bay Bridge
(www.fhwa.dot.gov/bridge/prefab/all.cfm?view=31)

Due to the complicated nature of the formwork for and reinforcement in bent caps, it is easier to construct them in a precasting plant rather than in the field, where they are generally located at high elevations or over water. Precasting bent caps also reduces safety concerns for workers: by constructing

the cap off site, workers need to spend less time at dangerous heights. There are two major types of bent caps: the rectangular bent cap and the inverted-tee bent cap. Precast bent caps can be used with both traditional cast-in-place

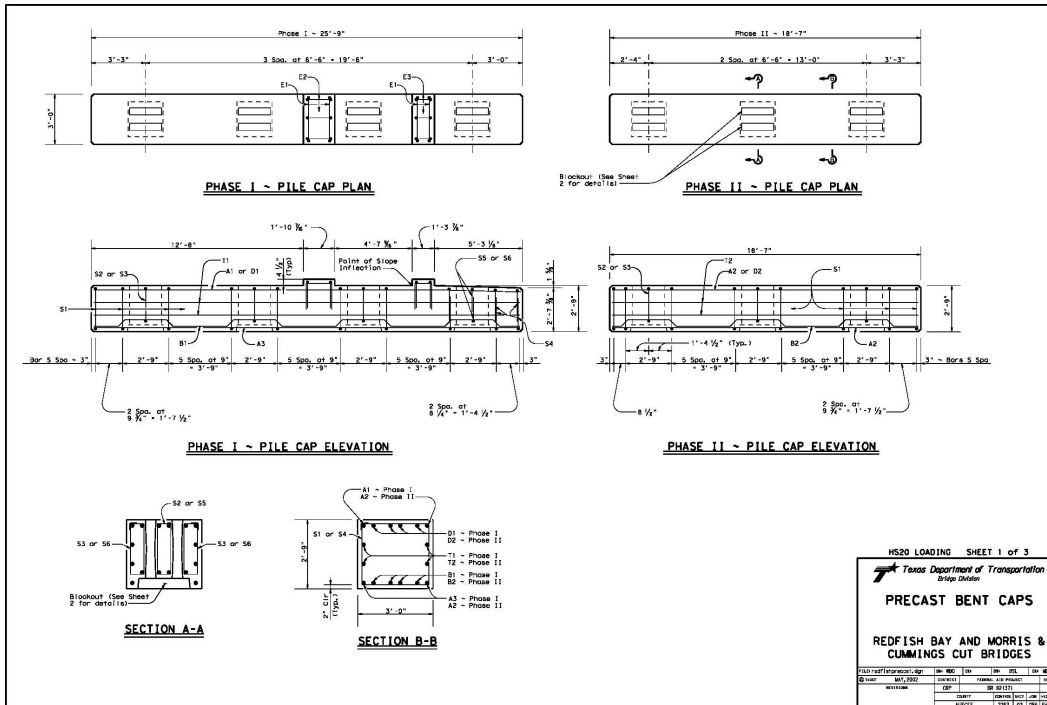


Figure 2.13: Precast Bent Detail Sheet for Redfish Bay Bridge (www.fhwa.dot.gov/bridge/prefab/redfish1.cfm)

(CIP) columns as well as with precast columns or piers. Similar to precast deck panels, there are many different ways to connect precast bent caps to their supports.

The precast rectangular bent cap is more widely used than the inverted-tee bent cap. They can be placed on CIP or precast columns, piers, or piles, depending on the appropriate design for the project. As the name implies, the bent caps are rectangular in shape and some even have a void in them to reduce the lifting weight. Similarly, the inverted-tee bent cap is shaped like an upside-down tee (Figure 2.14), and the beams or girders rest on the flanges of the tee (Fouad et al., 2006).

There are many different methods for connecting bent caps to columns

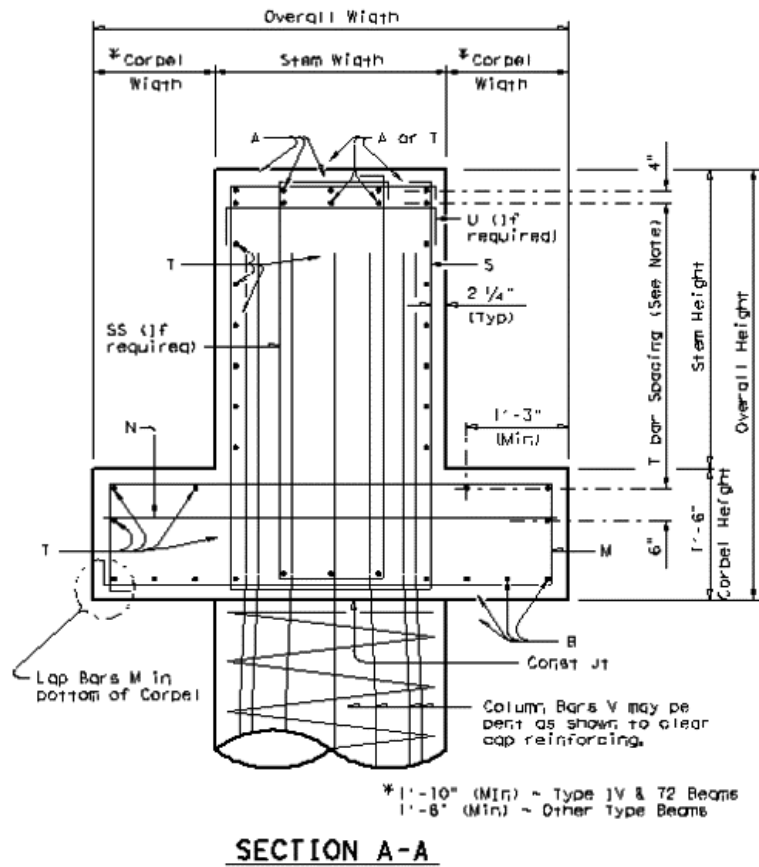


Figure 2.14: Inverted-tee Bent
 (onlinemanuals.txdot.gov/txdotmanuals/det/invertedt_cap_details.htm)

or piers. Most of them involve some form of grouted void, sleeve, or duct. In these connections, tendons or reinforcement extend up vertically from the pier or column, into the voids or ducts that have been precast into the cap (Figure 2.15). Shims are used under the bent caps to ensure that proper elevations have been met, and grout is placed into the ducts or voids to ensure connection between the substructure elements.

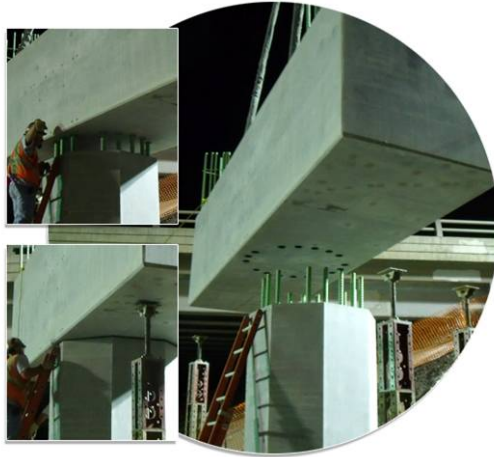


Figure 2.15: Cap-to-Column Connection using Grouted Sleeve
(www.fhwa.dot.gov/everydaycounts/technology/bridges/pbeswebinartraining/s2_m6.cfm)

2.5 Abutment and Wall Elements

Prefabricated abutment and wall elements eliminate activities that are associated with conventional abutment construction, including construction of formwork, reinforcement placement, concrete placement, and curing time. Prefabricated abutment elements (Figure 2.16) can also be built in a phased construction manner using conventional construction methods, built near an existing bridge without disrupting traffic. There are many examples of prefabricated elements used in abutment and wall elements: prefabricated caps for caisson or pile foundations; precast footings, wingwalls, or backwalls; steel or concrete sheet piling; prefabricated full-height wall panels; cast-in-place concrete abutments, used with or without precast elements, if built in a manner that is accelerated or has no impact to traffic mobility; mechanically stabilized earth (MSE) walls; and geosynthetic reinforced soil abutment (FHWA, 2011).

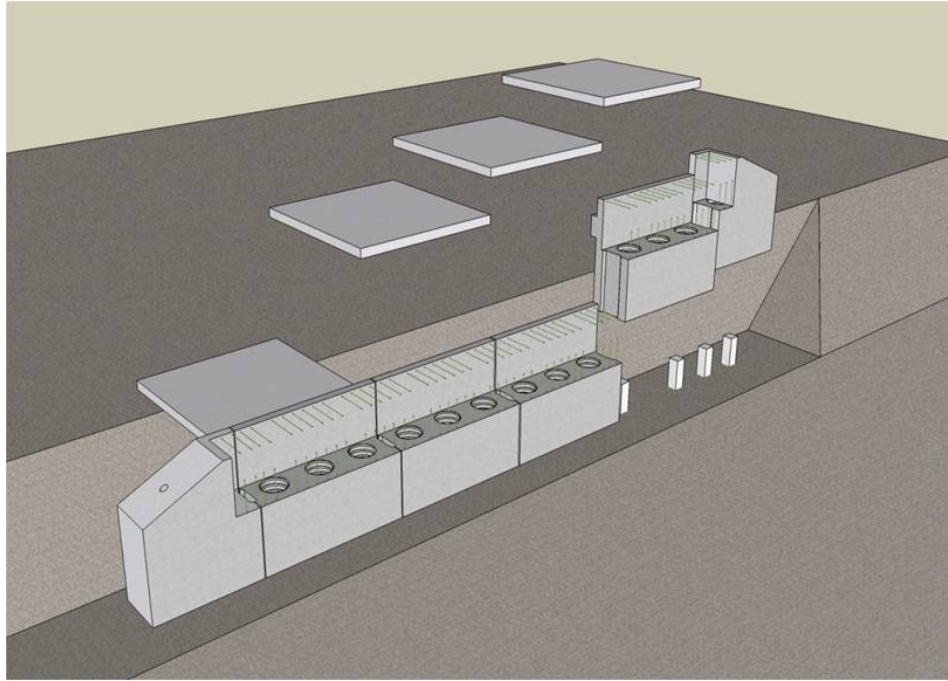


Figure 2.16: Total Precast Abutment
(www.fhwa.dot.gov/everydaycounts/technology/bridges/pbeswebinartraining/index.cfm)

2.6 Columns and Piers

Similarly to previously discussed precast elements, the use of precast substructure components assists in accelerating construction times. Some examples of precast column elements are segmental columns, whole columns, segmental piers, whole piers and piles. A segmental column consists of multiple segments that are placed on top of each other until the desired height is reached (Figure 2.17). These columns can be connected by post-tensioning or grouted coupling devices. Segmental columns are a good choice because they are easier to handle and erect than precast full-length columns (Fouad et al., 2006).

Whole columns are another option to speed up construction. They are cast as a single element according to the height required by the design. They can be placed onto precast spread footings or cast-in-place foundations. Tendons can be used to connect the columns to the footings, through ducts that are precast into the column and to tendons that extend up from the footing. These columns often have voided areas to decrease lifting weights. Piers or

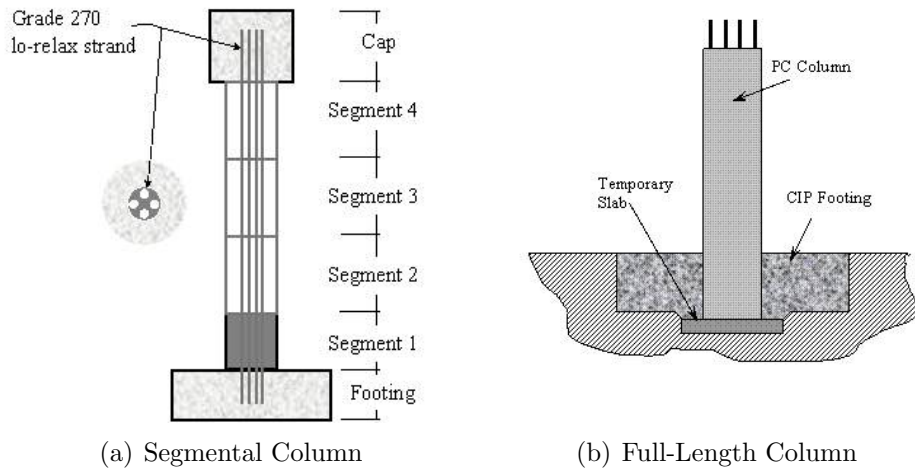


Figure 2.17: Precast Concrete Columns
 (www.fhwa.dot.gov/bridge/accelerated/followup2007/page3.cfm)

intermediate bridge supports can also be prefabricated similar to columns and can be full height or segmented. Precast driven piles are another example of precast columns. They are often used with precast bent caps where a corrugated pipe is cast into the bent; once the piles are at the proper elevation, the cap is lowered onto the piles, and the void is filled with grout.

CHAPTER 3

PREFABRICATED SUPERSTRUCTURE SYSTEMS

3.1 Introduction

As stated earlier, a prefabricated system is a combination of different elements. A prefabricated superstructure is the combination of elements that replaces the usual need for a CIP deck and girders. The use of a prefabricated superstructure reduces the time it takes to construct or replace a bridge's superstructure and is faster than using cast-in-place concrete and faster than using girders with slabs placed on top (FHWA, 2011).

Butted slab beam systems have been used for many years, and many states have standard details on these systems. Figure 3.1 is a chart showing different types of butted beam systems and their applicable span lengths (Culmo and Seraderian, 2010). Each of these systems has pros and cons, and these should be taken into account in design. A general advantage of these systems is that deck forming is not required. An asphalt overlay may extend the service life of the bridge, especially where deicing chemicals are used. The slab elements, 3 ft to 4 ft wide each, act as the structural deck. A disadvantage of the system is that joints between the slab elements have a tendency to leak or fail.

The adjacent slab/deck beams are a good option for short-span, low-volume bridges. Adjacent box beams are applicable for a very wide range of span lengths but, unfortunately, are more costly than other designs due to the complexity of their fabrication. The double-tee system has been successfully used for years on parking structures and is also a great option for bridges.

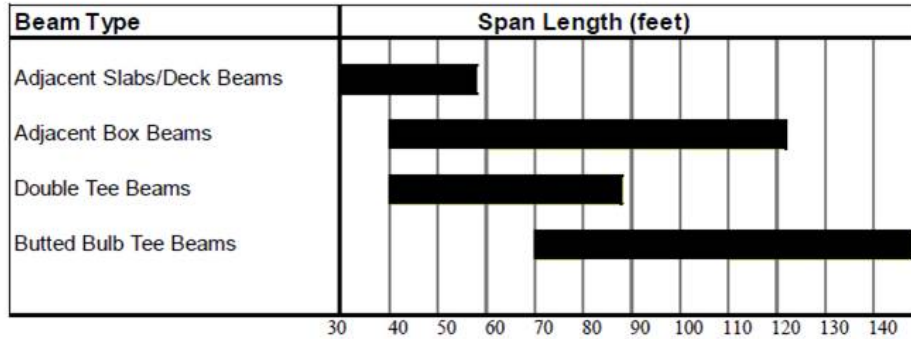


Figure 3.1: Adjacent Beam Bridge Span Ranges
 (www.fhwa.dot.gov/bridge/prefab/if09010/02a.cfm)

3.2 Precast Slab/Deck Beams

Adjacent slab beam bridges, a common superstructure type for short-span bridges, are applicable for 30- to 60-ft span lengths (Figure 3.1). Alabama’s prestressed slab units are post-tensioned together after the beams are placed side by side. Another example is Florida Department of Transportation’s (FDOT’s) developmental standards for Prestressed Slab Units (PSUs), which require no post-tensioning and are joined with longitudinal shear keys. The standards have two different depth units: 12 in. and 15 in. A fiber reinforced concrete deck is placed on top of the beams after they are placed and has a single mat of reinforcing steel. The overlay is either 6 in. or 6.5 in. deep, depending on the length of the span. The concrete overlay is of Class II or Class IV concrete with fiber reinforcing admixtures. The top surface of the slab units is required to be raked to provide a rough surface to ensure bond between the beams and the overlay. The standards have provisions for two beam widths of 48 and 60 in. To keep the units from sliding transversely, a keeper block must be installed on bridges with a cross slope of 3 % or greater. If there is a grade of 3 % or more on the finished bridge deck, there also needs to be some form of stopper to prevent units from sliding longitudinally. These beams are designed as simple spans and should not be used on bridges with more than three spans. The standards accommodate a skew of 30 degrees or less on beam ends. The thickness of the slab unit is to be consistent across the entire width of the roadway.

3.3 Precast Adjacent Box Beam

A popular, tried-and-verified prefabricated superstructure type is the adjacent box beam bridge (Figure 3.2). In this system, box beams span from support

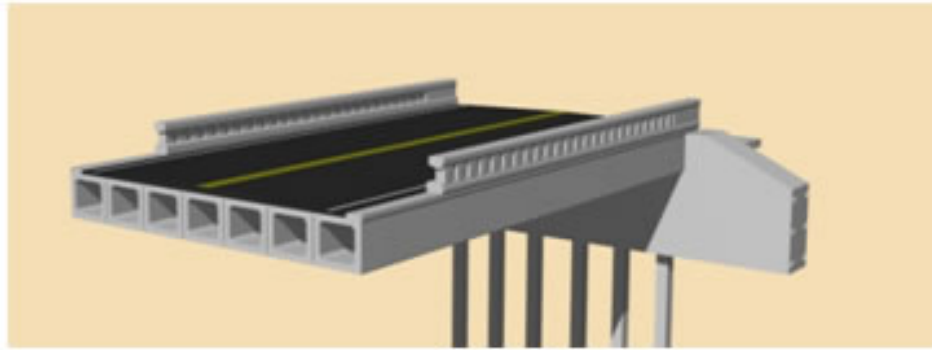


Figure 3.2: Precast Adjacent Box Beam Bridge
(www.fhwa.dot.gov/bridge/abc/prefab_def.cfm)

to support and are placed side by side. A disadvantage of the system lies in the longitudinal joints between the boxes, where leakage and durability are concerns. To alleviate these issues, post-tensioning can be used to connect the boxes transversely and provide compression across the joints. Precast box beams can also be longitudinally prestressed for added strength and for attaining longer spans. Many states have standards for precast box beams. Texas DOT has a nice set of plans for varying project parameters; their standards have four different depth beams, and with added depth, they can achieve longer spans. Texas allows transverse post-tensioning of these systems with the use of an asphalt overlay. When a 5-in. cast-in-place topping is used, transverse post-tensioning is not required. Although Texas standards call for a deck topping, it is not needed. Other states use this type of superstructure because it eliminates the need for deck panels or cast-in-place deck.

3.4 Poutre Dalle System (Inverted-tee Beams)

The Poutre Dalle system is a European bridge design that utilizes precast concrete inverted-tee beams (Figure 3.3). Minnesota DOT has adopted this design as an alternative for rapid replacement of bridges. The beams con-

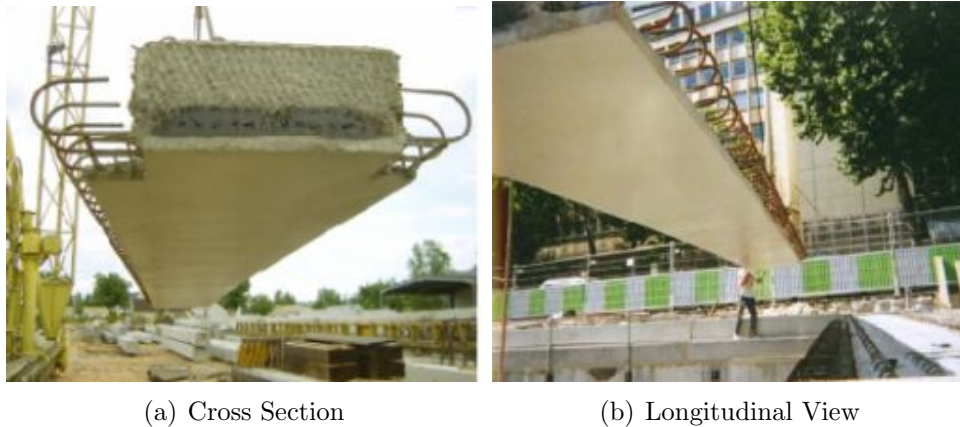


Figure 3.3: Poutre Dalle Beam
(www.fhwa.dot.gov/bridge/prefab/slab.cfm)

sist of a rectangular prestressed section with smaller flanges along the sides. When the beams are placed side by side, the flanges form a channel between the beams; this eliminates the need for formwork and further accelerates construction. Reinforcing rebar hooks extend from the beam into the channel and overlap in this region. The hooks are alternately spaced so they do not occupy the same space. After a pre-tied rebar cage is placed into the channel, a concrete closure pour is used to lock the sections together monolithically (Piccin and Schultz, 2012). Although easy to construct, the resulting solid cross section is an inefficient use of concrete material – compared to hollow box sections, for example.

3.5 Precast Adjacent Concrete Tee Beams

There are several different precast prestressed concrete tee systems currently in use across the country. Texas has both a modified deck slab beam with flanges as well as a double-tee section (Figure 3.4). These Texas beams are connected using a welded anchor plate and grout. Other states also have double-tee and

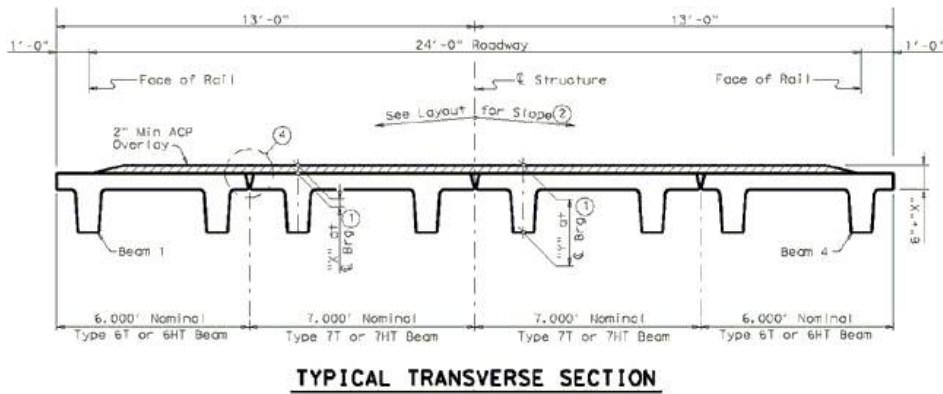


Figure 3.4: Double-tee Bridge Profile
(www.fhwa.dot.gov/bridge/prefab/if09010/appd.cfm#c)

triple-tee sections, and New York has a quad-tee system that spans the full width of a two-lane road.

The Northeast branch of the Prestressed/Precast Concrete Institute has standards for a double-tee bridge system called the Northeast Extreme Tee (NEXT) Beam. These standards include the NEXT F beam, which has a partial depth top flange and a reinforced concrete deck, and the NEXT D beam, which has a full-depth top flange and is a good option for low-volume roads. The NEXT D beam uses a closure pour to achieve connection from beam to beam, where headed reinforcement rods extend out of the flanges of the beams at alternating positions.

3.6 Precast Prestressed Concrete Deck Bulb-tee Systems

Bulb tees are precast prestressed concrete I-shaped beams that are different from regular I-girders in two ways. The bottom flange is wider to allow the use of more prestressing strands, and the top flange is about 4 ft wide. The cross section is an efficient use of concrete material: its depth provides stiffness and an effective use of prestressing force. Unlike for box beams, a deck is typically poured on top of the bulb tees because their flanges are too thin to support wheel loads. Casting the deck concrete requires formwork or, if allowed by the bridge owner, stay-in-place forms. Differential camber in the multiple girders can be problematic when aiming for the final, desired vertical curve geometry – especially when the girders are placed on a skew. The amount of CIP deck concrete needed to compensate for the camber can be large.

Design of bulb tees varies from state to state, although in some parts of the country, state DOTs have collaborated and agreed on a common set of sections that can be fabricated across state lines. Decked bulb tees and adjacent box beams are comparable, but the bulb tees have some advantages over box beams. Decked bulb tees offer easier access for inspection and a simplified fabrication process because there are no voids in the section (Figures 3.5 and 3.6) (PCI, 2001). Forms are removable and reusable.

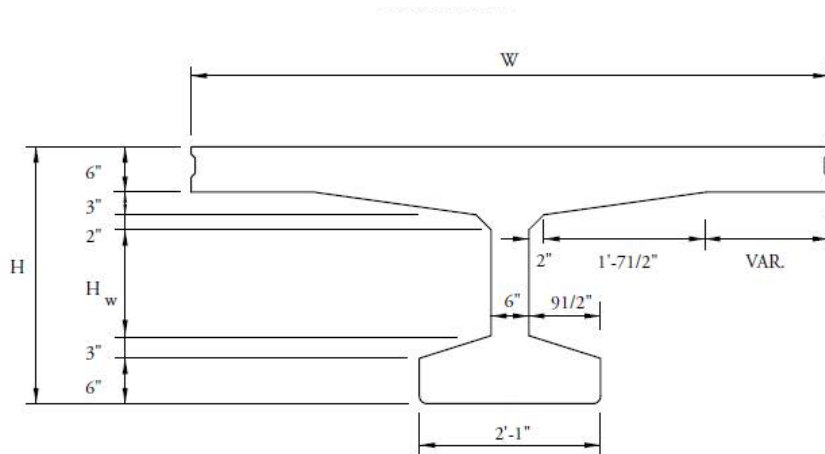


Figure 3.5: Decked Bulb-tee Cross section
 (www.pci.org/view_file.cfm?file=MNL-133-97_appendix_b.pdf)

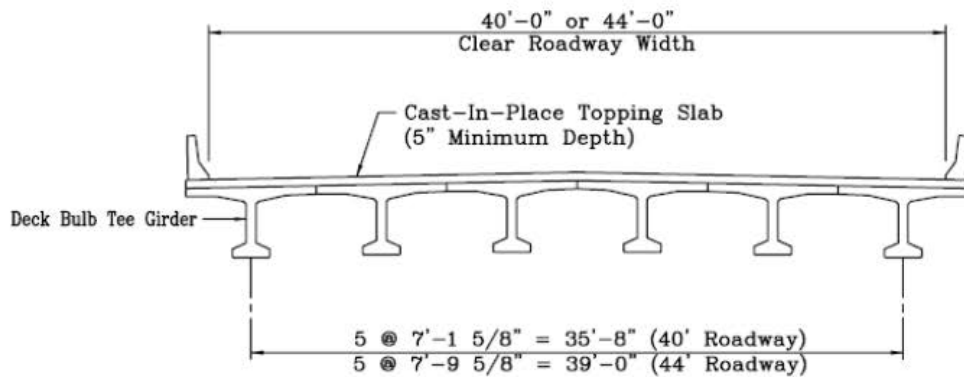


Figure 3.6: Roadway Profile Using Decked Bulb Tees
 (www.fhwa.dot.gov/bridge/abc/prefab_def.cfm)

3.7 Precast Concrete Deck on Steel Stringers

In early 2010, the Transportation Research Board's (TRB) Strategic Highway Research Program 2 (SHRP2) asked Iowa DOT to develop a standardized bridge system for rapid renewal. Iowa DOT chose a bridge on U.S. 6 over Keg Creek to be the test site. The new design was a three-span, 210-ft-long, steel/precast modular structure and incorporated precast approach slabs. To demonstrate the accelerated design, U.S. 6 was closed for only two weeks to minimize impact on traffic. If conventional construction methods were used, the bridge construction would have taken several months and caused substantial traffic disruptions.

The superstructure consisted of rolled steel beams with concrete deck modules that were prefabricated off site. This was the first bridge to be fabricated off site with steel girders and a concrete deck. To further accelerate construction, the exterior modules had the barrier prefabricated onto the section. Six modules were needed to achieve the 47-ft roadway width. The modules were joined longitudinally and transversely, on site, with the use of ultra high performance concrete. After the modules were made composite, the spans were post-tensioned longitudinally. Site selection was based on a common need (i.e., bridge dimensions) in Iowa and across the nation; the design was intended to be innovative and repeatable. The bridge was designed by HNTB in Omaha, Nebraska, and the contractor was Godbersen Smith Construction Co. Iowa's Department of Transportation website (<http://www.iowadot.gov/us6KegCreek/index.html>) has more information regarding this design, as well as a time-lapse video of the construction process.

CHAPTER 4

TOP PBES CANDIDATES

An extensive search was performed on each of the 50 states' Department of Transportation websites, looking for precast standard drawings and specifications. (See Appendix A.2 for Web links to state DOT standards.) The search revealed that many states had no standards within the scope of this project, while other states yielded a large quantity of prefabricated bridge standards. The states with the most information were Utah, Alabama, Texas, Minnesota, and a collaboration of Northeastern states. Further study revealed that, although Utah's DOT is considered fully implemented with the use of prefabricated bridge elements and systems, they had very little to offer on smaller short-span bridge standards which fall into the scope of this project. The systems that are considered to be the top PBES candidates for Florida's off-system bridges are discussed below. (See Appendix B for Web links to these standards, as well as more information on selected PBES and case studies on precast concrete bridges built with accelerated construction methods.)

4.1 Alabama

Alabama's standards for prefabricated bridges on secondary, low-volume roads consist of precast concrete slab beams that are placed adjacent to each other. Unlike many precast concrete systems, these beams do not use prestressing steel strands. The elements are transversely post-tensioned together using galvanized threaded bolts (Figure 4.1), but due to the harsh environment in Florida, the use of stainless steel bolts should be considered. One disadvantage of this system is that access to the underside of the bridge is required for post-

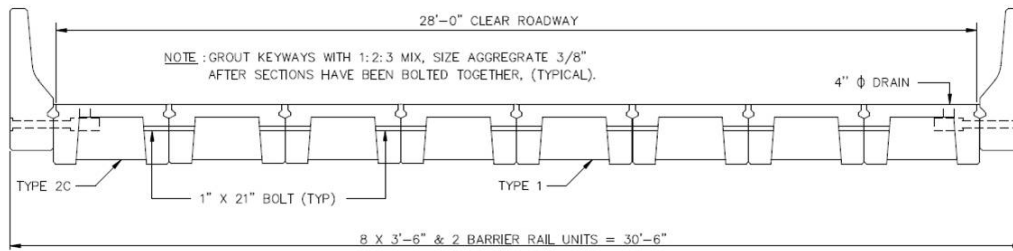


Figure 4.1: Alabama Precast Superstructure System
 ([www.dot.state.al.us/brweb/doc/PrecastStandards/PC-34-2\(Sheet2of2\).pdf](http://www.dot.state.al.us/brweb/doc/PrecastStandards/PC-34-2(Sheet2of2).pdf))

tensioning operations. However, the bottoms of the beams are open, which allows for easier inspection, compared to box beams. The standards have accommodations for varying span lengths (24, 34, and 40 ft) as well as different roadway widths. Alabama also has standards for a precast concrete barrier – to be used with this superstructure system – that can be bolted onto the fascia of the exterior beam in a similar fashion as how the individual beams are connected together transversely. Longitudinal joints are composed of a 5-in.-deep shear key that is filled with non-shrink grout after the beams have been bolted together (Fouad et al., 2006).

To go along with their precast superstructure details, Alabama also has a set of standards for a precast substructure. The substructure details include precast concrete bent caps that can accommodate steel H-piles, as well as prestressed concrete piles. Abutment panels are also a part of the substructure details. These panels are bolted to the driven piles and act as a retaining wall under the bent caps. These bridges are a great option for counties to use on their secondary roads that have low volumes of heavy trucks. This system was designed to carry an HS20-44 truck load, and the only durability issues that Alabama has had with this bridge type is from oversized loads using the bridge – where cracks formed along the longitudinal joints, and some spalling of concrete occurred around the bolted connection. Pros and cons of this system are summarized in Table 4.1.

Table 4.1: Summary of Pros and Cons of Alabama DOT Precast Slab System

Pros	Cons
<ul style="list-style-type: none">• Fast construction• No prestressing strands (pre-tensioned or post-tensioned)• Members are bolted together with post-tensioning (PT) bars• Underside connections are visible for inspections• Barriers are precast and bolted to exterior beams• Can be used with precast abutments and bents• No cast-in-place topping	<ul style="list-style-type: none">• Designed for HS20-44 loading, not HL-93• Spalling can occur around bolted connection• Access to underside is required for post-tensioning operations• No accommodation for skewed bridges

4.2 Minnesota

The Minnesota DOT, with help from local fabricators and the University of Minnesota, has developed a set of standards from a modified French design known as the Poutre Dalle System. This system consists of precast prestressed concrete inverted-tee beams (Figure 4.2). The beams have an applicable span range between 20 and 65 feet. The beams have a standard width of 6 ft, consisting of two 1-ft flanges on each side of a 4-ft-wide rectangular web. The use of a 6-ft section was chosen for a couple of reasons: to keep the number of beams required to span the width of the roadway minimal, and to limit the number of longitudinal joints. These beams are made continuous with the use of a longitudinal closure pour. Reinforcement extends out of the sides of the web so that, when placed side by side, it overlaps the adjacent flange. These beams were designed to be constructed without the use of overlays and post-tensioning, to speed construction. Although no post-tensioning is required,

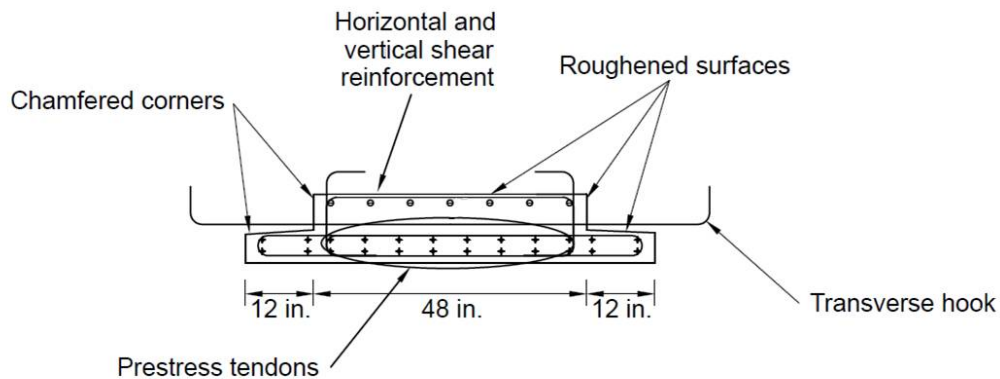


Figure 4.2: MnDOT Inverted-tee Beam Cross Section
 (www.pci.org/view_file.cfm?file=JL-12-SPRING-15.pdf)

durability could be increased with the addition of post-tensioning to aid in crack control.

In Europe, the exposed transverse reinforcement had a 180° hook that was used for continuity across the joint. Minnesota changed the exposed reinforcement to have a 90° hook, so that a pre-tied rebar cage can then be placed into the channel created by the two flanges on top of the reinforcement. This channel that is created is then filled with concrete, and the flanges act as stay-in-place forms, thus eliminating the need for formwork. The surfaces that are to have direct contact with the cast-in-place concrete should be roughened to provide a better bond between the precast section and CIP concrete. The sections of the precast beam that have contact with the form (flange tops and vertical faces of the stem) are roughened using a textured form liner. A rake is used to create a roughened surface on the top of the stem. To provide adequate cover requirements, the thickness of the flange was selected to be 5.25 in. with a 1:24 slope. This provides enough room for 1.5 in. of cover from the bottom of the beam to the #4 bar with a 180° hook around the longitudinal reinforcement, and the slope aids in removing the beam from formwork. Because the channel created by the flanges is to be filled with concrete, there is no cover requirement for the top of the flange. Although there is no required cover depth, there is a need for some concrete cover because the reinforcement needs to bond with the precast concrete. By having such a thin flange, the depth of cast-in-place concrete is increased; also, the location of the transverse

reinforcement is lower. Both of these factors aid in the ability of this system to distribute loads in the transverse direction (Piccin and Schultz, 2012).

A summary of the pros and cons of the Minnesota inverted-tee system is in Table 4.2. The system is comparable to FDOT’s PSU bridge type in a

Table 4.2: Summary of Pros and Cons of Minnesota’s Inverted-tee System

Pros	Cons
<ul style="list-style-type: none"> • Applicable span lengths from 20 ft to 65 ft • Standard 6-ft-wide beam • No formwork is necessary for casting of slab • Barriers can be precast on exterior beams • No post-tensioning required 	<ul style="list-style-type: none"> • Total bridge can be heavy, with 18-in.-thick concrete across width of bridge • Need room on site to assemble rebar cage • Rebar cage has to be installed after beams are erected

couple of ways: both systems have similar depths and a cast-in-place concrete deck, and neither system requires the use of transverse or longitudinal post-tensioning. One notable difference, besides the cross-sectional shape, is that the inverted-tee beam does not have different width options.

The first bridge constructed in Minnesota (Mn) using the modified inverted-tee section was the Center City Bridge (Mn bridge No. 13004), which spans a channel that allows boat traffic from North Center Lake to South Center Lake (Figure 4.3). The bridge has a total length of 71 ft, consisting of two 22-ft outer spans and a 27-ft interior span. The bridge width is 76 ft 5 in., providing a 10-ft-wide bike trail and a roadway width of 63 ft 3in. The design speed for this bridge is 45 mph (Piccin and Schultz, 2012).

The precaster of the members was County Materials Corporation out of Roberts, Wisconsin. The individual members were fabricated using concrete



Figure 4.3: Center City Bridge Under Construction
(www.dot.state.mn.us/bridge/manuals/LRFD/pdf/workshop/06InvertedTeeDesign.pdf)

with a compressive strength of 6500 psi. Two layers of seven-wire, 1/2-inch diameter, low-relaxation prestressing strands were used with a guaranteed ultimate tensile strength of 270 ksi. Each layer of prestressing had eight strands with a center-to-center spacing of 6 in. The vertical spacing between the strands was 2 in. The cold steel reinforcement was epoxy-coated rebar with a yield strength of 60 ksi. The precast members were 12 in. deep, and when the concrete deck was placed, the composite section had a uniform 18-in. depth across the width of the bridge. The 6-in.-thick deck provided 3 in. of cover above the longitudinal deck reinforcement. HL-93 live load was used in the design calculations, as well as a 20-psf uniformly distributed load for future wearing surface. For the traffic barriers and pedestrian barrier, a 450-plf (pounds per linear foot) and a 200-plf load, respectively, were distributed uniformly to all precast beams.

4.3 PCI Northeast NEXT Beam

The Northeast Extreme Tee (NEXT) Beam (Figure 4.4) was developed by the Precast/Prestressed Concrete Institute Northeast (PCINE), the nation's Northeast regional branch of PCI. They serve the northeastern states, including: Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont. The idea for the development of this beam was born in 2006 at Oldcastle Precast-Rotondo in Rehoboth, Massachusetts. The pre-

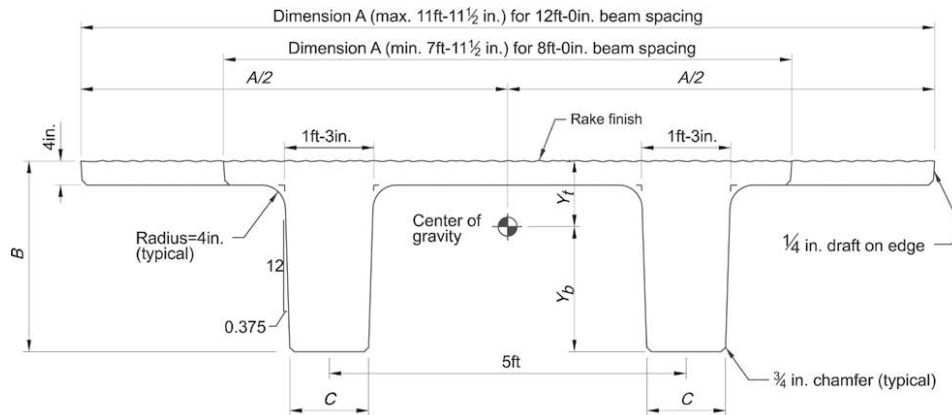


Figure 4.4: NEXT Beam Cross Section

(www.pcine.org/cfcs/cmsIT/baseComponents/fileManagerProxy.cfc?method=GetFile&fileID=29E93D11-F1F6-B13E-83B313BBC9C58FF5)

casters were in the process of casting a high-level railroad platform, and the developer thought that it had attributes that could be transferred to the bridge industry. This beam was developed to compete with the precast concrete adjacent box beam superstructure system, which has issues with inspectability and handling of utilities. The NEXT beam solves these issues purely through its geometry. The open underside makes inspection easy, because joints are visible. Utilities can be run parallel to the stems of the tee and, as long as they do not extend past the bottom of the stem, are hidden from sight. The NEXT beam is intended for use on medium span bridges with spans ranging from 40 ft to 90 ft. The section resembles that of a standard double-tee beam that is commonly used for parking structures (Culmo and Seraderian, 2010).

When used for parking garages, the double-tee beams can be installed without a topping; when this is the case, the flange is used as the vehicle contact area. Unfortunately, when used for bridges, the flange thickness needs to be about 8 in. thick to resist heavy truck loads. This introduces hauling and lifting considerations for longer spans. To reduce the weight of the section, PCINE first developed the NEXT F beam, which has a partial depth flange and a CIP concrete deck. PCINE set a weight limit of 120,000 lb for these beams; this is due to the fact that if it were any heavier, then special hauling permits would have to be obtained, and this could increase costs instead of reduce them. Connections of these beams with full-depth flanges and no topping are

also an issue when heavy truck loads are expected. Texas and some other state DOTs have researched and developed high capacity connections, but PCINE decided to stay away from these, initially. Therefore, developers made a decision to have a thin top flange and a reinforced cast-in-place concrete deck on top. Because the beams are placed adjacent to each other, there is little need for formwork construction, which will greatly reduce construction times. The exterior flanges of the NEXT F beams can also be reinforced to carry barrier loads. Because there is an 8-in.-thick cast-in-place deck on the NEXT F beams, PCI developed a precast barrier system that is grouted longitudinally to the bridge, has reinforcement that extends transversely from the barrier, and is tied to the deck reinforcement. The precast barrier acts as the side forms for the wet deck concrete (Figure 4.5). This type of connection is essentially the same as a traditional cast-in-place concrete connection (Culmo and Seraderian, 2010).

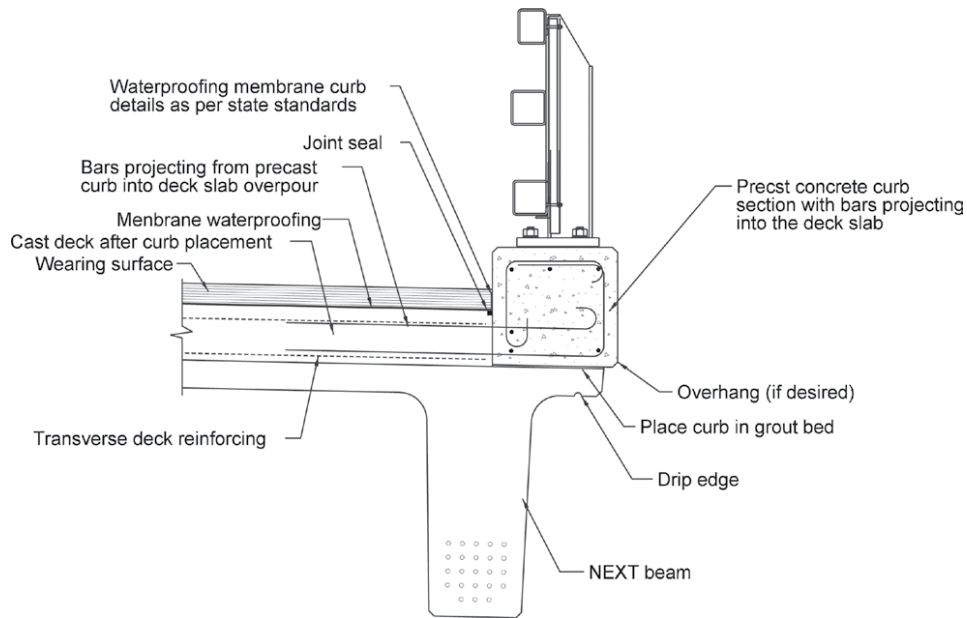


Figure 4.5: NEXT Beam Precast Railing Option
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To accommodate bridges with different widths, a variable width beam was

desired. In the development of the NEXT F beam, a maximum width of 12 ft was agreed upon to ease shipping and handling concerns, and the minimum width of the beam is limited to the stem spacing. To eliminate the need for multiple sets of forms, which can be extremely expensive, a decision was made to fix the dimension of the stems on the NEXT F beam, and to have differing flange widths. Due to issues like concrete cover, expected shear reinforcement sizes, and strand spacing, an initial stem width of 11 in. was chosen to accommodate four columns of prestressing strands and a No. 4 stirrup for shear reinforcement. The stem width dimension was later enlarged by 2 in. to provide enough room for another column of strands, which increased the maximum achievable span length. The maximum span length of the NEXT F beam is 87 ft, which is based on the use of the minimum 8-ft section (Culmo and Seraderian, 2010).

The spacing of the stems was a concern. The final design of the beam has the maximum spacing of the stems set at 5 ft to accommodate the minimum beam width of 8 ft. If the stems were any farther apart, the beam would act more like an inverted U-beam instead of a double-tee beam for the minimum width beam. There are four different standard depths for the NEXT F beam. PCI already has a bulb tee that is 39 in. deep, so when the NEXT F beam was developed, the maximum depth was limited to 36 in., to prevent competition between the superstructure types. The beam depths vary from 24 in. to 36 in. at 4-in. intervals. Spacer blocks are used in the formwork to accommodate the differing depths and negate the need for multiple forms (Figure 4.6).

A typical issue with prestressed members is high compressive stresses at the beam ends due to the prestressing strands. To correct this, there are a couple of solutions. The most efficient option is to drape some of the strands – requiring the use of some kind of hold down or deviator system to be incorporated into the formwork. This makes fabrication more difficult, which in turn adds to the cost of the beam. Due to these reasons, it was decided to use straight prestressing strands on the NEXT F beam and to debond them. By using straight strands, there is a loss in efficiency, but the production savings should offset this loss.

In January 2010, the NEXT D beam with a full-depth flange was developed that eliminated the need for a cast-in-place deck. This was the original



Figure 4.6: NEXT Beam Fabrication
(www.pci.org/view_file.cfm?file=JL-10-SUMMER-9.pdf)

desire of PCINE, but member hauling weights and connections resulted in the development of the NEXT F beam with a CIP concrete deck. The NEXT D beam (Figure 4.7) is intended for use on short-span bridges on low-volume roads where there is not a durability concern with the longitudinal joint. Because the top flange is intended to act as a structural deck, the connection longitudinally requires a closure pour between members. A shear key and headed reinforcing bars that extend from the flanges create the longitudinal connection for the beams. Removable formwork has to be used to contain the concrete for the closure pour and must also be able to accommodate differential camber of the beams. Because the top flange is being used as a riding surface, the parapets have to be either precast onto the beam during fabrication or must be cast-in-place on site after installation. The use of lightweight concrete on the full-depth, top-flange section can significantly reduce the self weight of the beam, and thus the shipping costs could be reduced also. With a reduction in weight, there is also a possibility to achieve longer spans with the use of lightweight concrete (PCINE, 2012a). A summary of the pros and cons of the NEXT beam is provided in Table 4.3.

The first Northeast Extreme Tee beam bridge was opened in November

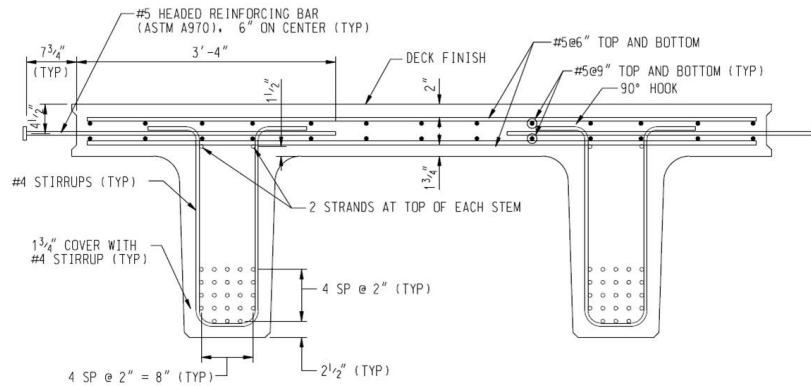


Figure 4.7: Full-depth Top Flange NEXT Beam
www.pcline.org/cfcs/cmsIT/baseComponents/fileManagerProxy.cfc?method=GetFile&fileID=29E93D11-F1F6-B13E-83B313BBC9C58FF5

Table 4.3: Summary of Pros and Cons of NEXT Beam

Pros	Cons
<ul style="list-style-type: none"> • Span lengths from 40 ft to 90 ft • Maximum beam width is 12 ft • Utilities are handled between stems to stay out of sight • Can be designed with a CIP deck or full-depth top flange • Skewed beam ends • Precast barriers can double as side forms with the use of NEXT F beam 	<ul style="list-style-type: none"> • Members can be very heavy due to their geometry • Differential camber can be an issue with NEXT D beams • Closure pour is necessary with use of the NEXT D beam

2010 and is located in York, Maine, spanning the York River. It was constructed by CPM Constructors of Freeport, Maine, and the beams were fabricated by Dailey Precast of Shaftsbury, Vermont. The bridge is 510 ft long and comprises seven spans: two 55-ft end spans and five 80-ft interior spans. The roadway width of 38 ft 2 in. is achieved by using four 36-in.-deep, 9-ft-

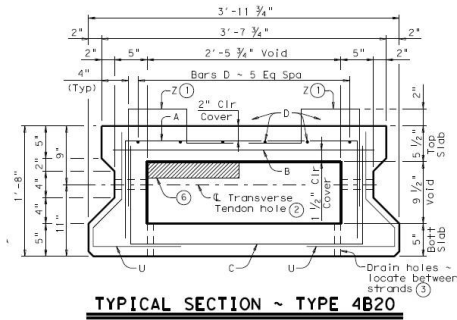
4.5in.-wide NEXT F beams side by side. Composite action is developed by a 7-in. cast-in-place concrete deck; the beams have a flange thickness of 4 in. (Hodgdon, 2011).

In the late summer of 2011, Hurricane Irene hit the Northeast coast of the country. The storm dropped record amounts of rain, and the rivers and streams overflowed with runoff, destroying a number of bridges. The Titus Road Bridge, a small bridge in Moriah, New York, was demolished from the flood waters; thereafter, it was put on a fast track construction using the NEXT D beam. The beams used for the bridge were 76 ft long and 7 ft wide and were precast with a 1-ft-6-in. integral backwall and 14° skew. Four beams were needed to achieve the roadway width of 30 ft. The beams were erected in April 2012, and the bridge was scheduled to be completed on May 31st of this year (PCINE, 2012b).

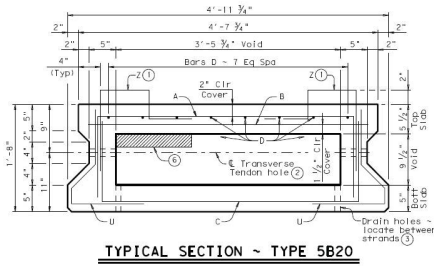
4.4 Texas Box Beam

Texas has a set of standards for a prefabricated prestressed concrete box beam that is appropriate for Florida's off-system bridges. These beams are placed adjacently to each other until the desired roadway width is achieved. There are three standard roadway widths that can be accommodated with the use of these box beams: 24, 28, and 30 ft. The standard drawings accommodate four different beam depths of 20, 28, 34, and 40 in., as well as two nominal widths of 4 and 5 ft. Both the 4- and 5-ft-wide beams (Figure 4.8) are used for the 24- and 30-ft-wide roadway. These beams are appropriate for bridges with spans from 30 to 100 ft and with no skew or horizontal curves. Due to differing beam depths, not all beams can accommodate the maximum span lengths. A summary of the pros and cons of the system is provided in Table 4.4.

These beams are designed according to the AASHTO Load and Resistance Factor Design (LRFD) Specifications for HL-93 loading. Grade 60 reinforcement and high performance concrete are used. Pretensioned to 75% of their ultimate tensile strength, the low-relaxation strands are located as low as possible while still maintaining proper cover requirements. The strands are placed symmetrically about the vertical axis of symmetry and spaced as equally as possible across the entire width of the beam. For ease of fabrication, only



(a) Standard 4-ft Box Beam



(b) Standard-5 ft Box Beam

Figure 4.8: Texas Adjacent Box Beam

(www.txdot.gov/insdot/orgchart/cmd/cserve/standard/bridge-e.htm#BoxBeams)

Table 4.4: Summary of Pros and Cons of Texas Box Beam

Pros	Cons
<ul style="list-style-type: none"> • Large range of span lengths, 40 ft to 100 ft • No post-tensioning with use of CIP deck • Standards have been in place for years 	<ul style="list-style-type: none"> • Expensive fabrication • Difficult to inspect beam-to-beam connection after fabrication • No skewed beam ends

straight strands are used, and some of them must be debonded to reduce member end compressive stresses. Debonded strands are also to be symmetric about the vertical centerline and staggered in each row. The debonded lengths are increased from the center of the beam towards the edges. Plastic sheathing is used to encase the strands along the entire debonded length, and waterproof tape seals the ends. Split plastic sheathing can be used, as long as waterproof tape is used to prevent any concrete from contacting the strands. The beams are cast using a two-stage monolithic process. In the first stage, the bottom flange of the beam is cast, and the webs and the top flange are cast during the second stage. The concrete from the first stage is to remain plastic during the

second stage of construction, and it is vibrated to make sure the two castings are consolidated.

Once the beams are placed side by side, they can be topped with either a 5-in. cast-in-place deck, which is preferred by the Texas Department of Transportation, or a 2-in. asphaltic concrete pavement (ACP) topping. The ACP topping is recommended only for use on bridges with low volumes. Transverse post-tensioning is also required with the use of the ACP topping, but is not required with the 5-in. reinforced concrete deck. When post-tensioning is used, a 3-in.-diameter hole is cast into the webs of the interior beams. If Polyvinyl Chloride (PVC) pipe is used to make the hole, the inner diameter of the pipe must be 3 in. For the exterior beams, a 1.5-in. hole is to be cast in the beam for a post-tensioning strand to pass through. Similar to the interior beams, if PVC pipe is used to form the hole, a 1.5-in. inner diameter must be provided. A pipe sleeve must be used in the shear key to ensure that no grout comes in contact with the post-tensioning strand. Two types of tendons are allowed for post-tensioning. The first type is a 1/2-inch diameter, Grade 270 monostrand that is encased in a seamless plastic sheath filled with corrosion-inhibiting grease. The other approved tendon is a 5/8-inch diameter, Grade 150, threaded bar that must be covered in heavy grease prior to placement. On the exterior beams, the anchorage device for the post-tensioning must be positioned so that no portion of the tendon inside the point of anchorage is left uncovered or exposed. The ends of the tendons must be protected so that corrosion does not occur. A waterproof corrosion resistant cap is used to protect the tendon ends. After the end cap is installed, the anchorage recess is to be filled with grout until it is flush with the exterior of the beam.

A disadvantage to the precast box beam is that it is generally more expensive than other precast options, due to its complexity of fabrication. Also, many adjacent box beams are needed to achieve the desired bridge width; for a standard 38-ft-wide roadway profile, it takes eight beams. Although not PBES, a cheaper option is to spread out the box beams and to cast or place an 8-in. concrete deck on top. Referred to as the Texas X-beam (Figure 4.9), this could require only five beams instead of eight to achieve the same bridge width. The X-beam is similar in shape to the adjacent box beam, but the stems are 1.5 in. thicker, and the bottom flange is 2 in. thicker to accommo-

or a crowned section can be constructed. Joints between units are filled with non-shrink grout, with the aid of a foam backer rod placed near the bottom of the joint (see Figure 4.11). Perhaps the most attractive feature of PSUs is that they do not require post-tensioning, which is beneficial, considering Florida's harsh environmental conditions. A summary of the pros and cons of the system is provided in Table 4.5.

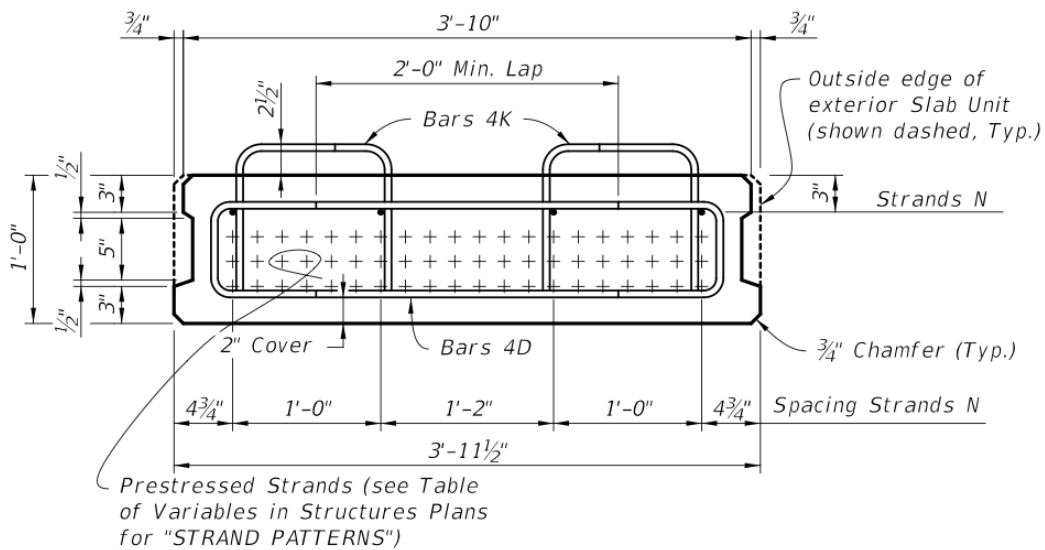


Figure 4.10: Cross Section of Florida Prestressed Slab Unit, 12 in. x 48 in. (www.dot.state.fl.us/rddesign/DS/Dev/D20354.pdf)

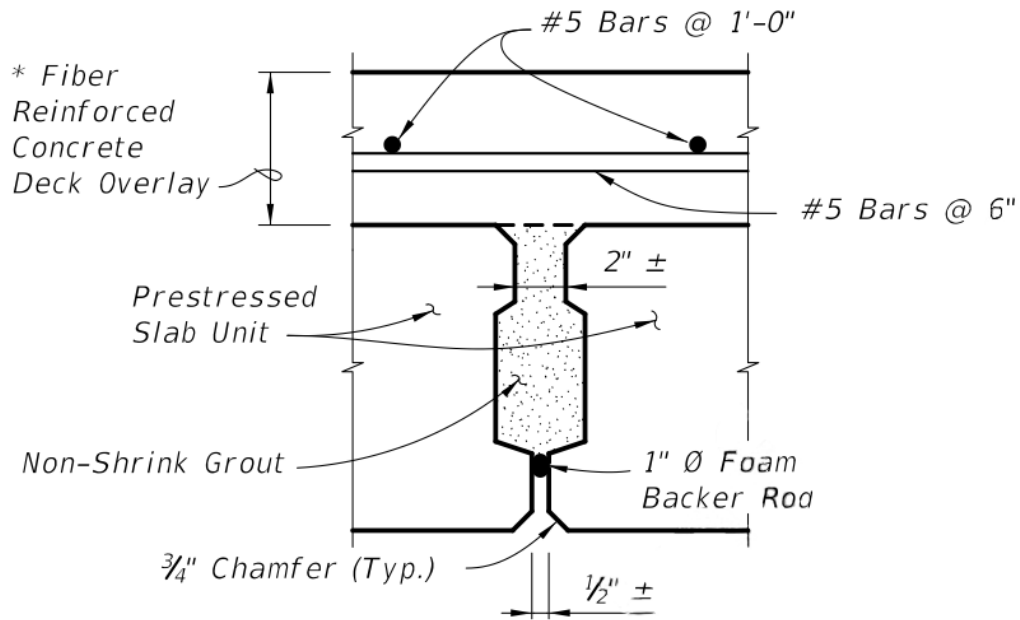


Figure 4.11: Keyway Detail for Florida Prestressed Slab Unit
 (www.dot.state.fl.us/rddesign/DS/Dev/D20350.pdf)

Table 4.5: Summary of Pros and Cons of Florida Prestressed Slab Unit

Pros	Cons
<ul style="list-style-type: none"> • Shallow section helps with vertical clearance • No post-tensioning required • Accommodates skewed ends • Concrete deck overlay covers joints between units 	<ul style="list-style-type: none"> • Requires joints between units • Solid section is inefficient use of concrete • Requires cast-in-place concrete deck overlay

CHAPTER 5

CONCLUSIONS

5.1 Summary

With the aging infrastructure in the United States, there is a need for a change in the bridge construction industry in order to build and replace bridges quickly and more economically. The use of Prefabricated Bridge Elements and Systems can facilitate the needed change. There are many advantages to using PBES to accelerate the bridge construction process. Among these are time savings, cost savings, safety advantages, increased constructability and environmental protection. By moving the time consuming activities off the critical path of bridge construction, there are less traffic disruptions – which increases safety for both the traveling public as well as the workers on site. Concrete curing is a time consuming task that can take up to 28 days to gain full strength; by having the individual members of the bridge prefabricated off site, this task can start at anytime to ensure the members are ready when needed at the site. With the temperamental weather in Florida, PBES offers an advantage over conventional construction because the majority of the elements are fabricated or precast in a controlled environment; therefore, the weather can only affect the portion of work done on site. With the standardization of short-span bridges, cost savings will be seen over multiple projects. Reducing the time it takes to construct a bridge will also reduce cost for the owner, but cost savings can be seen by more than just the owner. With shorter construction times, road users can see a cost savings in reduced fuel usage as well as a savings in time.

5.2 Recommendations

After researching every state's DOT website looking for PBES drawings and standards, the top candidates were selected and detailed in this report, along with their advantages and disadvantages. A summary of the systems' attributes is provided in Table 5.1.

Alabama's system consists of adjacent slab beams that are bolted together transversely. Barriers are also precast, to accelerate construction times, and are bolted on to the sides of the bridge in the same manner as the beams are connected. There have been some cases where spalling of the concrete around this bolted connection has occurred due to use by heavy trucks. Bridges that are not subject to heavy truck traffic on low-volume roads have performed with no issues, and county engineers report that this is a great system to use if the site conditions are appropriate.

Minnesota's precast system comes from a modified French system known as the Poutre Dalle system and consists of an inverted-tee shape. One advantage of this system is that there is no need for formwork. When placed adjacently, the flanges of the beams form a channel and act as stay-in-place forms. Transverse and longitudinal reinforcement across the joint, combined with a concrete closure pour, provide the connection and composite action. Parapets can be precast onto the exterior beams in the casting yard to further accelerate construction times.

From the Northeast region of the country comes the NEXT beam. This modified double-tee section was developed by the Northeast division of the Precast/Prestressed Concrete Institute for accelerated bridge construction. For bridges with high ADT and heavy truck loads, the NEXT F beam is recommended. It has a 4-in. top flange that is topped with an 8-in. reinforced concrete deck. No formwork is required, and precast barriers can act as side forms for the deck. PCINE also developed the NEXT D beam with a full-depth top flange that acts as the contact surface for vehicles. Some formwork is required with this design, due to the transverse connection between beams that is achieved by a closure pour.

Texas has been a leader in bridge construction for many years. Their box beam standard design accommodates a wide range of span lengths and skewed

Table 5.1: Summary of Attributes of Top PBES Candidates

	Alabama Slab Beam	Minnesota Inverted-T	Texas Box Beam	NEXT D Beam	NEXT F Beam	FDOT PSU
Span Length	24', 34', 40'	20' – 65'	30' – 100'	30' – 90'	30' – 90'	20' – 50'
Section Width	3' – 6'	6'	4' and 5'	8' – 10'	8' – 12'	4' and 5'
Section Depth	1' – 5"	12"	20", 28", 34", 40"	24", 28", 32", 36"	24", 28", 32", 36"	12" and 15"
Standard Roadway Width	24', 24'-6", 28'	N/A	24', 28', 30'	with variable flange width any width achievable	with variable flange width any width achievable	40"
Topping/Wearing Surface	None	6" cast-in-place reinforced concrete deck	5" cast-in-place reinforced concrete deck or 2" ACP	None	8" cast-in-place reinforced concrete deck	6" minimum cast-in-place fiber reinforced concrete deck
Post-tensioning	Transverse	None	Transverse PT required with use of ACP overlay	None	None	None
Utility Accommodations	None	None	None	Utilities are handled between the stems of the beam	Utilities are handled between the stems of the beam	None
Barrier Connections	Bolted	Precast on exterior beams	Precast on exterior beams	Precast parapet	Precast curb	N/A
Skew	N/A	N/A	N/A	≤ 30°	≤ 30°	≤ 30°
Maintenance/ Inspection	Requires underside access	N/A	N/A	Underside is open for easy inspection	Underside is open for easy inspection	N/A
Design Live Loading	HS20-40	HL-93	HL-93	HL-93	HL-93	HL-93
Phase Construction/Widening	Future widening is possible	Future widening is possible	Future widening is possible. More difficult if Transverse PT is used	Future widening is possible	Future widening is possible	Future widening is possible
Section Efficiency	Spalling issues at bolted connection	Easy to erect, no formwork required	Expensive fabrication	Efficiently designed to minimize labor	Efficiently designed to minimize labor	N/A

site conditions. Unfortunately, box beam bridges tend to cost more than other designs, due to the complex fabrication process. In addition, the interior of the box shape and the joints between adjacent box beams are difficult to inspect. The standards can be used with either an asphaltic concrete pavement overlay or a reinforced concrete deck. When the ACP overlay is used, the beams are required to be post-tensioned together transversely, which adds additional costs to this already expensive design. No post-tensioning is required with the use of the reinforced concrete deck.

In summary, many design types were found across the nation, and the top candidates were explained in detail in this report. Besides FDOT's developmental standards for PSUs, the two systems that are most suitable for Florida's off-system bridges are the NEXT D beam and Minnesota's inverted tee. The NEXT beam requires removable formwork for its beam-to-beam connection. Minnesota's inverted-tee shape uses its geometry to its advantage and does not need formwork; a minimal number of beams is required to achieve desired roadway widths. It has been successfully used in Europe and on multiple projects in Minnesota; all are performing well, and no durability issues were found in the literature.

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Appendices

APPENDIX A

A.1 FHWA WEBLINKS FOR EDC, ABC, AND PBES

FHWA PBES General Information

<http://www.fhwa.dot.gov/everydaycounts/technology/bridges/intro.cfm>

FHWA PBES Description

<http://www.fhwa.dot.gov/bridge/abc/prefab.cfm>

FHWA PBES Presentations

<http://www.fhwa.dot.gov/everydaycounts/technology/bridges/pbeswebinartraining/index.cfm>

FHWA PBES for ABC Presentation

http://www.fhwa.dot.gov/everydaycounts/technology/bridges/pbeswebinartraining/s1_m1.cfm

(Note: See Slide 46 for Map of States that Currently Use PBES)

FHWA Innovative PBES Projects

<http://www.fhwa.dot.gov/bridge/prefab/projects.cfm>

FHWA Highways for LIFE Project Summaries

http://www.fhwa.dot.gov/hfl/summary/projects_summary.cfm

FHWA Accelerated Bridge Construction (ABC)

<http://www.fhwa.dot.gov/construction/accelerated/index.htm>

FHWA Accelerated Bridge Construction Technologies, Reports and Presentations

<http://www.fhwa.dot.gov/bridge/accelerated/index.cfm>

FHWA Connection Details for PBES

<http://www.fhwa.dot.gov/bridge/prefab/if09010/index.cfm>

A.2 STATE DEPARTMENTS OF TRANSPORTATION WEBLINKS FOR STANDARD DRAWINGS AND SPECIFICATIONS

ALABAMA

Alabama DOT Structures Design Detail Manual

<http://www.dot.state.al.us/brweb/doc/ALDOTStructuresDesignDetailManual.pdf>

Standard Drawings

<http://www.dot.state.al.us/brweb/StandardDrawings.htm>

ALASKA

Standard Drawings

<http://www.dot.state.ak.us/stwddes/dcsprecon/stdwgeng.shtml>

Standard Specifications

<http://www.dot.state.ak.us/stwddes/dcsspecs/index.shtml>

ARIZONA

Structure Detail Drawings

<http://www.azdot.gov/Highways/bridge/DetailDwg/Index.asp>

Bridge Design Guidelines

<http://www.azdot.gov/Highways/bridge/Guidelines/DesignGuidelines/index.asp>

ARKANSAS

Standard Drawings

http://www.arkansashighways.com/bridge_division/list_standard_drawings.aspx

Standard Specifications

http://www.arkansashighways.com/standard_spec_2003.aspx

CALIFORNIA

Bridge Standard Detail Sheets

<http://www.dot.ca.gov/hq/esc/techpubs/manual/bridgemanuals/bridge-standard-detail-sheets/>

Construction Standards

<http://www.dot.ca.gov/hq/esc/oe/standards.php>

COLORADO

Bridge Design Manual

<http://www.coloradodot.info/library/bridge/bridge-manuals>

Standard Drawings

<http://www.coloradodot.info/library/bridge/design-standards>

CONNECTICUT

Bridge Design Manual

<http://www.ct.gov/dot/lib/dot/documents/dpublications/bridge/bdm.pdf>

Standard Drawings

<http://www.ct.gov/dot/cwp/view.asp?a=2303&q=410884>

DELAWARE

Bridge Design Manual

http://deldot.gov/information/pubs_forms/manuals/bridge_design/index.shtml

FLORIDA

Design Standards

<http://www.dot.state.fl.us/rddesign/DesignStandards/Standards.shtm>

PBES Website

<http://www.dot.state.fl.us/structures/edc/>

GEORGIA

Bridge and Structures Design Manual

http://www.dot.state.ga.us/doingbusiness/PoliciesManuals/roads/BridgeandStructure/GDOT_Bridge_and_Structures_Policy_Manual.pdf

Design Memos

<http://www.dot.state.ga.us/doingbusiness/PoliciesManuals/bridge/Pages/Memos.aspx>

Policies and Manuals, Bridge Design

<http://www.dot.state.ga.us/doingbusiness/PoliciesManuals/bridge/Pages/default.aspx>

HAWAII

None found

IDAHO

Standard Drawings

<http://itd.idaho.gov/design/StandardDrawings.htm>

Bridge Drawings

<http://itd.idaho.gov/bridge/cadd/cadddrawings.htm>

ILLINOIS

Bridges and Structures Technical Manuals

<http://www.dot.state.il.us/bridges/brmanuals.html>

Standard Specifications

http://www.dot.state.il.us/desenv/spec2007/SpecBook_TOC.pdf

Manual for Fabrication of Precast Prestressed Concrete Products

<http://www.dot.state.il.us/materials/ppcproductsmanual.pdf>

Standard Drawings

<http://www.dot.state.il.us/bridges/bscadd2.html>

INDIANA

Standard Drawings

<http://www.in.gov/dot/div/contracts/standards/drawings/sep10/e/sep700.htm>

Design Manual

<http://www.in.gov/dot/div/contracts/standards/dm/2011/index.html>

IOWA

ABC Workshop Presentations

http://www.iowadot.gov/bridge/abc_ppt.htm

LRFD Design Manual

<http://www.iowadot.gov/bridge/manuallrfd.htm>

Innovative Bridge Research

http://www.iowadot.gov/bridge/ibrcibrd_research.htm

Standard Drawings

<http://www.iowadot.gov/bridge/v8ebrgstd.htm>

KANSAS

Standard Specifications

<http://www.ksdot.org/burConsMain/specprov/2007SSDefault.asp>

Standard Drawings

<http://www.ksdot.org/burdesign/caddrsc.asp>

KENTUCKY

Standard Drawings

<http://transportation.ky.gov/Highway-Design/Pages/2012-Standard-Drawings.aspx>

Standard Specifications

<http://transportation.ky.gov/construction/pages/kentucky-standard-specifications.aspx>

LOUISIANA

Bridge Design Home

http://www.dotd.la.gov/highways/project_devel/design/home.asp?ID=BRIDGE

Standard Drawings

http://www.dotd.la.gov/highways/project_devel/design/bridge_design/documents/Request%20Instructions.pdf

MAINE

Standard Specifications

http://www.state.me.us/mdot/contractor-consultant-information/ss_standard_specification_2002.php

Standard Details Book

http://www.maine.gov/mdot/contractor-consultant-information/ss_standard_details_book.pdf
(See *Precast Concrete Deck Panels*, pg. 502(07-12))

Concrete Design Guide

<http://www.maine.gov/mdot/technical-publications/brdesignguide/chapter6concretefinal.pdf>

Precast Voided Slab/Box

<http://www.maine.gov/mdot/technicalpubs/documents/pdf/bpdg/chpt4.pdf>

(See pg. 28)

MARYLAND

Standard Drawings

<http://apps.roads.maryland.gov/businesswithsha/bizstdspecs/obd/bridgestandards/index.asp>

MASSACHUSETTS

Standard Drawings

http://www.mhd.state.ma.us/default.asp?pgid=bridge/bridgemanual_04&sid=about
(See Sections 4.2 and 6.2 for Precast Concrete Box Beams)

List of Preferred Connection Details for Prefabricated Precast Bridge Elements and Systems
http://www.mhd.state.ma.us//downloads/bridge/Prefab_Bridges_Combined.pdf

MICHIGAN

Bridge Design Guide

<http://mdotwas1.mdot.state.mi.us/public/design/englishbridgeguides/>

Bridge Design Manual

<http://mdotwas1.mdot.state.mi.us/public/design/englishbridgemanual/>

Standard Details

<http://mdotwas1.mdot.state.mi.us/public/design/englishstandardplans/index.htm>

MINNESOTA

Bridges and Structures Resources

<http://www.dot.state.mn.us/bridge/>

Presentation on Three-sided Structures

<http://www.dot.state.mn.us/bridge/manuals/LRFD/pdf/workshop/14ThreeSidedBridges.pdf>

Technical Memo on Three-sided Precast Concrete Bridge Structures

<http://www.dot.state.mn.us/products/bridge/pdf/techmemo519b04-2010.pdf>

MnDOT/FHWA Precast Slab System Workshop Summary Report

<http://www.fhwa.dot.gov/bridge/prefab/slab.cfm>

MISSISSIPPI

Standard Drawings

http://sp.gomdot.com/Roadway%20Design/Lists/Standard_Drawings/AllItems.aspx

Standard Specifications

<http://sp.gomdot.com/Construction/Pages/Standard%20Specifications.aspx>

MISSOURI

Bridge Standard Drawings

http://www.modot.mo.gov/business/consultant_resources/bridgestandards.htm

Safe and Sound 800

<http://www.modot.gov/safeandsound/index.htm>

MONTANA

Bridge Standard Drawings

http://www.mdt.mt.gov/business/contracting/bridge/cad_files.shtml

Standard Specifications

http://www.mdt.mt.gov/business/contracting/standard_specs.shtml

NEBRASKA

Bridge Manual and CAD Drawings

<http://www.roads.ne.gov/design/bridge/downloads-manuals.html#cad>

NEVADA

Standard Specifications and Plans for Road and Bridge Construction

<http://www.nevadadot.com/Content.aspx?id=1559&terms=standard%20specifications%20and%20plans>

NEW HAMPSHIRE

Standard Specifications

<http://www.nh.gov/dot/org/projectdevelopment/highwaydesign/specifications/index.htm>

Bridge Design Document Library

<http://www.nh.gov/dot/org/projectdevelopment/bridgedesign/documents.htm>

Precast Concrete Deck Panel Performance On Long Span, High Traffic Volume Bridges

<http://www.nh.gov/dot/org/projectdevelopment/materials/research/projects/documents/FHWA-NH-RD-13733D.pdf>

NEW JERSEY

Design Manual for Bridges

<http://www.state.nj.us/transportation/eng/documents/BSDM/>

NEW MEXICO

Standard Specifications and Drawings

<http://dot.state.nm.us/en/PSE/Standards.html>

NEW YORK

Office of Structures

<https://www.dot.ny.gov/divisions/engineering/structures>

Bridge Design Manual

<https://www.dot.ny.gov/divisions/engineering/structures/manuals/bridge-manual-usc>
(Section 5 is bridge decks)

Precast, Prestressed, Post-tensioned Concrete Deck System
<https://www.dot.ny.gov/spec-repository/557.0491--11.pdf>

Bridge Detail Sheets
<https://www.dot.ny.gov/main/business-center/engineering/cadd-info/drawings/bridge-detail-sheets-usc>

Specifications
<https://www.dot.ny.gov/main/business-center/engineering/specifications>

NORTH CAROLINA

NCDOT Bridge Replacement Process, Low Impact
<http://www.ncdot.org/projects/ncbridges/default.html>

Standard Drawings
<https://connect.ncdot.gov/resources/Structures/Pages/Structure-Standards.aspx>

Design Manuals
<https://connect.ncdot.gov/resources/Structures/Pages/Design-Manual.aspx>

Structure Design Unit Design Manual
https://connect.ncdot.gov/resources/Structures/StructureResources/LRFD_Manual_Text_2007.pdf

NORTH DAKOTA

Standard Drawings
<http://www.dot.nd.gov/dotnet2/view/std drawings.aspx>

OHIO

Standard Drawings
<http://www.dot.state.oh.us/Divisions/Engineering/Structures/standard/Bridges/Pages/StandardBridgeDrawings.aspx>

OKLAHOMA

Standard Drawings
<http://www.okladot.state.ok.us/bridge/standards.htm>

OREGON

Standard Drawings
http://cms.oregon.gov/ODOT/HWY/ENGSERVICES/Pages/bridge_drawings.aspx

Standard Details

http://egov.oregon.gov/ODOT/HWY/ENGSERVICES/details_bridge.shtml#Slabs_Boxes_DET_3400s

PENNSYLVANIA

Index of Bridge Standards

<ftp://ftp.dot.state.pa.us/public/Bureaus/design/bqad/2010/BD/BD600M.pdf>

Archived Bridge Standards

<http://www.dot.state.pa.us/Internet/BQADStandards.nsf/bd-archives?readform>

Index of Standards for Bridge Construction

<ftp://ftp.dot.state.pa.us/public/Bureaus/design/bqad/2010/BC/BC700M.pdf>

Structures Design Manual

<ftp://ftp.dot.state.pa.us/public/PubsForms/Publications/PUB%2015M.pdf>

RHODE ISLAND

Bridge Design Standard Details

http://www.dot.state.ri.us/documents/engineering/BlueBook/RIDOT_Bridge_Standards%202010.pdf

LRFD Bridge Design Manual

<http://www.dot.state.ri.us/documents/engineering/br/RILRFDBridgeManual.pdf>

SOUTH CAROLINA

Bridge Design Manual, Design Memos

<http://www.scdot.org/doing/structural.aspx>

Bridge Drawings and Details

http://www.scdot.org/doing/structural_Drawings.aspx

SOUTH DAKOTA

Structural Design Manual

<http://sddot.com/resources/manuals/StructuresManual.pdf>

TENNESSEE

Bridge Standard Drawings

http://www.tdot.state.tn.us/Chief_Engineer/engr_library/structures/stdenglishdrawings.htm

TEXAS

Bridge Information

http://www.txdot.gov/business/contractors_consultants/bridge/default.htm

Complete List of Bridge Standards

<http://www.txdot.gov/insdtdot/orgchart/cmd/cserve/standard/bridge-e.htm>

A Guide to Bridge Standard Drawings

<ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/guideste.pdf>

Spread Box Beam Presentation

http://ftp.dot.state.tx.us/pub/txdot-info/brg/0611_webinar/holt.pdf

UTAH

Utah DOT ABC Drawings

<http://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:2394>

ABC Manuals

<http://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:2090>

VERMONT

Structures Design Manual

http://www.aot.state.vt.us/progdev/Publications/DocumentsPUBLICATIONS/Structures_Design_Manual.pdf

Design Calculations

<http://www.aot.state.vt.us/progdev/sections/Structures%20Info/StrucDesignTools62011.htm>

Integral Abutment Design Guidelines

<http://www.aot.state.vt.us/progdev/Publications/DocumentsPUBLICATIONS/StructuresSEI-08-004-1.pdf>

Structural Standard Drawings

http://www.aot.state.vt.us/Caddhelp/DownLoad/Details/Structures/StructuresDetails_Set.pdf

VIRGINIA

Structure and Bridge Manual

<http://www.virginiadot.org/business/bridge-manuals.asp>

Prestressed Concrete Calculations, Design Tables, Drawings, and Details

<http://www.extranet.vdot.state.va.us/locdes/electronic%20pubs/Bridge%20Manuals/VolumeV-Part2/Chapter12.pdf>

WASHINGTON

Bridge Design Manual

<http://www.wsdot.wa.gov/Publications/Manuals/M23-50.htm>

Bridge Standard Drawings

<http://www.wsdot.wa.gov/eesc/bridge/drawings/>

Accelerated Bridge Construction (ABC) Resources

<http://www.wsdot.wa.gov/eesc/bridge/ABC/>

State-of-the-Art Report on Precast Concrete Systems for Rapid Construction of Bridges

<http://www.wsdot.wa.gov/research/reports/fullreports/594.1.pdf>

WEST VIRGINIA

Standard Specifications Roads and Bridges 2010

<http://www.transportation.wv.gov/highways/contractadmin/specifications/Documents/2010%20Standard%20Specifications%20Roads%20and%20Bridges/Complete%20Publications/2010StandardRoadsnBridges.pdf>

Bridge Design Manual

<http://www.transportation.wv.gov/highways/engineering/files/WVBDML.pdf>

Standard Drawings

<http://www.transportation.wv.gov/highways/engineering/Pages/StandardDetailsBookVol3.aspx>

WISCONSIN

Standard Drawings

http://on.dot.wi.gov/dtid_bos/extranet/structures/LRFD/standards.htm

WYOMING

Bridge Applications Manual

http://www.dot.state.wy.us/wydot/engineering_technical_programs/bridge/bridge_applications_manual

Standard Plans

http://www.dot.state.wy.us/wydot/engineering_technical_programs/manuals_publications/standardplans

Standard Drawings

http://www.dot.state.wy.us/wydot/engineering_technical_programs/bridge/standard_details;jsessionid=DF841040D6305D3731BFC4DC4187BFBO

Bridge Replacement "Off System" (B.R.O.S.) Program

http://www.dot.state.wy.us/wydot/engineering_technical_programs/bridge/bros

APPENDIX B

B.1 LINKS TO STATE DEPARTMENTS OF TRANSPORTATION STANDARD DRAWINGS FOR PBES

ALABAMA

Bridge Standard Drawings: <http://www.dot.state.al.us/brweb/StandardDrawings.htm>

		Drawing No.	Sheet No.	Description	Link to Drawing
Superstructure	Deck Elements	PC-24	1 of 2	Typical beam shape 24' span, Barrier rail connection detail, post-tensioning details, shear key detail, bar bends	http://www.dot.state.al.us/brweb/doc/Precast%20Standards/PC-24%20%28Sheet%201%20of%202%29.pdf
			2 of 2	Typical road profile, 24' span, AASHTO HS20-44 live load, 24' and 28' roadway option	http://www.dot.state.al.us/brweb/doc/Precast%20Standards/PC-24%20%28Sheet%202%20of%202%29.pdf
		PCBR-1(24)	1 of 1	Precast Barrier rail reinforcement, shows pick-up points, bar bend details, handling device detail, guard rail attachment detail	http://www.dot.state.al.us/brweb/doc/Precast%20Standards/PCBR-1%2824%29.pdf
		PC-34-2	1 of 2	34' span length, typical beam reinforcement, Exterior & Interior beam sections, Barrier connection detail, PT details, shear key detail, bar bends	http://www.dot.state.al.us/brweb/doc/Precast%20Standards/PC-34-2%20%28Sheet%201%20of%202%29.pdf
			2 of 2	Typical road profile, 34' span, AASHTO HS20-44 live load, 24' and 28' roadway option	http://www.dot.state.al.us/brweb/doc/Precast%20Standards/PC-34-2%20%28Sheet%202%20of%202%29.pdf
		PCBR-1(34)	1 of 1	Precast Barrier rail reinforcement, shows pick-up points, bar bend details, handling device detail, guard rail attachment detail	http://www.dot.state.al.us/brweb/doc/Precast%20Standards/PCBR-1%2834%29.pdf
		PC-40	1 of 1	40' span length, typical beam reinforcement, Exterior & Interior Sections, barrier connection detail, PT details, shear key, bar bends, 28' roadway profile, AASHTO HS20-44 live loading	http://www.dot.state.al.us/brweb/doc/Precast%20Standards/PC-40.pdf
		PCBR-1(40)	1 of 1	Precast Barrier rail reinforcement, shows pick-up points, bar bend details, handling device detail, guard rail attachment detail	http://www.dot.state.al.us/brweb/doc/Precast%20Standards/PCBR-1%2840%29.pdf

		Drawing No.	Sheet No.	Description	Link to Drawing
Substructure	Abutment Panels	PCP-2400-CP	1 of 1	Can be used with 24', 34' & 40' span lengths, 24' roadway, 14" x 14" prestressed concrete piles, abutment panel assembly	http://www.dot.state.al.us/brweb/doc/Precast%20Standards/PCP-2400-CP.pdf
		PCP-2400	1 of 1	Shows precast panel reinforcement and connection details for 24'-6" roadway width	http://www.dot.state.al.us/brweb/doc/Precast%20Standards/PCP-2400.pdf
		PCP-2800-CP	1 of 1	Can be used with 24', 34' & 40' span lengths, 28' roadway, 14" x 14" prestressed concrete piles, abutment panel assembly, AASHTO HS15-44 or HS20-44 live loading	http://www.dot.state.al.us/brweb/doc/Precast%20Standards/PCP-2800-CP.pdf
		PCP-2800	1 of 1	Shows precast panel reinforcement and connection details for 28' roadway width	http://www.dot.state.al.us/brweb/doc/Precast%20Standards/PCP-2800.pdf
	Bent Cap	PCB-2840-CP	1 of 1	24', 34', & 40' span lengths, 28' roadway, bent cap supported on 14" square prestressed concrete piles, HS20-44 Live loading, reinforcement placement detail, grouted connection between piles and cap,	http://www.dot.state.al.us/brweb/doc/Precast%20Standards/PCB-2840-CP.pdf
		PCB-2840	1 of 1	Bent cap w/ steel piles, field welding req'd, reinforcement details, HS20-44 Live load, applicable for 24', 34', & 40' span lengths, 28' roadway shown	http://www.dot.state.al.us/brweb/doc/Precast%20Standards/PCA-2840-CP.pdf

COLORADO

Standard Drawings

<http://www.coloradodot.info/library/bridge/design-standards/structural-worksheets-pdfs>

(See Sheets B-600s for Precast Panel Deck Forms)

FLORIDA

Standard Drawings: <http://www.dot.state.fl.us/rddesign/DesignStandards/Standards.shtm>

Developmental Standard Drawings: <http://www.dot.state.fl.us/rddesign/DS/Dev.shtm>

Developmental Standard Drawings for Prestressed Slab Units (PSUs):

Drawings	Link to Drawings
Prestressed Slab Units	http://www.dot.state.fl.us/rddesign/DS/Dev/D20350.pdf
12" Custom Width Prestressed Slab Unit-Standard Details	http://www.dot.state.fl.us/rddesign/DS/Dev/D20353.pdf
12"x48" Prestressed Slab Unit - Standard Details	http://www.dot.state.fl.us/rddesign/DS/Dev/D20354.pdf
12"x60" Prestressed Slab Unit - Standard Details	http://www.dot.state.fl.us/rddesign/DS/Dev/D20355.pdf
15" Custom Width Prestressed Slab Unit-Standard Details	http://www.dot.state.fl.us/rddesign/DS/Dev/D20363.pdf
15"x48" Prestressed Slab Unit - Standard Details	http://www.dot.state.fl.us/rddesign/DS/Dev/D20364.pdf
15"x60" Prestressed Slab Unit - Standard Details	http://www.dot.state.fl.us/rddesign/DS/Dev/D20365.pdf
Overlay & Deflection Data for Prestressed Slab Units	http://www.dot.state.fl.us/rddesign/DS/Dev/D20399.pdf

IOWA

Bridge Standard Drawings

<http://www.iowadot.gov/bridge/v8ebrgstd.htm>

Plans for Single-span Precast Box Girder Bridge

http://www.iowadot.gov/bridge/ibrc_projects/acc_madison_plans.htm

Plans for Accelerated Bridge Construction (ABC) in Boone County

http://www.iowadot.gov/bridge/ibrc_projects/acc_boone_plans.htm

Waffle Deck Panel Bridge Plans, Wapello County

http://www.iowadot.gov/bridge/ibrc_projects/waffle_deck001.PDF

Final Paper on Madison County ABC Bridge

http://www.iowadot.gov/bridge/ibrc_projects/final_accelerated_construction.pdf

	Drawings	Link to Drawings
Superstructure	Precast Deck Panel Details	http://www.iowadot.gov/bridge/standards/english/EnglishMiscellaneousBridges.pdf
	Bulb Tee Beams with Stub Abutment	http://www.iowadot.gov/bridge/standards/english/EnglishBTStubBridges.pdf
	Bulb Tee Beams with Integral Abutment	http://www.iowadot.gov/bridge/standards/english/EnglishBTIntegralBridges.pdf
	Beams	http://www.iowadot.gov/bridge/standards/english/EnglishBeams.pdf
	Barrier	http://www.iowadot.gov/bridge/standards/english/EnglishDeckRailBridges.pdf
Sub-structure	Stub Abutment	http://www.iowadot.gov/bridge/standards/english/EnglishStubBridges.pdf
	Integral Abutment	http://www.iowadot.gov/bridge/standards/english/EnglishIntegralBridges.pdf

MASSACHUSETTS

Bridge Manual: Standard Details

http://www.mhd.state.ma.us/default.asp?pgid=bridge/bridgemanual_04&sid=about

Prestressed Concrete Deck Beam, Box Beam, and Abutment Drawings:

		Drawings	Link to Drawings
Superstructure	Precast Concrete Deck Beams	36" Wide Beam Properties	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.3.pdf
		36" Beam Strand Pattern	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.5.pdf
		48" Wide Beam Properties	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.4.pdf
		48" Beam Strand Pattern	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.6.pdf
		Prestressing Notes	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.7.pdf
		Shear Key Details	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.8.pdf
		Typ. Midspan Section	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.9.pdf
		Alternate Stirrup Pattern	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.10.pdf
		Typ. End of Beam Section View	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.11.pdf
		Typ. End of Beam Plan View	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.12.pdf
		Longitudinal Section View	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.13.pdf
		Typ. Longitudinal Joint Elevation View	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.14.pdf
		Typ. Longitudinal Joint Section View	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.15.pdf
		Bearing Layout <50' Spans	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.18.pdf
		Bearing Layout >50' Spans	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.19.pdf
		Transverse Post-Tensioning Anchorage	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.17.pdf
		Stage Construction Detail	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.20.pdf
Staged Construction Notes	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.1.21.pdf		

		Drawings (cont'd.)	Link to Drawings (cont'd.)
		Superstructure (cont'd.)	Precast Concrete Deck Beams (cont'd.)
Sidewalk and Curb Details	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.3.1.pdf		
Sidewalk Detail with Utility Bay	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.3.3.pdf		
Exterior Utility Supports	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.3.5.pdf		
Typ. Utility Support Details	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.3.7.pdf		
Precast Concrete Box Beams	Standard 36" Wide Beams		http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.3.pdf
	Standard 48" Wide Beams		http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.4.pdf
	Strand Pattern for 24"-36" Deep Beams		http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.5.pdf
	Strand Pattern for 39"-48" Deep Beams		http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.6.pdf
	Prestressing Notes		http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.7.pdf
	Shear Key Details		http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.8.pdf
	Typ. Midspan Section		http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.9.pdf
	Typ. End of Beam Section View		http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.10.pdf
	Typ. End of Beam Plan View		http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.11.pdf
	Longitudinal Section View		http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.12.pdf
	Typ. Longitudinal Joint Elevation View		http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.14.pdf
	Typ. Longitudinal Joint Elevation View		http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.15.pdf
	Typ. Layout of Bearings		http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.18.pdf
	Transverse Post-Tensioning Anchorage		http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.17.pdf
	Construction Sequencing Notes		http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.16.pdf
Stage Construction Detail	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.19.pdf		

		Drawings (cont'd.)	Link to Drawings (cont'd.)
Superstructure (cont'd.)	Precast Concrete Box Beams (cont'd.)	Stage Construction Notes	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.20.pdf
		Stage Construction Framing Plan	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.2.2.pdf
		Sidewalk and Curb Details	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.3.2.pdf
		Sidewalk Detail with Utility Bay	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.3.4.pdf
		Exterior Utility Supports	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.3.6.pdf
		Typ. Utility Support Details	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.3.7.pdf
Substructure	Abutment Details	Abutment Plan View	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.4.1.pdf
		Abutment Elevation View	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.4.2.pdf
		Detail at U-Wingwall Corner	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.4.3.pdf
		Abutment End, Splayed Wingwall, Plan View	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.4.7.pdf
		Roadway Section View for 12" & 15" Deck Beams	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.4.9.pdf
		Roadway Section View for 18" & 21" Deep Deck Beams	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.4.10.pdf
		Roadway Section, Box Beams	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.4.11.pdf
		Construction Notes for Abutments	http://www.mhd.state.ma.us/downloads/bridge/manual_lfrd/part2/Chapter%204%20pdf/4.4.12.pdf

TEXAS

Prestressed Concrete Box Beam Drawings:

	Drawing Title and Web Link	Page	Comments
Beam Details	Type B20 ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbs_tde01.pdf	1	Note 2 & 6, Block out detail
		2	Skewed application Note 2 & 6, Block out detail
		3	Block out detailing, reinforcement and anchorage detail, bar bends
	Type B28 ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbs_tde02.pdf	1	Note 2, 4 & 6, Block out detail, Beam properties
		2	Skewed application Note 2, 4 & 6, Block out detail
		3	Block out detailing, reinforcement and anchorage detail, bar bends
	Type B34 ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbs_tde03.pdf	1	Note 2, 4 & 6, Block out detail, Beam properties
		2	Skewed application Note 2, 4 & 6, Block out detail
		3	Block out detailing, reinforcement and anchorage detail, bar bends
	Type B40 ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbs_tde04.pdf	1	Note 2, 4 & 6, Block out detail, Beam properties
		2	Skewed application Note 2, 4 & 6, Block out detail
		3	Block out detailing, reinforcement and anchorage detail, bar bends
	Elastomeric Bearings ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbs_tde08.pdf	1	Typical application of bearing of ABC bridges
Post-Tensioning Details ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbs_tde05.pdf	1	Detail showing transverse PT and anchorage	
Rail Anchorage w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbs_tde09.pdf	1		
Rail Anchorage w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbs_tde10.pdf	1		

	Drawing Title and Web Link (cont'd.)	Page (cont'd.)	Comments (cont'd.)
24' Roadway Details No Skew	Type B20 Std. Design w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde11.pdf	1	Typical beam and strand layout
	Type B20 Spans w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde19.pdf	1	Typical 2-lane application ranging span length of 30'-65'. Reinforcement of slab shown
		2	Diaphragm detail, Interior bent detail does not match drawing, Quantities Shown
	Type B20 Std. Design w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde12.pdf	1	Typical beam and strand layout
	Type B20 Spans w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde20.pdf	1	Typical 2-lane application with ACP overlay ranging span length of 30'-60'. Note 2 and 3. PT detail shown
		2	Diaphragm detail, Quantities Shown
	Type B28 Std. Design w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde13.pdf	1	Typical beam and strand layout
	Type B28 Spans w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde21.pdf	1	Typical 2-lane application ranging span length of 30'-75'. Reinforcement of slab shown
		2	Diaphragm detail, Quantities Shown
	Type B28 Std. Design w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde14.pdf	1	Typical beam and strand layout
	Type B28 Spans w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde22.pdf	1	Typical 2-lane application with ACP overlay ranging span length of 30'-75'. Note 2 and 3. PT detail
		2	Diaphragm detail, Quantities Shown
	Type B34 Std. Design w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde15.pdf	1	Typical beam and strand layout
	Type B34 Spans w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde23.pdf	1	Typical 2-lane application ranging span length of 30'-95'. Reinforcement of slab shown
		2	Diaphragm detail, Quantities Shown
	Type B34 Std. Design w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde16.pdf	1	Typical beam and strand layout
	Type B34 Spans w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde24.pdf	1	Typical 2-lane application with ACP overlay ranging span length of 30'-90'. Note 2 and 3. PT detail
		2	Diaphragm detail, Quantities Shown

	Drawing Title and Web Link (cont'd.)	Page (cont'd.)	Comments (cont'd.)
28' Roadway Details No Skew	Type B20 Std. Design w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde25.pdf	1	Typical beam and strand layout
	Type B20 Spans w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde33.pdf	1	Typical 2-lane application ranging span length of 30'-65'. Reinforcement of slab shown
		2	Diaphragm detail, Quantities Shown
	Type B20 Std. Design w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde26.pdf	1	Typical beam and strand layout
	Type B20 Spans w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde34.pdf	1	Typical 2-lane application with ACP overlay ranging span length of 30'-65'.
		2	Diaphragm detail, Quantities Shown
	Type B28 Std. Design w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde27.pdf	1	Typical beam and strand layout
	Type B28 Spans w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde35.pdf	1	Typical 2-lane application ranging span length of 30'-80'. Slab Reinforcement Shown
		2	Diaphragm detail, Quantities Shown
	Type B28 Std. Design w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde28.pdf	1	Typical beam and strand layout
	Type B28 Spans w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde36.pdf	1	Typical 2-lane application with ACP overlay ranging span length of 30'-80'
		2	Diaphragm detail, Quantities Shown
	Type B34 Std. Design w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde29.pdf	1	Typical beam and strand layout
	Type B34 Spans w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde37.pdf	1	Typical 2-lane application ranging span length of 30'-100'. Slab reinforcement shown
		2	Diaphragm detail, Quantities Shown
	Type B34 Std. Design w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde30.pdf	1	Typical beam and strand layout
Type B34 Spans w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde38.pdf	1	Typical 2-lane application with ACP overlay ranging span lengths of 30'-100'	
	2	Diaphragm detail, Quantities Shown	

		Drawing Title and Web Link (cont'd.)	Page (cont'd.)	Comments (cont'd.)
30' Roadway Details No Skew		Type B20 Std. Design w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde39.pdf	1	Typical beam and strand layout
		Type B20 Spans w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde47.pdf	1	Typical 2-lane application ranging span length of 30'-65'. Reinforcement of slab shown
			2	Diaphragm detail, Quantities Shown
		Type B20 Std. Design w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde40.pdf	1	Typical beam and strand layout
		Type B20 Spans w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde48.pdf	1	Typical 2-lane application with ACP overlay ranging span lengths of 30'-60'
			2	Diaphragm detail, Quantities Shown
		Type B28 Std. Design w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde41.pdf	1	Typical beam and strand layout
		Type B28 Spans w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde49.pdf	1	Typical 2-lane application, ranging span length of 30'-75', Slab reinforcement shown
			2	Diaphragm detail, Quantities Shown
		Type B28 Std. Design w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde42.pdf	1	Typical beam and strand layout
		Type B28 Spans w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde50.pdf	1	Typical 2-lane application with ACP overlay, ranging span length of 30'-75'
			2	Diaphragm detail, Quantities Shown
		Type B34 Std. Design w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde43.pdf	1	Typical beam and strand layout
		Type B34 Spans w/ Slab ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde51.pdf	1	Typical 2-lane application, ranging span length of 30'-100', Slab reinforcement shown
			2	Diaphragm detail, Quantities Shown
		Type B34 Std. Design w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde44.pdf	1	Typical beam and strand layout
		Type B34 Spans w/ Overlay ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/bbstde52.pdf	1	Typical 2-lane application with ACP overlay, ranging span length of 30'-100'
			2	Diaphragm detail, Quantities Shown

UTAH

Accelerated Bridge Construction (ABC) Drawings

<http://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:2394>

	Drawings	Link to Drawings
Superstructure	Precast Bulb Tee	http://www.udot.utah.gov/main/uconowner.gf?n=14493404283799689
	Pretensioned Bulb Tee	http://www.udot.utah.gov/main/uconowner.gf?n=6175029503633397
	Post-Tensioned Bulb Tee	http://www.udot.utah.gov/main/uconowner.gf?n=4954105825732675
	Pretensioned Decked Bulb Tee	http://www.udot.utah.gov/main/uconowner.gf?n=6173822483574618
	Full-depth Precast Concrete Deck Panels	http://www.udot.utah.gov/main/uconowner.gf?n=5440222707642218
Substructure	Precast Substructure	http://www.udot.utah.gov/main/uconowner.gf?n=4925304343682175
	Precast Approach Slab	http://www.udot.utah.gov/main/uconowner.gf?n=4953719415717635
	Precast Integral Abutment	http://www.udot.utah.gov/main/uconowner.gf?n=4924913777665971
	Precast Cantilevered Abutment	http://www.udot.utah.gov/main/uconowner.gf?n=4925105597673057
	Tolerances for Precast Bent Caps, Abutments, Wall Elements, and Approach Slabs	http://www.udot.utah.gov/main/uconowner.gf?n=4925532178699651

B.2 SELECTED PREFABRICATED/PRECAST BRIDGE ELEMENTS AND SYSTEMS

1. *Bridge-in-a-Backpack*

<http://www2.umaine.edu/aewc/content/view/185/71/>

Advanced Infrastructure Technologies

<http://www.aitbridges.com/>

2. *Minnesota Inverted-tee Beam (Poutre Dalle Slab System)*

http://international.fhwa.dot.gov/prefab_bridges/chapter_two_d.cfm

Research Report, "Application of Precast Decks and Other Elements to Bridge Structures"

<http://www.lrrb.org/pdf/200637.pdf>

Presentation on Inverted-tee Design

<http://www.dot.state.mn.us/bridge/manuals/LRFD/pdf/workshop/06InvertedTeeDesign.pdf>

Article on MnDOT Inverted-tee System

http://www.aspirebridge.org/pdfs/magazine/issue_15/Project_Minnesota.pdf

PCI Spring 2012 Journal on MnDOT Inverted-tee System

<http://www.pci.org/pdf/publications/Journal/2012/Spring/JL-12-SPRING-15.pdf>

3. *PCI Northeast Extreme Tee (NEXT) Beam*

PCI Northeast

www.pcine.org

Guidelines for NEXT Beam; Frequently Asked Questions; Full-depth Flange no CIP Slab (NEXT D Beam); and Partial Depth Flange 8" RC slab (NEXT F Beam)

<http://www.pcine.org/cfcs/cmsIT/baseComponents/fileManagerProxy.cfc?method=GetFile&fileID=29E93D11-F1F6-B13E-83B313BBC9C58FF5>

Development of the NEXT Beam (PCI Journal Article, Summer 2010)

www.pcine.org/index.cfm/resources/bridge/Northeast_Extreme_Tee_Beam

4. *PCI Full-depth Deck Panels*

Guidelines for Accelerated Bridge Deck Replacement or Construction 2nd Edition

<http://www.pcine.org/cfcs/cmsIT/baseComponents/fileManagerProxy.cfc?method=GetFile&fileID=2D90746A-F1F6-B13E-82A745AB150E0E16>

B.3 SELECTED CASE STUDIES ON TOTAL PRECAST CONCRETE BRIDGES

1. David Narrows Bridge Across the Bagaduce River, Brooksville, Maine

Aspire Bridge Magazine, Winter 2007

<http://www.pcine.org/cfcs/cmsIT/baseComponents/fileManagerProxy.cfc?method=GetFile&fileID=1F8FDFC9-C942-9960-02EB70D4DF5258F8>

Winner of the 2006 PCI Bridge Design Award for the Best Bridge with Spans Between 65 ft and 135 ft and the 2006 PCI All-Precast Solution

2. Mill Street Bridge, Epping, New Hampshire

All Precast Substructure Accelerates Construction of Prestressed Concrete Bridge in New Hampshire

PCI Journal, May-June 2005

<http://www.pcine.org/cfcs/cmsIT/baseComponents/fileManagerProxy.cfc?method=GetFile&fileID=1F9FCE57-D508-F427-F46B88ED0BCE26EE>

Aspire Bridge Magazine, Spring 2007, Peter E Stamnas and Mark D. Whittemore

<http://www.pcine.org/cfcs/cmsIT/baseComponents/fileManagerProxy.cfc?method=GetFile&fileID=1F90ED71-A587-64FD-876BF791E98AF825>

Technical Details

<http://www.pcine.org/cfcs/cmsIT/baseComponents/fileManagerProxy.cfc?method=GetFile&fileID=1FA081D8-AB15-221D-01D91E9C05204C83>

3. Route 10 Bridge Over Mink Brook, Hanover, New Hampshire

Precast Design Meets Tight Schedule

<http://www.pcine.org/cfcs/cmsIT/baseComponents/fileManagerProxy.cfc?method=GetFile&fileID=1F91FC8F-0F2A-729A-1D888DDD114DE45F>

Winner of the 2007 PCI Best Design Award for Best Bridge with Spans Less Than 75 ft

4. South Maple Street Bridge, Enfield, Connecticut

Single-span, Total Precast Bridge Replacement in 17 Days

Aspire Bridge Magazine, Summer 2011

<http://www.pcine.org/cfcs/cmsIT/baseComponents/fileManagerProxy.cfc?method=GetFile&fileID=5EA4B2EB-B15E-51D0-A25FB2D19A7D101D>