Contracting and Construction of Accelerated Bridge Construction Projects with Prefabricated Bridge Elements and Systems

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U.S. Department of Transportation
Federal Highway Administration

HIGHWAYS FOR LIFE
Accelerating Innovation for the American Driving Experience.

Foreword

This manual has been developed for the purposes of enhancing the use of Prefabricated Bridge Elements and Systems (PBES) as part of accelerated construction projects. FHWA continues to focus on a need to create awareness, inform, educate, train, assist and entice State DOTs and their staff in the use of rapid construction techniques. This manual is a follow-up of a previously completed manual on Accelerated Bridge Construction (ABC). The purpose of this manual is to provide more in-depth information on Contracting and Construction of Accelerated Bridge Construction with Prefabricated Bridge Elements and Systems. Portions of the previous ABC manual are reproduced in this manual in order to provide a stand-alone document with minimal cross references.

Users of this manual will be able to perform the following tasks:

- Understand the different contracting methods and contracting provisions that are commonly used with ABC projects.
- Understand the various construction methods used for ABC with PBES.
- Understand how to manage an ABC construction project.

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Notice

Quality Assurance Statement

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16. Abstract

Through the Every Day Counts (EDC) program, the Federal Highway Administration (FHWA) has been taking initiatives to bring Accelerated Bridge Construction (ABC) technologies into the market that can impact the ways highway agencies do business. With ABC technologies, highway agencies can replace bridges faster within a shorter time frame, and thereby significantly reduce adverse work zone impacts to the traveling public. The manual focuses on the construction aspects of ABC using Prefabricated Bridge Elements and Systems (PBES). The purpose of the PBES/ABC construction manual is to provide owners, engineers, and contractors with guidance and tools necessary to implement and manage construction. This manual focuses on the timeframe that begins the completion of design, pre-bid, contract award, on-site construction, and final close-out phases of construction.

The manual summarizes various aspects that should be considered during the pre-bid phase of a project relating to constructability reviews, hauling and staging, working with the construction industry at various levels, establishing construction schedule and cost estimates, and various contracting methods and clauses for effective delivery of the project. The manual also discusses the need for a pre-bid meeting for discussing various project-related issues. The manual also addresses the contractor pre-qualification requirements such as project-specific experience, past performance, technical ability, organizational and managerial structure, financial capability and bonding/surety needs. The manual addresses self-performance requirements to be undertaken by the contractor or supplier during pre-fabrication.

The manual provides guidance on planning the construction phase to ensure the successful delivery of the project. Staffing needs of the owner agency for oversight and acceptance operations are also discussed. The manual also addresses various aspects relating to the planning of pre-erection, erection, and post-erection activities to be undertaken during construction. A list of contractor submittals, such as assembly plans, logistics, and erection details, is also identified. The manual addresses the quality assurance aspects of a PBES/ABC project relating to prequalified projects, certification of fabrication facilities, individual PBES elements, grouting, erection, and measures for accelerating the materials testing process. The manual also addresses transportation management plan needs, project safety monitoring, crew fatigue management, and coordination with local law enforcement. The manual also discusses various public involvement and outreach activities to ensure public support and reduce problems during construction.

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SI* (Modern Metric) Conversion Factors

APPROXIMATE CONVERSIONS 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
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

SI* (Modern Metric) Conversion Factors

APPROXIMATE CONVERSIONS FROM SI 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 (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
^oC	Celsius	1.8C+32	Fahrenheit	^oF
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003).

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LISTING OF ACRONYMS

The following is a listing of typical acronyms that may be found in this document.

Acronym	Definition
ABC	Accelerated Bridge Construction
ACCT	Accelerated Construction Technology Transfer (FHWA Program)
ADT	Average Daily Traffic
AMVA	American Association of Motor Vehicle Administrators
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
AISC	American Institute of Steel Construction, Inc.
AISI	American Iron and Steel Institute
AMTRAK	National Railroad Passenger Corporation (Amtrak is not a governmental agency; it is a private company called the National Railroad Passenger Corporation)
ANSI	American National Standards Institute
ASBI	American Segmental Bridge Institute
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BCA	Benefit-Cost Analysis
C SHRP	Canadian Strategic Highway Research Program
CD	Compact Disc
CERF	Civil Engineering Research Foundation
CFLHD	Central Federal Lands Highway Division
CFR	Code of Federal Regulations
CIP	Cast-in-place
CRP	Cooperative Research Program (TRB)
CSD	Context Sensitive Design
DOT	Department of Transportation
ECMT	European Conference of Ministers of Transportation
EFLHD	Eastern Federal Lands Highway Division
EIT	Electronic Information and Technology
EPS	Expanded Polystyrene
EU	European Union
EUREKA	European Research Coordination Agency
F SHRP	Future Strategic Highway Research Program (now known as SHRP 2)
FAA	Federal Aviation Administration
FAQs	Frequently Asked Questions
FHWA	Federal Highway Administration
FRP	Fiber Reinforced Polymer
FY	Fiscal Year
GIF	Graphic Interchange Format
GSA	U.S. General Services Administration
GRS IBS	Geosynthetic Reinforced Soil Integrated Bridge System

HBP	Highway Bridge Program
HBRRP	Highway Bridge Replacement and Rehabilitation Program
HITEC	Highway Innovative Technology Evaluation Center
HRTS	Office of Research and Technology Services
HSIP	Highway Safety Improvement Program
HSS	Hollow Structural Section
HTML	HyperText Markup Language
IBRD	Innovative Bridge Research and Deployment
IBTTA	International Bridge, Tunnel and Turnpike Association
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
JPEG	Joint Photographic Experts Group
LCCA	Life Cycle Cost Analysis
LRFD	Load and Resistance Factor Design
NAS	National Academy of Sciences
NBI	National Bridge Inventory
NBIS	National Bridge Inspection Standards
NCHRP	National Cooperative Highway Research Program
NCSRO	National Conference of State Railway Officials
NDE	Nondestructive Evaluation
NEXTEA	National Economic Crossroads Transportation Efficiency Act of 1997
NHI	National Highway Institute
NHS	National Highway System
NHTSA	National Highway Traffic Safety Administration
NIST	National Institute of Standards and Technology
NRC	National Research Council
NSF	National Science Foundation
NTSB	National Transportation Safety Board
OSHA	Occupational Safety and Health Administration
PBES	Prefabricated Bridge Elements and Systems
PCA	Portland Cement Association
PCC	Portland Cement Concrete
PCI	Precast/Prestressed Concrete Institute
PDF	Portable Document Format
PI	Principal Investigator
QA	Quality Assurance
QC	Quality Control
R&D	Research and Development
ROI	Return on Investment
SAFETEA	Safe, Accountable, Flexible, and Efficient Transportation Equity Act of 2003
SCOBS	Subcommittee on Bridges and Structures (AASHTO)
SCOH	Standing Committee on Highways (AASHTO)
SCOR	Standing Committee on Research (AASHTO)
SHA	State Highway Administration
SHRP	Strategic Highway Research Program

TIFF	Tagged Image File Format
TIG	Technology Implementation Group
TRB	Transportation Research Board
TRIS	Transportation Research Information Services (TRB)
TRL	Transportation Research Laboratory
UHPC	Ultra High Performance Concrete
USACE	U.S. Army Corps of Engineers
USDOT	U.S. Department of Transportation
WFLHD	Western Federal Lands Highway Division

CHAPTER 1. PURPOSE AND USE OF THE MANUAL

1.1 INTRODUCTION

The use of Accelerated Bridge Construction (ABC) using Prefabricated Bridge Elements and Systems (PBES) has become more commonplace over the last 20 years in the United States. In the past, the use of ABC for the most part has been driven by acute traffic control issues at specific sites.

FHWA has been at the forefront of ABC and PBES for many years. Part of their efforts focused on the development of several manuals on the subject, which have been used by many agencies. They include:

- Decision-Making Framework for Prefabricated Bridge Elements and Systems (PBES), Publication Number FHWA-HIF-06-030, May 2006 [1].
- Manual on the Use of Self-Propelled Modular Transporters to Remove and Replace Bridges, Publication Number FHWA-HIF-07-022, June 2007 [2].
- Connection Details for Prefabricated Bridge Elements and Systems, Publication Number FHWA-IF-09-010, March 2009 [3].
- Accelerated Bridge Construction – Experience in Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems, November 2011 [4].

The last manual listed was developed as an overview of all aspects of accelerated bridge construction using PBES. The approach for this manual was to give an overview of accelerated bridge construction technologies and processes. The approach of this manual was to explore typical design, planning and construction processes, identify how they relate to ABC, and offer guidance on where to obtain more information on each subject.

More recently, the Federal Highway Administration (FHWA) has undertaken an initiative called Every Day Counts (EDC). The goal of EDC is to bring new technologies into the market that can have an immediate impact on the way that agencies and contractors build our infrastructure. ABC and PBES are significant parts of EDC. The desire to reduce impacts to the traveling public is driving this effort.

The EDC program included many workshops, meetings, and exchanges between transportation agencies and FHWA. The EDC program has been very successful in encouraging agencies to take a serious look at ABC and PBES. During many of these meetings, participating agencies expressed a need to have more information on the construction of projects using ABC and PBES. Previous manuals had some information on this subject, but not sufficient detail. The purpose of this manual is to expand on the previous work and to provide owners, engineers, and contractors with tools necessary to implement and manage ABC with PBES. The focus of this manual will be on the timeframe from the completion of design through final closeout in construction. The goal is to ensure that the approach and design that was envisioned during planning and design is fulfilled.

It should be understood that all potential bridge types and ABC technologies cannot be covered in any one manual. The most common forms of ABC and PBES will be covered in some detail; however, all designs in use in the United States will not be covered.

1.2 INTENDED USERS OF THIS MANUAL

1.2.1 Contracting Engineers

There are several different project delivery methods that are in use in the United States that are applicable to ABC projects. The role of the contracting engineer is to determine which contracting method best fits the goals of the project. If the goal is to reduce the overall project delivery time, the design-build (DB) method of contracting might be the best solution. If the goal is to use new innovations to reduce project construction time, the Construction Manager General Contractor method of contracting might be the best solution. This method of project delivery teams the owner with the contractor and the design engineer so that the owner can dictate the incorporation of innovative concepts and construction methods. Some agencies do not currently have the legal authority to use this project delivery method; however, this may change in the future.

This manual will explore these methods along with several contracting clauses that are applicable to ABC and PBES. The use of these methods and provisions should give the contracting engineer the tools necessary to accomplish virtually all of the construction methods outlined in the manual.

1.2.2. Agency Construction Engineering and Inspection Staff

In most state transportation departments, the construction management is handled by in-house staff. On larger projects and certain smaller projects, the management of construction is undertaken by consulting firms. Inspection of construction works is handled by both agency staff and consulting staff. Even with consulting assistance, it is important for agencies to understand the impact of ABC and PBES on construction engineering and inspection.

The main focus of "Accelerated Bridge Construction" is reduced construction time. This means that construction staff members play a key role in the success of any ABC project. ABC does not necessarily mean just building a bridge the same as before, but with more construction workers or double shifts. ABC technologies sometimes change the entire approach to the construction of a bridge.

Prefabrication of bridge elements is not new. The bridge construction industry has been prefabricating bridge beams for over 50 years on virtually all projects. The goal of ABC with PBES is to expand the use of prefabrication to all elements in the bridge. This will place more emphasis on erection and rigging and less emphasis on casting concrete. Construction engineers need to be more versed in these techniques and some of the equipment used to construct these bridges.

This manual will present recommended changes to the role of the construction engineering staff. In addition to new methods and equipment, the overall management of the projects may need to change in order to expedite the construction of the bridge. More emphasis on document management, project scheduling and decision making processes need to be addressed in an ABC project. Fortunately, the vertical construction industry has embraced this approach for years. Accelerated construction of buildings is common. The bridge construction industry can take the lead from these other industries and apply them to the construction of bridges.

1.2.3. Contractors

Contractors play a significant role in the success of an ABC project built with PBES. High quality plans and specifications are only part of the solution. The final implementation of the technologies falls into the hands of the contractor.

The interstate highway system was built primarily using cast-in-place concrete and fabricated steel and concrete beams. Certain forms of prefabrication can change the role of the general contractor into more of a construction manager. Prefabrication is a process that can remove the construction of elements from the bridge site to an off-site facility. In many cases, this will be performed by a separate company (e.g. a subcontractor or fabricator). This manual will address these issues and the different ways that owner agencies can address them. The impacts to the contractor will be part of this discussion.

There are many contracting provisions that are often included in ABC projects. This manual will address the most common provisions and explore the role they play in the construction of the bridge.

Several contractors were involved on the team that developed this manual. This was done to ensure that the contractor's perspective is covered, which should make the manual more valuable to the contracting community.

1.2.4. Design Engineers

Design engineers can either be owner agency engineers or consulting engineers hired by the agency to execute the design. Bridge design engineers are asked to take the concepts that are developed in the project planning process and turn them into plans and specifications that are suitable for project bidding and construction. Projects built using ABC and/or PBES technologies require a slightly different approach when compared to bridges built using conventional methods.

The nature of the use of prefabricated elements in ABC projects is that they will require different construction methods and equipment. The design engineer needs to be more versed in the equipment and methods for erecting prefabricated elements. In many cases, the design engineer will need to check potential erection methods in order to ensure that a bridge can be built within a given construction site. This does not necessarily mean that designers need to develop full erection plans during design development. The contractor is still responsible for the means and methods of building the bridge. The design engineer's role is to check that a bridge can be constructed within the available right of way, ensure the final erected structure satisfies the design requirements, and to review the contractor's proposed methods.

CHAPTER 2. DEVELOPING THE CONSTRUCTION CONTRACT—THE PRE-BID PHASE

2.1 CONSTRUCTABILITY REVIEWS DURING DESIGN

Some of the most successful ABC projects involved the incorporation of construction reviews early in the design process. The agency should consider the establishment of an independent constructability review team for ABC projects that include PBES. This team should consist of experienced staff from both the design and construction offices of the agency. The construction management and inspection staff can bring a different perspective to the design process.

The Construction staff should be brought in during the preliminary project scoping to offer insight into the capabilities of the local contractor and the construction equipment that is available. This should not dissuade the design team from investigating new technologies; however, it may affect some of the contract provisions that are used.

Two formal reviews are recommended during the design process. At the completion of the 30 percent design phase, the general approach for the project is established, including the layout, line, and grade of the bridge. A constructability review can be held to ensure that the concepts are sound and that the equipment required for the project is available. The review should also investigate the required right of way areas needed to successfully complete the project.

At the completion of the 60 percent design phase, another more in-depth constructability review should take place. This review should focus on the specific erection/construction techniques. The needs for falsework and the crane/equipment placement areas should be reviewed. It is also important to determine how the elements will be transported to the site. Special consideration should be given to the potential conflicts with the anticipated traffic management plan.

A detailed review of the estimated construction schedule should be undertaken. This should include specific timelines for all tasks involved in the ABC construction process. The team should evaluate if the timelines are reasonable. When evaluating timelines, it is important to not be too conservative. If overly conservative time estimates are used, there is a high potential for contractors to propose value engineering changes.

Estimating timelines for tasks based on past contractor performance is not appropriate. ABC projects will employ new materials, elements and connections that may not need significant time to construct. It is also safe to assume that construction staffing will be larger than on conventional projects, which will also expedite the construction process. Experience has shown that even aggressive timelines can be met successfully. The FHWA has complied information on numerous ABC projects built to date and has published this data online in an ABC project database. An important part of the timeline review is the understanding of the time required for material placement and curing. The construction management staff can help to identify the time required to execute tasks such as soil placement and backfill, concrete placement and curing, paving, etc. The design staff can assist by describing any new materials that may be used such as high early strength concretes and specialized hardware. The design staff can also help to identify what material strengths are required at specific stages of erection. For instance, a concrete pour may require five days to attain full design strength; however, it is highly likely that construction of subsequent portions of the bridge can take place as the concrete cures and gains strength. This type of information exchange between the design team and the construction team will most likely require a face-to-face meeting to review the project and the construction process. This method is far more productive than the more formal review/comment/resolution process.

2.1.1. What to Look for During Design Phase Plan Review to Ensure Plans Can Be Built in an Accelerated Manner

On design-bid-build (DBB) contracts, it is difficult to investigate various limitations on shipping, handling, and erection of elements, since the design team typically does not know where the elements will be fabricated. This is not the case on a DB project. The design team can work with the contractor and the specific fabricator to plan a route that will accommodate the size of the pieces.

On design-bid-build projects, it is recommended that the design team allow flexibility in element sizes by specifying optional joints and member sizes. This will allow the contractor to maximize the size of elements and the number of elements based on the specifics of the fabrication plant, the hauling routes, and the required erection equipment on site.

The following sections contain more information on the specific items that should be reviewed during constructability plan reviews.

2.1.1.1. Shipping Dimensions

Most states have limitations on shipping dimensions. In general, following maximum shipping dimensions are reasonable to ship in most areas:

Width:
- 8 ft without a permit.
- 12 ft with a permit (may need escorts).
- Over 12 ft is possible with police and private escort vehicles.

Height:
- 10 ft (assuming a 3-ft-tall trailer).
- Small pieces can get taller if they can fit on a low bed trailer.

Length:
- 60 to 80 ft for elements hauled on typical flatbed trailers on most roadways.
- 120 ft for elements that can be hauled on dolly extension trailers and steerable trailer (not a continuous flatbed).
- Longer elements can be shipped with specialty hauling equipment, but problems may arise with turning radii on local roads.

The design team should become familiar with the local width limitations, including the increased costs associated with over width shipping. Departments of transportation or motor vehicles typically issue permits for trucks. They can be contacted for information on local regulations and permits. Fabricators can also be used for information based on their past experiences. Another source of information is the Specialized Carriers & Rigging Association (SC&RA). This organization has published a manual entitled "Oversize/Overweight Permit Manual" that can be purchased at the SC&RA website (www.scranet.org). This manual contains the regulations for roadway permits in all 50 states.

The maximum element height is typically controlled by the height of bridge overpasses, overhead signs, and overhead traffic signals. The design vertical clearances for bridges specified in AASHTO codes is not a reasonable source of height limitations. There are many bridges in the national inventory that have substandard height. Many agencies set maximum vertical height of trucks, which is typically in the range of 13 ft, 6 inches. While over-width elements can be hauled with escort vehicles, over-height elements require different routes in order to avoid the clearance restrictions. In extreme situations, traffic signals and overhead signs can be temporarily removed; however, this is a costly process that may need to be done during off-peak hours. For instance, removal and resetting of a signal span pole can exceed $10,000 in most regions.

Shipping length is normally not an issue in rural areas; however it can be a significant problem in urban areas. Long elements may require the use of steerable dollies in order to maneuver corners while avoiding conflicts such as utility poles, traffic signal poles, and signs. As with overhead conflicts, traffic signal poles and signs can be temporarily removed; however, this adds complexity and cost to the move. If steerable dollies are required, the constructability review team should investigate the availability of these specialized trailers. There may be problems if the project has a large number of elements that need to be moved at one time. If the availability of equipment is limited, the team may need to re-think the construction sequence or timeline. In extreme situations, the team may need to re-design the entire system based on the available equipment.

2.1.1.2. Shipping and Pick Weights

Heavy elements can pose problems with both shipping and erection. Shipping weights can be problematic if there are load restricted bridges in the area. As with the shipping dimensions, the design team on a design-bid-build project does not know the fabrication site or the hauling route. A DB team will be able to investigate a specific haul route and possibly increase the element weights.

Once on site, the elements will need to be erected. The constructability review should look into the size and type of equipment that will be required. The location and size of the crane is critical to the erection of the elements and the constructability of the bridge. The combination of pick weight and pick radius establishes the size of the crane. As the radius increases, the crane capacity diminishes rapidly. The constructability review team should verify that the work areas for equipment are within the available right of way and beyond the limits of any environmentally regulated areas.

It is important to establish an element delivery route for the hauling equipment to access the site and off-load the elements. The team should attempt to minimize the number of times that an element is handled. Each element move increases cost and the potential for damage as the element is picked and set.

2.1.1.3. Equipment Availability

Specialized construction often requires specialized equipment. Local contractors often have cranes and falsework at their disposal; however some ABC projects will require larger and more sophisticated equipment.

The constructability review team should identify the equipment required to execute the construction. If not available locally, they should investigate out-of-state companies. The FHWA maintains a list of specialized heavy move companies. These companies own specialized equipment such as SPMTs. Most of these companies also own large cranes and other lifting equipment such as strand jacks and hydraulic jacks.

Heavy crane and rigging equipment can be very expensive. The cost of the cranes can vary greatly depending on the situation. A significant portion of large equipment costs is in the mobilization of the equipment. Large cranes use counterweights to resist the overturning forces. Counterweights on a large crane can be as large as 500,000 lbs. These counterweights need to be transported separately on multiple trucks. Crawler cranes require assembly and disassembly. All this leads to high setup costs. The specific costs vary by region, depending on the availability of the equipment.

The most cost effective way to justify the cost of this equipment is to keep it in use as much as possible. Typical contractors cannot justify the cost of owning the equipment, which is why specialty rigging companies exist. These companies can justify the cost of the equipment by working for multiple contractors around a region. There are several associations that represent the crane and rigging industry including the SC&RA (www.scranet.org) and the Association of Crane and Rigging Professionals (www.acrp.net). These associations can be used to locate crane and rigging companies in a region. The constructability team should contact these companies to check availability of the required equipment.

If the elements are large, specialty hauling vehicles such as extended trailers and steerable dollies may be required. A simple internet search of the words “heavy hauling companies” will produce a listing of these companies in the region. The constructability team should contact these companies to check availability of the required shipping equipment.

ABC projects often require the use of temporary falsework and staging equipment. The constructability team should normally not investigate falsework equipment unless the project requires highly specialized materials. The selection and design of falsework typically falls under the category of “contractor means and methods.” Contractors will often use materials on hand or materials that are locally available. Contractors have also employed innovative low-cost materials for falsework. One common approach is to use shipping containers to support temporary work. These are readily available for rent, highly resistant to lateral forces, and easily delivered, installed, and removed. Containers come in different sizes and capacities. There is no standard load carrying capacity for containers. Each manufacturer designed for specific load carrying capacity and stacking capacity according to various ISO specifications (International Organization for Standardization). In general, ISO standards require that containers be capable of being stacked at least six high. Many containers are designed to be stacked higher. The stacking capacity is required to be noted on a placard on the container according to the International Convention for Safe Containers (CSC). Typical stacking limitations are 300,000 to 500,000 lbs. It should be noted that this load capacity is only allowed on the corners of the container. The roof and sides only have nominal load carrying capacity. This fact will require the use of distribution framing to get the falsework loads to the corners of the container.

2.1.1.4. Manufacturing Availability

The constructability review team should identify any specialty products that may be required for the construction of the prefabricated bridge.

Fabrication plants: There are several ways to prefabricate elements. The first way is to use established certified fabrication facilities. Most states maintain a list of certified fabrication plants for both steel and precast concrete products.

Most states require the use of AISC certified fabrication facilities for steel elements. AISC maintains the following levels of fabrication plant certification categories:

- Steel Bridge Structures: Consist of un-spliced rolled sections.

- Major Steel Bridge: Typical bridges that do not require extraordinary measures. Typical examples might include:
  1. A rolled beam bridge with field or shop splices, either straight or with a radius over 500 ft.
  2. A built-up I-shaped plate girder bridge with constant web depth (except for dapped ends), with or without splices, either straight or with a radius over 500 ft.
  3. A built-up I-shaped plate girder with variable web depth (e.g., haunched), either straight or with a radius over 1,000 ft.
  4. A truss with a length of 200 ft or less that is entirely or substantially preassembled at the certified plant.

- Advanced Bridges: Those requiring an additional standard of care in fabrication and erection, particularly with regard to geometric tolerances. Examples include tub or trapezoidal box girders, closed box girders, large or non-preassembled trusses, arches, bascule bridges, cable-supported bridges, moveable bridges, and bridges with a particularly tight curve radius.

- Standard for Bridge and Highway Metal Component Manufacturers (CPT): This category is modeled on the Building Category but describes certification requirements for facilities that manufacture and supply specific components, composed primarily of metal to bridge and highway construction projects. Certification is appropriate for manufacturers of components that include bracing not designed for primary loads (diaphragms, cross frames and lateral bracing); camera, light, sign, and signal support structures; bridge rail; stairs; walkways; grid decks; drains; scuppers; expansion joints; bearings; ballast plates; and mechanical movable bridge equipment.

Designers should specify the appropriate level of steel fabrication plant certification based on these descriptions. It is acceptable to specify different certification levels for different elements. For instance, the designer could specify fabrication of plate girders in a major steel bridge fabrication plant, and bridge railing elements in a CPT plant. Allowing flexibility will lead to reduced costs and better availability.

Most state agencies specify fabrication plant certification for precast and prestressed concrete products. There are several certification programs that are in use in the United States. The most common certification is administered by the Precast/Prestressed Concrete Institute (PCI). PCI specifies the following levels of bridge product certification for bridges:

- B1 – Precast Bridge Products (No Prestressed Reinforcement). Mild-steel-reinforced precast concrete elements, including some types of bridge beams or slabs, as well as products such as piling, sheet piling, pile caps, retaining wall elements, parapet walls, and sound barriers.

- B2 – Prestressed Miscellaneous Bridge Products (Non-Superstructure). Any precast, prestressed elements except for superstructure beams. This includes piling, sheet piling, retaining-wall elements, stay-in-place bridge deck panels, full depth deck panels, and all products covered in B1.

- B3 – Prestressed Straight-Strand Bridge Beams (Superstructure). All precast, prestressed superstructure elements using straight, pre-tensioning, or post-tensioning strands such as box beams, I-girders, bulb-tee beams, stemmed members, solid slabs, segmental box beams, and all products covered in B1 and B2.

- B4 – Prestressed Deflected-Strand Bridge Beams (Superstructure). Precast concrete bridge members that are reinforced with deflected pre-tensioning or post-tensioning strand. Included are box beams, I-girders, bulb-tee beams, stemmed members, solid slabs, and all products in B1, B2, and B3.

- BA – Bridge Products with an Architectural Finish. These products are the same as those in Group B, but they are produced with an architectural finish. They will have a form, machine, or special finish. Certification for Group BA production supersedes Group B in the same category.

There is also the possibility of allowing fabrication of elements by general contractors (on-site, near site, or off-site). The use of prequalified precast fabrication plants can lead to higher prices due to shipping costs, but they generally also provide higher quality.

The use of certified PCI plants is recommended in order to achieve the highest level of quality. General contractors place and cure concrete on every project; however, prefabrication of elements require a higher level of quality control in order to manage tolerances. Non-certified plants can also fabricate precast products to a certain degree of quality; however, the level of quality may not be acceptable. The state of Utah allows general contractors to precast elements; however, they also require that the contractors obtain PCI certification for the work.

The proper fit-up of elements at the project site is critical in order to maintain a project schedule and avoid delays. The companion manual for this manual entitled "Engineering Design, Fabrication, and Erection of Prefabricated Bridge Elements and Systems" contains a chapter on element tolerances and how to detail a bridge to accommodate tolerances.

If an element does not fit-up properly in the field, re-casting of an element or substituting a cast-in-place portion of the structure might be necessary. This work will lead to delays on the project and extension of the construction work zone timeframe. If other methods of precast fabrication are to be considered, the agency should take a careful look at the quality control measures that will be in effect for the fabrication. A quality control program should be established and approved by the agency prior to the start of fabrication. Some states require that specific quality control programs be submitted and approved.

If contractor fabrication certification requirements are planned, the agency should consider establishing a program of projects instead of just a few projects. This way, contractors can distribute the cost of certification programs over a number of projects as opposed to imposing the cost on one project.

Standard Products: Certain details and connections may require specialty products and hardware. The typical connections that are identified in the FHWA manual entitled "Connection Details for Prefabricated Bridge Elements and Systems" [3] are mostly based on commonly available hardware. The appendix of this manual contains names of companies that commonly supply mechanical connectors. If a project required a small number of connectors (less than 250) a check on availability is probably not warranted. If a large number of mechanical connections are anticipated on a fast track project, the team should contact these companies to check for availability and lead times.

2.1.1.5. Maneuvering and Placing Equipment/Outrigger Locations/Loads

The erection of prefabricated elements will typically induce significant loads in the area surrounding the construction site. The location and magnitude of the loads will depend on the method of construction that is employed.

Constructability reviews should investigate the construction site for potential crane locations. The crane setup location should take into account the size of the crane tracks or outriggers and required crane mats. These locations should have ample room and level grading to support the crane.

The following sections contain information on specific types of equipment used on various PBES/ABC projects.

Self-Propelled Modular Transporters (SPMTs): The FHWA document entitled "Manual on the Use of Self-Propelled Modular Transporters to Remove and Replace Bridges" [2] offers guidance on investigating a site for bridge moves using SPMTs, including ways to estimate wheel loads under the SPMTs. It is recommended that a staging area and travel path be investigated and shown on the contract plans. Geotechnical investigations are typically required in order to determine the suitability of the soils to support the SPMTs. It is important to check slope stability of the supporting soil if the SPMTs are to travel near adjacent slopes.

If the SPMTs are to travel over structures such as vaults, manholes, or culverts, the constructability review team should verify that the structures can resist the forces. Bridging can be used to span over small structures that cannot support the SPMT loads. If bridging is required, it should be clearly shown on the contract plans. The design of the bridging is typically under the purview of the contractor; however, the constructability review team should investigate the potential thickness of the bridging and whether or not it will influence the travel path for the SPMTs.

All utilities (both underground and overhead) within the recommended travel path should be checked. In most cases, the underground utilities will not be affected because the wheel loads of SPMTs are designed to be approximately the same as typical trucks that travel on the roads. There have been concerns raised with regard to settlement of soils under SPMTs when the loaded machines are stationary over sensitive utilities for an extended period of time. This should be evaluated on a case-by-case basis depending on the anticipated construction sequence.

All of this work should be done during design development. The contractor should be required to verify this work during construction based on the actual equipment and loads. The engineering data developed during the design phase (geotechnical reports, pavement analysis, etc.) should be made available to the contractor.

Crane Placement and Loads: If cranes are used to erect elements, the effects of the outriggers need to be addressed. The constructability review team should investigate the size of cranes required for the work. The team should select specific cranes that are available and verify that they can lift and place the elements within the required safety factors. The footprint of the crane should also be checked. Large cranes can require large working areas. The team should check that there is sufficient room for the crane and the delivery of elements.

Hydraulic cranes typically use outriggers to resist overturning. These outriggers place large concentrated loads within a relatively small area. The magnitude of the load on outriggers will vary based on the location of the load relative to the crane. Crane companies have developed software that can determine the load on each outrigger with the load in various positions.

Crawler cranes distribute load through the tracks under the crane. The magnitude of the track loads will vary based on the location of the load relative to the crane. Crane mats are typically used to spread this load out to a larger area.

Crane mats and steel plates are often used to distribute the outrigger loads and crawler crane track loads to larger areas. If a crane mat is to be placed in a sensitive area, the constructability review team should contact crane manufacturers to determine these maximum loads based on the anticipated erection plan.

The constructability review team should determine the allowable soil pressures and investigate the size of the required crane mats. Geotechnical investigations may be required in order to determine the suitability of the soils to support the cranes. It is very important to check slope stability if the cranes are to be placed near slopes. Collapses of cranes have occurred that were caused by a slope failure under the crane. The team should check that there is ample room for these mats. The impact of the mats on the element delivery trucks should also be checked.

Forces Imparted on Adjacent Structures: The effect of any construction equipment on surrounding structures should always be checked. The loads do not need to be directly on a structure to cause influence on them. Lateral soil pressures caused by the surcharge of the load can cause significant lateral forces on underground structures. This should be evaluated by the designer and the constructability review team. Older and unknown structures should be avoided or bridged over to prevent failures during construction. These structures and the need to avoid load on them should be clearly shown on the contract plans.

The delivery of elements may use paths that cross existing bridges and structures. On a design-bid-build project, the design team does not know the location of the fabrication plants. For these projects, the design team may choose to limit the weight of elements in order to ensure that they can be delivered. If delivery of elements using nearby or adjacent bridges is part of the anticipated erection plan, the team can check them for load capacity.

On a DB project, the team can plot a route based on the selected fabrication facility. This may allow for heavier elements, since the exact haul route can be checked.

The existence of steep slopes near the crane layout area could lead to slope stability issues. The existence of earth retaining structures near the crane can also be problematic, as the crane could induce a large surcharge load on the structure. All of these issues should be addressed in the constructability review. Additional geotechnical investigations, analysis of soil slopes, and analysis of adjacent structures may all be warranted.

In certain circumstances (congested sites), the cranes may need to be set on top of, or directly adjacent to, existing structures. These structures should be checked for their ability to accommodate the equipment loads. The constructability review team should investigate at least one method of construction and verify that it can be accomplished using typical equipment. If specialized equipment is required to accomplish the work, or if there are limitations at the site, they should be clearly stated on the contract plans. If there is more than one anticipated method of erection, the plans and specifications should allow for alternate construction methods.

Project plans and specifications should note that the structures were checked for "typical" equipment, or the plans should indicate the capacity of the structures to resist the loads. The contractor is still responsible for an analysis of the structure based on the actual equipment that is to be used.

2.1.1.6. Equipment Set-Up/Breakdown Times

The set-up time for cranes and specialized equipment such as SPMTs needs to be considered. Large cranes such as crawler cranes are shipped in pieces and require dozens of trailers to deliver the parts, as well as a large area to assemble them. Set-up time for a large crawler crane can exceed several days. One advantage of crawler cranes is that they can be moved easily once set up. This is based on the assumption that the supporting soil along the travel path is adequate to accommodate the loads and that the travel path is relatively level (less than five percent grade).

Pneumatic tire cranes with telescoping booms are much faster to set up. It is possible to partially assemble one of these cranes near the construction site and drive it into position rapidly. Once set, the final set-up time to add counterweights can be reduced to approximately one to two hours. In most cases, a pneumatic tire crane cannot be moved with all counterweights attached, and they cannot be moved while carrying loads. If an assembly plan includes re-positioning of the crane, the constructability team should allow for approximately two hours to reposition the crane (which accounts for removal and re-installation of the counterweights).

SPMTs and the associated temporary framing can take days or weeks to set up. The constructability team should identify areas for this set-up work and be aware of the time required to complete the set up.

2.1.1.7. Erection Stress

Historically, the methods of handling, shipping, and erecting bridge beams have been under the purview of the contractor. The thought has been that a beam has ample bending strength to resist handling forces. The reality is that beams that are intended to be composite can be quite difficult to handle prior to installation of the deck. The contractor's erection engineer is responsible for checking the interim stability of the beams for all conditions prior to the final assembly. The design engineer is responsible for checking the beams for construction conditions such as deck placement, based on the assumption that all framing is in place.

In general, this approach is still the case for PBES/ABC projects. A prefabricated element such as a deck panel or a pier cap is designed by the design engineer to resist all forces specified in the AASHTO LRFD Bridge Design Specifications [5]. The contractor is responsible for checking the elements for handling, shipping, and erecting. This includes the design of any lifting hardware that may be necessary.

The PCI Design Handbook (seventh edition) is an excellent source for information on handling, erection, and bracing of precast concrete products. The manual includes examples of handling calculations and information on form suction forces. The manual also includes recommendations for handling stresses, including recommended maximum stresses for handling of elements to have "no discernible cracking." The recommended stress level for this is the modulus of rupture of the concrete divided by a 1.5 safety factor.

The handling of thin concrete panels is not normal in bridge construction projects; however, it is very common in building construction. The PCI Design Handbook contains recommendations for checking thin panels. Design engineers should specify that the lifting and handling stresses be checked by the contractor's erection engineer using the PCI Design Handbook. The previously published FHWA manual entitled "Accelerated Bridge Construction – Experience in Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems" [4] contains an example of lifting calculations for a precast full depth bridge deck panel. Design engineers should become familiar with these calculations in order to properly review handling calculations submitted by the contractor's erection engineer.

Deck panels can be difficult to handle due to the relatively thin sections. Many deck panels have holes cast in them to accommodate shear connectors, which further reduces the bending capacity. The design engineer cannot properly check the element stresses because he/she does not know the exact lifting hardware that will be used. The most common hardware used is a four-point pick using slings. Fabricators of precast panels know that if this arrangement does not produce satisfactory stresses, the lifting hardware can be changed to a six-point or even eight-point pick. This is common in tilt-up building systems. Figure 2.1.1.7-1 shows the lifting of deck panel using an eight-point pick.

Figure 2.1.1.7-1. Eight Point Pick of a Precast Concrete Deck Panel. (Source: Utah DOT).

Design engineers should know that very large panels will require these more elaborate lifting methods, which will lead to higher costs. The constructability review team should consider the size of these thin elements and consider breaking the element into two pieces with a small closure pour connection between the panels.

The evaluation of lifting stresses on bridge systems installed with SPMTs is somewhat different. In these cases, the design engineer typically checks the erection stresses in the superstructure system during the design phase. This is necessary since the erection stresses may control the design of the beams, especially if larger cantilevers are proposed. In most cases, the design engineer will choose lifting points that are as close to the beam ends as possible in order to minimize the stresses in the beams, deck, and barriers. Most agencies require that the heavy lift engineer check the stresses in the superstructure during the move. Three-dimensional (3D) modeling of the superstructure is often required. Most contract specifications have provisions for calculating the allowable twist in the structure during the move. A 3D model is required to complete this analysis. If the support framing between the bridge superstructure and the SPMTs is flexible, the framing may need to be modeled in the analysis.

For SPMT moves, the transporters typically need to be centered on the lifting points, which limits how far they can be placed from the beam ends. The constructability review team should evaluate these lifting locations and the impact of the locations on the topography and travel path. Adjustments to the travel path may be required, including the installation of temporary earth supports and temporary fills. The FHWA document entitled “Manual on the Use of Self-Propelled Modular Transporters to Remove and Replace Bridges” [2] offers guidance on investigating a site for bridge moves using SPMTs.

Erection stresses for lateral slide projects can be less cumbersome, especially if the temporary supports are coincident with the final supports. Lateral slides that make use of rigid sliding frames will not impart significant twisting in the superstructure; therefore a 3D analysis of the structure is often not required. The designer should specify that the contractor should verify that the new bridge can accommodate the jacking forces, and that the contractor is responsible for modifications to the bridge to accommodate the jacking forces. The design engineer cannot check this since there are a number of ways to jack a bridge (e.g., pull versus push). Also the friction force in the sliding system would be a function of the temporary bearings chosen (rollers versus sliding bearings).

2.1.1.8. Element Details

There are a number of sources of element details, including:

1. PCI Northeast Bridge Technical Committee (www.pcine.org).
2. Utah DOT ABC Standards (www.udot.utah.gov).
3. Previously published FHWA Manual entitled "Connection Details for Prefabricated Bridge Elements and Systems" [3].
4. Strategic Highway Research Program, Project R04- Innovative Bridge Designs for Rapid Renewal (ABC toolkit to be finalized and published in 2013).

It is important to note that all prefabricated elements are built to tolerances. The layout and detailing of elements should account for this fact. The PCI Northeast Bridge Technical Committee has established recommended tolerances for typical bridge elements. The width of joints between elements is a function of the element tolerance specification.

The tolerance of connecting hardware is also critical for the successful connection of adjacent elements. These hardware devices are also built to specified tolerances. The spacing of these devices should be specified to match the device tolerances. It is very important to specify tolerances that are measured from a common working point or line. Measuring tolerance based on center-to-center spacing will inevitably lead to a build-up of errors.

The designer should specify horizontal element setting tolerances. This is required to ensure that the layout of the completed structure will match the intended alignment. As with connection hardware, the layout of elements should be based on a working point or line.

The designer also should specify vertical element setting tolerances. This is required to ensure that the elevation of the completed structure will match the intended profile. Erection elevation tolerances should be shown on the plans in the form of an elevation tolerance. These are typically shown at the top of the lower element at the connection locations. The width of the horizontal joints is still a function of the element tolerance.

The companion manual to this manual, entitled "Engineering Design, Fabrication, and Erection of Prefabricated Bridge Elements and Systems," contains more information on designing a prefabricated bridge to accommodate tolerances.

The constructability review team should check the following:

1. That appropriate element tolerances are specified in the contract documents and that the connection joints can accommodate these tolerances.
2. That appropriate connection tolerances are specified and that the tolerances are based on working points or lines.
3. That appropriate element horizontal and vertical setting tolerances are specified.

It is very important for the design team to check the internal reinforcing of precast elements. The connection hardware and post-tensioning hardware should be checked to ensure that they can fit within the element and that there are no conflicts with internal reinforcing.

One common problem area is the internal reinforcing on precast pier caps. The longitudinal reinforcement in pier caps can get very congested. The connection hardware can often interfere with the pier cap reinforcement, especially with round column connections. The constructability review team should review these connections. If conflicts are found, the design of the elements can be modified to eliminate the conflicts, which can be accomplished by increasing the size of the bars and reducing the number of bars.

Another problem area for internal reinforcement is the end anchorage for precast concrete full-depth deck panels. The anchorage hardware should be detailed with appropriate concrete cover so that the completed deck is a durable structure. The hardware includes reinforcement that is used to transfer the forces into the deck. There have been problems with anchorages in relatively thin decks. For example, a standard four-strand tendon anchorage assembly is designed with a 2x2-inch pattern (square). The anchorage plate for this configuration is approximately 6x6 inches. If this were placed mid-depth in an eight-inch thick deck, the top cover over the anchorage would only be one inch. In order to get two inches of top cover, the deck thickness would need to be increased to 10 inches.

There are post-tensioning anchorages that are specifically designed to fit in thin decks; however, there is a limit to the minimum thickness of a post-tensioned deck system. These anchorages are referred to as "flat anchorages." They consist of a four-strand tendon with the strands anchored in a horizontal alignment. In general, the minimum thickness of a precast post-tensioned deck should be 8.5-inches (based on a 4.5-inch tall anchorage plate (available from several companies), 2-inch top cover and 1-inch bottom cover). The constructability review team should check the anchorage area and the hardware that is proposed to ensure there is adequate concrete cover.

The flat anchorages used in deck panels were originally designed to be used with flat oval ducts. These ducts have proven to be problematic on longer decks with many ducts splices at deck panel joints. The problems relate to difficulties with pushing the tendons through the duct. The use of a 2-inch diameter round duct is recommended, since it has a much larger inside area and can accommodate tolerances at the panel joints. The post-tensioning system manufacturers have developed special duct connections to marry the flat anchorage to the round duct. The constructability review team should ensure that the size of the duct is adequate to allow for easy and fast installation of the tendons.

Other potential connection hardware conflicts include erection hardware, welded stud embeds, bridge scuppers, etc.

The congestion of reinforcement can also lead to concrete placement problems. Some states allow the use of self-consolidating concrete (SCC) for precast elements, which can improve concrete placement. If congestion is a problem, the design of the elements can be modified to reduce the congestion. This often can be done by increasing the size of the bars and reducing the number of bars.

2.1.1.9. 3D/4D/5D Modeling for Constructability

The construction of complex prefabricated bridges can be akin to building a 3D jigsaw puzzle. A 3D design can be more than a pretty picture for display purposes, although these pictures can be useful in public outreach and construction management.

Modern computer-aided design tools are in place and enhancements are being developed that can provide tools for the construction of a complex prefabricated structure. The goal of these programs is to integrate the design and construction process into one computer model. The design files are shared with entities such as fabricators, and can be used to create more accurate shop drawings. This can lead to better control of geometry and reduction in errors. These models can also be used to virtually build the bridge in a computer 3D world.

Unfortunately, most designs today are still completed in a 2D environment. The current common approach for a project is to have a designer detail a bridge in a 2D (XY) computer model. The design is shared with the contractor in the form of 2D plans and specifications. Designs in 3D are rarely used due to the current complexity of the modeling and concerns over liability, which can arise due to ownership and accuracy of the 3D model. In a design-bid-build project, the designer’s computer files are not normally furnished to the contractor. The contractor is required to re-establish the design using survey and CAD. While this is cumbersome, it does provide a back-check of the design geometry. Software is in development that will facilitate 3D modeling and bring this approach into mainstream use.

Sharing of electronic design information between the design engineer and the contractor is best managed in a DB environment because the team can work together to format the data to suit the DB team participants.

Most engineers are aware of what a 3D model is. A 4D model is similar to a 3D model, except that the model can be built with other element attributes such as installation times, productivity rates, crew sizes, and costs. A 5D model adds more information such as element pricing and budgeting for the project. This approach can produce a model that can grow in complexity and become a data-rich font of project knowledge. Each stakeholder can approach the model with different questions and what-if scenarios and receive near-instant analysis of the situation.

This approach has been born out of the vertical construction industry where multiple trades are associated with every building. Large building projects with many sub-contractors have a need for high-level management and scheduling. On most bridge construction projects, the level of detail that these systems provide is normally not justified. They may be useful in the more complex prefabricated bridge projects, complex bridges such as movable bridges, or projects with many bridges. As with 3D modeling, 4D and 5D modeling is most likely best suited for DB projects at this time, since the designer is on the same team as the contractor.

2.1.1.10. Utility Conflicts

Utility conflicts can be a significant hindrance to any construction project and especially on ABC projects with limited construction timeframes. On conventional construction projects, significant amounts of time are scheduled to allow for utility relocations. The goal of many ABC projects is to minimize the mobility impacts while the bridge is actually in construction. Because of this, it is often desirable to relocate utilities prior to the start of an ABC project when possible.

All states have some sort of “one call system” in place that is funded by the utilities themselves; however, not all utilities are required to participate (namely cities, municipalities, counties, and the state agency themselves). Outreach may have to be to several agencies, not just the “one call system.” Field exploration and documentation is essential if excavation is part of the ABC project. Transmission lines may have a scheduled shut down period that is coordinated to coincide with low power demand timeframes. In northern regions, gas companies and steam pipe companies may be able to shut down lines during summer months. These types of efforts can take up to six months to coordinate and schedule. Utility companies can be very good resources and can be very creative with their approach to protection or relocations.

The preliminary design team should invest time and resources into field investigations of existing utilities. The cost and time to complete test pits are justified since they can save significant time and cost during construction. The information gained during design development will help to eliminate delays when unanticipated conflicts are discovered during construction. The Second Strategic Highway Research Program (SHRP2) included a project that investigated ways to “*quickly identify and resolve conflicts between road and bridge projects and the presence of utility infrastructure*” (SHRP2 Project R15B). The results of this research are published in a document entitled “Integrating the Priorities of Transportation Agencies and Utility Companies.”

The constructability review team should verify that all utility companies have been contacted and the appropriate field explorations completed prior to the start of construction. All agreements for modifications and temporary shut-downs should be in place or in progress during the design development.

2.1.1.11. Environmental and Public Commitments/Restrictions

Nighttime work is inevitable on some ABC projects. Many agencies have noise restrictions for construction work that may or may not include nighttime work restrictions. Local restrictions may also be in place for weekends and holidays for events such as concerts, fairs and parades.

Public outreach, especially with elected officials can be instrumental in allowing local ordinances to be relaxed for the use of PBES/ABC methods. The agency needs to meet with the affected property owners and local officials to demonstrate the benefits of ABC and how they can outweigh the impacts. For example, the 93 Fast 14 project in Medford, Massachusetts, was built primarily on a 24-hour schedule on 10 successive weekends. Some houses were literally feet from several of the bridges. There was a large hotel less than 200 ft from one of the bridges. Through public outreach, the town and adjacent property owners agreed to the fact that 10 weekends of nighttime and weekend work (two weekends per bridge site) was far better than the anticipated four years of staged construction.

The constructability review team should review any local restrictions and coordinate with the agency public outreach group to coordinate construction schedules and potentially lift them for the project.

2.1.1.12. Geotechnical Review

Subsurface irregularities and unknowns can be a major cause of delays in an ABC project. For this reason, it is critical to identify the sub-surface conditions prior to construction. The level of explorations is somewhat a function of the speed of construction. The amount of sub-surface exploration is inversely proportional to the amount of potential delays due to unforeseen underground conditions. If ample time is given to install foundations, typical subsurface explorations may suffice. If a project is planned with a construction timeframe that has little or no room to accommodate foundation change orders, more explorations would be in order. An exception to this may be an area with very uniform soils or exposed bedrock, where the potential for subsurface unknowns is limited.

The constructability review team should verify that adequate subsurface investigations have been completed. Additional explorations should be considered if variability is found in the preliminary results. Issues such as the presence of boulders, and older structure foundations should be cause for concern. In the worst cases, the team may need to consider relocating substructures to avoid potential unknowns.

The design team should consider adapting the foundation design to facilitate ABC. In some cases, driven piles can be a faster construction method when compared to drilled shafts, even if it is less economical. The geotechnical engineer should evaluate all options for cost and construction speed. The evaluation should include the required cost and mobilization time for equipment and the need for pile splicing. For larger projects, a pile test program can be completed before construction to confirm pile lengths or bearing capacity.

The geotechnical team should investigate the potential for the use of different foundations on a single bridge. In some cases, deep foundations are used on an entire bridge due to poor soils at one substructure. The thought is that it will lead to efficiencies once a pile rig is mobilized. The reality is that shallow foundations can be built more rapidly than deep foundations. Allowing mixed foundations can lead to reduced overall construction time and potentially reduced construction costs.

DB projects offer the opportunity to investigate several foundation types. In most cases, the agency will conduct geotechnical investigations prior to solicitation of the DB contract. The agency can then develop a geotechnical report and suggested foundation types based on the investigations. This information should be shared with the DB teams. The agency should note that additional investigations may be required and that the DB team would be responsible for the time and cost of additional investigations. The agency should verify that the DB teams will have adequate time and access to procure additional subsurface investigations, which can be completed both before and after the solicitation process.

Armed with the proper geotechnical exploration information, the DB team can evaluate the various foundation options and choose the one that works best for the site and the schedule. This can be done through a flexible bid specification or through the Alternative Technical Concept (ATC) process.

Another issue that can be problematic is the management of contaminated soil within a project site. There are established means for managing contaminated soils on typical highway projects. This can involve the use of stockpile areas and temporary storage. The constructability review team should verify that there is ample space and time to manage these soils. Additional soil investigations may be necessary to better classify these soils prior to construction so that a better understanding of the level of effort is identified.

2.1.1.13. Restrictive Contract Terms

It is common to impose restrictions on construction as part of a specification package. These restrictions are typically not problematic on projects with long construction schedules. Contractors understand the restrictions and can schedule around them, provided they are given ample time to complete the entire project. Typical examples of restrictive terms include restrictions on access to wetlands, time of year work restrictions to minimize impacts to threatened or endangered species, restrictions to work hours due to local events, noise restrictions, and third party delays.

The use of restrictive terms in contracts on ABC projects can place a significant amount of risk on the contractor. The management of risks can lead to increased work hours, nighttime work, and weekend work in order to complete the project within the limited timeframe of an ABC project. If incentives are included in a project contract, the cost of these risks can lead to a loss of incentive dollars.

ABC can be used to minimize the amount of time on a site to help alleviate most of these risks. For instance, if construction activities could threaten spawning of fish during a construction timeframe, ABC can help the contractor complete the work prior to the spawning timeframe without the risk of a project shutdown delay.

In the contracting world, increased risk equates to increased cost. The more restrictive a contact is, the higher the bid prices. Based on this, it is in the best interest of the agency to minimize the use of restrictive contract terms. It may be inevitable that restrictions will apply to a project. The constructability review team should evaluate each restriction in its impact to the construction schedule. This can be done through a risk analysis process, where risks are identified and evaluated. If the risks cannot be removed and they are deemed to be too significant, the team should consider re-evaluating the construction schedule.

On DBB and DB projects, the risks typically fall on the contractor. The contracting method called Construction Manager General Contractor (CM/GC) offers an opportunity to manage risk prior to construction. In this form of contracting, the contractor is part of the design team, which includes the owner. Part of the design process can include a risk analysis process, where risks can be identified, mitigated, or assigned to the party that can best address and control it with an understanding of the cost and time implications. If restrictive terms are cause for a particular risk, the agency can evaluate the terms and make adjustments if possible.

2.1.1.14. Staging Areas/ROW Requirements

Several approaches can be used for the establishment of staging areas. The first and most ideal approach is to use available right of way in the vicinity of the bridge site. Highway interchanges are often ideal for project staging. The Utah DOT converted an interstate highway cloverleaf into a "bridge farm," where seven bridge superstructures were prefabricated prior to installation. This allowed the contractor to make better use of equipment by mass producing the seven bridges with the same equipment.

Another approach is to have the agency identify a specific staging area and obtain temporary or permanent rights to use the area during construction. This is especially true for projects that involve full superstructure installations using either SPMTs or lateral slide techniques. The contractor needs to have a specific location for staging the project and establish a travel path that is clear of obstructions. The staging areas for these projects need to have ample room for erection cranes and delivery of girders and materials.

Another approach to staging areas is to leave the selection of a staging area up to the contractor. This will save time during the project development phase since right of way acquisition will be limited or eliminated. This method allows for flexibility in the approach for staging the project, but it also can lead to increased risk on the contractor. In congested urban areas, the staging areas may be many miles from the project site, which will lead to increased project costs.

The constructability review team should review and evaluate all potential staging areas based on the construction methods proposed. If no specific staging areas are proposed, this information should be clearly shared with the contractors in pre-bid meetings or in the bid documents.

2.1.1.15. Railroad Impacts

Impacts to railroads can be problematic and a source of project delays. Removing a track from service can result in the shutdown of an entire rail corridor. For this reason, restrictions are put into place for bridges adjacent to or over railroads, especially if the railroad is electrified. ABC projects can be a solution to restricted sites. The use of prefabricated elements can reduce the need to use extended track closures.

Another impact to construction is work adjacent to a live track. Railroad flaggers are typically required in order to alert the contractor of oncoming trains and to ensure that construction activities do not foul the tracks. Railroad flagging costs can be very significant. ABC can be used to minimize the cost of flagging, thereby saving in overall project costs. This concept should not be foreign to railroad companies. The use of ABC has been relatively common in the railroad industry for many years. Some of the concepts in use for highway bridges were born in the railroad construction industry.

The constructability review team should review the project work plan and evaluate the railroad impacts. The team should review proposed track closures and ensure that the appropriate railroad flagging force accounts are in place.

2.1.1.16. Impacts for Approach Roadway Tie-In

Often, the bridge design team overlooks the work required to properly connect the approach roadway to the bridge. This work often involves the installation of embankment fills and roadway approach slabs.

Many ABC projects include the use of precast concrete approach slabs. There have been issues with delays associated with the installation of precast approach slabs caused by preparation of the backfill under the slabs. The delays are with respect to the need for support under the approach slabs. Designers have specified finely graded substrate and grouting to ensure contact of the approach slab to the substrate. In some cases, contractors have had to re-install precast approach slabs multiple times in order to get reasonable contact between the slab and the soil.

In order to address this problem, one must understand the role that approach slabs play in the performance of a bridge structure. Approach slabs are designed to span across a potential settlement depression directly behind the abutment. This settlement occurs for several reasons. First, it is very difficult to get proper compaction directly behind the abutment. It is almost inevitable that the soils will settle over time. Another reason is caused by differential settlement of the abutment with respect to the roadway approaches. If the abutment is supported on a deep foundation in an embankment with compressible soils, the approach roadway will settle more than the relatively rigid abutment foundation. Differential settlement can take placed between the abutment and the approach embankment, causing a depression behind the abutment.

There is a misconception that approach slabs need to be supported on the underlying soil over their entire length. The reality is that a void will form under the portion behind the abutment. Because of this, the grading of the approach slab base need not be perfect in this area. The goal should be to support the slabs on the abutment and at the far end. The support at the far end can be accomplished in several ways. Many agencies use precast concrete sleeper slabs to support the precast approach slab. Another approach that has been used is to place grout or flowable fill under the far end of the approach slab to seat it on the substrate. This seating need only be applied to the last few feet of the slab. The area under the majority of the approach slab can be built with minor gaps that can be left in place. These methods should reduce construction time for the approach slab installation.

The Utah DOT has developed another approach to rapid approach slab installation when bridge systems are installed using the lateral sliding method. The approach slabs are attached to the superstructure in the offset position before the slide. During the slide, the entire superstructure and the approach slabs are slid into place at one time after the installation of substructures and precast sleeper slabs. This method essentially converts a single-span bridge into a three-span bridge (main span plus two approach slabs). Once in place, the area under the approach slabs is filled with flowable fill. The flowable fill will shrink somewhat; however, the approach slab is properly supported at the bridge and at the sleeper slab.

Installation of approach roadway embankments can become the critical path on an ABC project. Control of conventional roadway grading is accomplished through the use of survey grade stakes. This can be a time consuming process, especially if the grade stakes are damaged or moved by construction equipment. Modern grading equipment can be controlled by electronic global positioning sensor (GPS) and laser guided equipment. Sensors attached to the grading equipment can be tied to a 3D model of the roadway, eliminating the need for roadway grade stakes.

Another process that can lead to delays in roadway construction is the need for soil testing during placement. Soil testing can be a slow process and it can delay the installation of soils while operators wait for the testing results of previous lifts. Intelligent compaction is a new technology that can reduce the time for this quality control process. Intelligent compaction equipment is built into the compaction machines so that they can measure and record the quality of compaction during the actual compaction process. The equipment measures the compactor's force in real time and is able to adjust the machine in order to increase the amount of compaction if necessary. The equipment also prevents over-compaction. GPS equipment is used to record the quality of the compaction in all areas, which improves the quality of record keeping.

Another way to expedite embankment construction is to use lightweight expanded polystyrene blocks. These blocks are extremely lightweight so they can be placed without heavy equipment. The blocks are stacked in an interlocking pattern. Two issues need to be understood with the use of expanded polystyrene block backfill:

- The blocks have very low unit weight, which means they can easily float. They should only be used above the expected high water table level.
- The blocks have limited ability to resist concentrated wheel loads. A layer of soil must be place between the blocks and the roadway.

Another option for rapid backfill construction is to use flowable fill. This material is comprised of sand, water, and a small amount of cement. There are various classes of flowable fill that are available (excavatable and non-excavatable). There are several issues that need to be understood when using flowable fill:

- The material has low viscosity. Areas to be filled need to be contained or formed.
- Flowable fill will settle during curing. For thick fill areas, multiple lifts or an additional layer of compacted fill will need to be placed in order to meet the desired grading.

The constructability review team should evaluate the construction of embankment fills and determine if these construction techniques are required.

2.1.1.17. Agency Resources

The use of innovative contracting methods and accelerated construction techniques places more demands and responsibilities on field staff during construction, often requiring additional overtime work and/or increased staffing levels. In some cases, ABC projects require expedited decision making, expedited submittals, and pay requisitions in order to keep the project moving forward at an accelerated pace.

It is recommended that the agency place experienced construction management staff on the initial ABC projects in order to handle these increased responsibilities. The initial projects should also be used as a training ground for future construction management staff.

Expedited decision making will most often require the use of a senior level design engineer on site. This engineer does not necessarily need to be the engineer of record, but should be familiar with the project and the technology. The bridge design engineer may be unaware of the contractual requirements of the project; therefore, more than one decision-maker may be needed: one for design issues, and one for contractual issues.

The need for overtime and weekend work for construction administration employees should be evaluated for every project. The fact is that many ABC projects will require the use of overtime labor. The cost of the overtime labor is not necessarily an extra cost to the project. The overtime costs are mitigated by the reduced duration for the overall project. The use of PBES transfers construction inspection from the field to a fabrication facility. Thus, the need for field construction personnel is reduced. Inspection of element production in a fabrication plant is more efficient since an inspector or group of inspectors can oversee multiple projects without leaving the facility. Downtime on individual projects can be filled with oversight on other projects using the same staff. This is not easily done with construction management staff in separate project field offices.

The constructability review team should evaluate the resources necessary both in the field and in the fabrication facility. Some agencies have expressed concern over the need for more construction administration staff as projects are built faster. This is an issue that may need to be addressed if a program of ABC projects is instituted. The use of consulting engineers can be used to fill gaps in personnel as a program matures. These consultants should have experience with ABC and PBES technologies. They should also be given a certain level of decision-making authority, or have an agency engineer available to assist with decisions in a rapid manner.

2.1.2. Outcomes

The previous sections outline major items that should be addressed in a constructability review. Several reviews are recommended for complex projects. The level of the review should be consistent with the level of design completion. The following sections outline recommended levels of review.

2.1.2.1. Preliminary Design Constructability Review (30 percent)

The goal of a preliminary design review is to verify if the concept is reasonable and constructible. Major concepts should be evaluated and the general construction process should be scrutinized. One of the goals of this review is to determine and identify what needs to be completed and checked during the semi-final plan development phase.

This review should also confirm the adequacy of any environmental and non-construction controls such as EIS statements, ROW needs, utility relocations, and any other parallel tasks that may need to be addressed as the design progresses. All sections contained in Section 2.1.1 should be investigated.

It is recommended that a preliminary design checklist be established and filled out for each project review. The goal is not to answer all of the questions outlined in the previous sections, but to identify which issues need to be addressed.

2.1.2.2. Semi-Final Design Constructability Review (60 percent)

This phase of the design development involves the production of more details plans and specifications. The overriding question that needs to be addressed is: *Are the plans and specifications buildable?*

By this point in the design process, material sourcing, potential vendor availability and competency, and potential equipment access and usage, have all been evaluated. There should be no known impediments to a successful completion of a certain buildable scheme.

Some agencies develop project concepts to this level for DB projects. Concerns have been raised that this level of effort is unnecessary for DB projects and that it limits the ability of contractors to develop innovative solutions that are different than design plans. This concern needs to be addressed by individual agencies. Many agencies cannot obtain environmental permits and right of way acquisitions without detailed plans. It may be possible to obtain preliminary permits and rights of way with preliminary plan concepts; however, the project schedule should allow ample time for the DB contract team to revise permits and acquire additional right of way if needed.

2.2. ENGAGING THE CONSTRUCTION INDUSTRY DURING DESIGN DEVELOPMENT

Some of the most successful ABC projects built to date involved interaction with the construction industry. The I-93 Fast 14 project in Medford, Massachusetts, included numerous meetings with potential DB teams during the concept development phase. Previous sections in this manual include recommendations for communication with various industries, such as crane and rigging companies. All of this effort will ensure that the project is buildable and successful. Industry engagement can also be used to reduce risk or perceived risk on the part of contractors.

2.2.1. Industry Groups

Fortunately, there are several national industry groups that represent the construction industry as a whole. They include the Associated General Contractors (AGC) and the American Road and Transportation Builders Association (ARTBA). Individual states also have contractor associations that can be of assistance.

The goal of engaging the construction industry is to gain feedback on project concepts and the ability of contractors in the area to complete the projects.

2.2.2. Program Level

Engagement of the construction industry is a critical part of the development of a successful PBES/ABC program. The construction industry is a critical partner in a successful ABC program. It should be part of the program development process. The following sections contain recommendations on this subject.

2.2.2.1. Regular Industry Workshops

If an agency decides to pursue a program of PBES/ABC projects, they should engage the industry at regular intervals during the program development process. Meetings in the form of workshops can be a very effective tool. In general, a workshop should include:

- Presentations by the agency management outlining the goals of the program.
- Information on the scope of the program, including specific projects.
- Informational presentations covering construction approaches, procedures, and details.
- An open forum where contractors can ask questions and provide feedback on the program.

It is important for the agency to understand how an ABC program can affect the local contractors. The agency should provide an open forum and be open to criticism. The goal should be to discuss the issues and strive to address them as the program develops.

The agency should record the feedback and respond in a subsequent report. It is also important to present the program of projects so local contractors can be assured that investment in labor and equipment will be justified by the program.

One issue that will inevitably be discussed is the fact that prefabrication will move some construction activities away from the project site and shift them to a fabrication facility. Contractors will perceive this as a potential loss of work. There are several approaches that can be pursued to resolve this issue. The contractors can take on more projects without adding significant labor. The agency can also consider allowing contractors to self-perform certain precast concrete elements provided that an appropriate quality control program is in place. Section 2.1.1.4 contains more information on this approach.

2.2.2.2. Use of Pre-Qualified Contractors

Some ABC projects require special expertise for construction. An example of this would be the installation of a bridge system using SPMTs or lateral sliding techniques. These types of projects are becoming more commonplace; however the expertise needed for them may not be available in the local contracting pool. The goal is to have experienced contractors executing these critical construction methods.

One way to address this is to establish a list of pre-qualified contractors and sub-contractors. In order to do this, an agency needs to establish the criteria for the pre-qualification. The criteria can include examples of successful projects and the experience of key personnel on the contracting team. The latter of these two is very important. Even an experienced construction company can run into problems if the project superintendent is not experienced. Agencies may wish to interview the companies to gain more detailed information on their experience and quality control processes.

It is important to establish prequalification lists before projects are bid, since there may not be sufficient time to review and prequalify companies during the bid process.

Another approach to obtaining a pre-qualified contractor or sub-contractor is to include language in the project specifications that require a certain level of experience. For instance, the specifications can call for a firm that has successfully completed three previous similar projects. The same type of requirements can be set for the project superintendent as well.

2.2.3. Project-Level Pre-Bid Meetings

The agency may choose to engage the industry on a project level. Limited resources may preclude these engagements for every project, but this should be considered for larger PBES/ABC projects.

2.2.3.1. Design-Bid-Build Projects

Project informational meetings should be considered prior to bidding a project. The goal is to demonstrate the scope of the project and the specific construction methods that are being considered. This meeting should be held at the semi-final design phase of the project. The concepts and major details should be well enough along to present the approach; however, ample time should be left for obtaining feedback and allowing for subsequent project modifications.

Agencies may wish to make these meetings mandatory for all potential bidders; however, this may limit the competition and available bidders. It is important to have agency representatives present who are cognizant of the PBES/ABC process. It is inevitable that many contractors will hesitate to speak or ask questions in a large group setting, so it is incumbent on management to communicate as much information as possible. This process should also encourage the request for information (RFI process to clarify the proposal and potential release of addendums. If RFI documents are kept confidential, the agency will receive more effective feedback.

2.2.3.2. Design-Build Projects

Agencies typically short-list a small number of teams on a DB project. The small number of teams offers the opportunity to have one-on-one confidential meetings with the short-listed teams. These meetings should be held after the request for proposals is issued. Larger DB projects may require the use of several meetings to discuss potential options:

- Concept-level meetings can be held to discuss the general approach to the design and construction. Potential alternative technical concepts (ATCs) should be presented. The meeting can be used to determine if a particular concept is acceptable to the owner and to discuss the design and detailing approach that will be required to fully develop the concept. The goal of this meeting is to vet the feasibility of the concept and whether or not the agency is open to it.

- Once a concept is more fully developed, the DB team may wish to meet with the owner to further discuss the details and obtain comments on major concerns and potential required changes.

It is important for decision-makers to be present at these meetings. The input from the agency will be the basis for the DB team approach. They need to know what will be acceptable to the owner in the final proposal. The agency technical staff needs to be involved so that all potential design issues are discussed and agreed upon.

The agency may want to enlist the assistance of their legal staff to ensure that the meetings are kept confidential and to provide a level of transparency to the process. In some cases, a third party is brought in to provide an even better layer of transparency. In order for these meetings to work properly, confidentiality should be stressed to all participants. Some agencies require that all participants sign non-disclosure statements prior to the meetings to ensure confidentiality.

Some DB projects involve the use of stipends. Some agencies that have used stipends have taken the stance that they are paying for the preliminary design and that they should have the right to share these ideas with all bidders. The thought is that this will reduce the project bid prices because all teams will have access to the ideas. In reality, this typically does not happen. The teams are reluctant to share innovative concepts because they will lose their competitive edge in the bidding process. In lieu of this, they typically keep the concept confidential and approach the owner with it as a value engineering proposal. The problem with this approach is that the owner will only recoup a portion of the savings.

Agencies should weigh these facts and discuss them with the construction industry during the program development workshop process previously discussed in Section 2.2.2.1.

2.3. PRE-BID SCHEDULE

The owner agency needs to establish a pre-bid schedule as part of the contract procurement process. Different schedules are required for different procurement methods. The key difference is the time required for DB teams to develop a technical proposal and bid price.

2.3.1. What is Possible?

The FHWA is encouraging agencies to expedite the project delivery process through the Every Day Counts initiative. One of the goals of the EDC program is to reduce the project delivery timeframe by 50 percent. This is done in part through alternative contracting methods and alternative contracting provisions. The management of the pre-bid schedule is also part of this process. The following sections contain information on what is possible in the pre-bid schedule for typical projects.

2.3.1.1. Design-Bid-Build Projects

Agencies should evaluate the time required for contractors to submit bids on DBB projects that employ ABC methods, especially if the goal is to reduce mobility impact time as opposed to total project time. More time may be required if a project contains a new method or equipment that is not common to the area. The contractors will need time to explore the implication of the process on their normal operations. Increasing the bid development timeframe will also give contractors flexibility in managing the workload of preparing several bids at once, which may allow more contractors to bid on the project. Increased competition will inevitably lead to decreased prices. The pre-bid meetings described in section 2.2.3. will help reduce the time required for this process.

2.3.1.2. Design-Build Projects

The time required to procure a DB project is a function of the size and complexity of the project. There are several levels of details that need to be developed prior to a bid, depending on the complexity of the project and the flexibility of the agency to accept alternative concepts.

The most flexible process is when the agency simply lays out the footprint of the bridge and defines the alignment of the roadway along with the required right of way. In some cases, even the alignment is left up to the contractor. While this approach is easiest for the owner, it places significant risk on the contractor, especially if the procurement of permits and the public outreach process is assigned to the DB team. This approach will save significant time during the procurement process, but add time to the contract after bidding as the DB team works through the permitting process.

Another approach for DB procurement documents is to include a preliminary design (30 percent) of the project before the DB procurement process begins. The owner can layout the specific bridge and alignment that they want. This approach requires more time in the pre-procurement process, but saves significant time during the bidding process because the DB teams are essentially finishing the owner's design and applying a cost to it. One downside to this approach is that there is less room for innovation. The only innovative aspect of the project is the actual construction sequence and methods.

Some agencies secure permits and right-of-way prior to the DB procurement process in order to expedite the process and reduce risk on the DB team. The agency will obtain ample right of way and develop permit applications based on the anticipated construction methods shown in the DB procurement documents. The agency should ensure that the right of way and work areas are adequate for the anticipated design, especially for foundation construction requiring in-water work. Environmental regulatory agencies normally require designers to investigate the environmental impacts of all feasible alternatives in order to determine the alternative that offers the least environmental impact. This can be difficult in a DB project where environmental permits are obtained based on sketch plans that may or may not represent the final design. The areas shown for in-water work should be large enough to accommodate the final foundations, but not be too large to complicate the environmental permitting process. In these cases, the agency should require that the DB teams submit permit application revisions if their designs vary from the sketch plans in the DB procurement documents. The DB team should also be contractually obligated to build the original sketch plan concept if their alternative is found to be unacceptable to the regulatory agency. The project specifications should also note that delays in the permit revision process will not be cause for adjustment to the contract schedule.

In order for teams to establish an accurate price, they will need to complete a significant portion of the preliminary design during the procurement process. It is not uncommon for DB teams to develop plans to the 60 percent design level so that an accurate estimate of the construction costs can be determined. On complex projects, stipends can be used to help the DB teams offset the cost of developing the designs. Typically, stipends are offered to the teams that are not selected.

There is a limit to what a DB team can produce in short order. Very short bid schedules will result in contractors submitting bids on limited information. This places a large amount of risk on the contractor, which will result in higher bid prices. Longer bid schedules will provide ample time for teams to develop innovative designs, submit RFIs, and develop and submit ATCs.

Procurement of a complex DB project requires several steps. The duration of some of the steps depends on the complexity of the project and the level of information that is given to the DB team. The key to the length of the process is the amount of “design” that the DB team will need to complete in order to submit a bid. Teams need ample time to develop a design and determine the construction process and the materials required. If this timeframe is reduced too much, the quality of the design will decrease and the price will increase. Figure 2.3.1.2-1 is a table of the typical minimum timeframes required to complete most DB project procurements.

Basic Design-Build Procurement Process

Qualifications Request and Submission	30 days
Short List of Teams	15 days
Technical Proposal Submission	45-120 days
Review proposals and Interview Teams	30-45 days
Award Contract	10 days
Total Procurement Time	**130-210 days**

Figure 2.3.1.2-1. Typical Minimum Design-Build Procurement Timeframes.

It is possible to reduce some of the steps noted above; however, some of the steps can take even longer. While process timeframe may seem long, DB projects still typically require less time when compared to DBB projects with their separate design and procurement phases.

2.3.1.3. Construction Time Metrics

ABC can be used to reduce several key construction time metrics. Every accelerated project should have a goal to reduce one or more of these metrics.

Construction time metrics are typically linked to incentive/disincentive (ID) clauses. The types of ID clauses will vary from project to project depending on the roadway type, traffic volume, and maintenance of traffic (MOT) options. The following are typical metrics important to accelerating a project.

Total Contract Time: This is the total time it takes from project initiation (pre-design) to completion in construction. Reductions in total contract time can be achieved by using innovative planning and contracting methods and accelerating construction through the use of PBES. The companion manual to this manual entitled “Project Planning for ABC Projects with PBES” offers ways to incorporate ABC and PBES into the planning process. Another companion manual to this manual entitled “Engineering Design, Fabrication, and Erection of Prefabricated Bridge Elements and Systems” offers more information on the use of PBES to accelerate the actual construction of the bridge. Section 2.4.4 of this manual contains information on contracting methods that can expedite the time to procure a construction project.

The use of ID clauses based on total construction time can help limit the overall impact of the project on the roadway system.

On-Site Construction Time: The period of time from when a contractor alters the project site location until all construction-related activity is removed. This includes, but is not limited to, the removal of MOT items, construction materials, equipment, and personnel.

On-site construction time can be a significant factor in the planning of a project that will minimize road user impacts. On high-volume roadways that are running at capacity, the simple act of placing a piece of construction equipment along the side of the road can lead to significant back-ups. For low-volume roads, this may not be an issue.

A different approach may be required when designing a project to minimize on-site construction time. Methods of construction that use SPMTs or lateral sliding may have an impact on traffic if the staging area is close to the roadway. In these cases, the project team may want to investigate the use of smaller prefabricated elements that are built far from the project site. Once fabrication is complete, the on-site construction can begin and the bridge completed rapidly without a significant on-site presence prior to construction.

An example of this method is the Massachusetts DOT 93 Fast 14 project. There was minimal construction activity on the roadbed of the 14 bridges prior to the replacements. There was significant preparatory work completed below the bridges; however, the I-93 travelers could not see this work and were not impacted. The bridge superstructures were replaced during ten 55-hour weekend closures. Anecdotal information from local travelers indicated that they were not even aware that the construction had commenced after the first bridges were completed. They simply traveled home from work on Friday on the old bridge, and returned on Monday on the new bridge. Additionally, on-site construction time was hardly noticed by weekday travelers.

The success of the 93 Fast 14 project is linked to the innovations incorporated into the design and the ID clause that required all eight lanes of the highway to be opened by each Monday morning rush hour.

Mobility Impact Time: Mobility impact time is any period of time that traffic flow is reduced due to on-site construction activities. This is typically caused by the closure of lanes during construction; however, the closure of shoulders can have an impact on mobility if vehicles become disabled within the work zone.

All forms of ABC have a positive effect on mobility impact time.

Innovative contracting methods such as lane rentals can help to reduce lane closures. Section 2.4.5.5 contains more information on lane rentals.

2.3.1.4. Typical Construction Timeframes for Various ABC Methods

The time required to construct bridges using various ABC technologies can be much less than conventional construction. As contractors become more familiar with ABC methods, the timeframes can become shorter.

The specified on-site construction time that affects mobility impacts can have a dramatic effect on the cost of the project. In general, projects with very short durations can have high construction costs and high risk. In the contracting world, risk equates to cost. Contractors bidding a project with high risk will often bid the project with a higher price to offset the need for more man-power, equipment, and overtime. If disincentives are specified in a contract with very short construction timeframes, the contractor may bid the project assuming that a portion of the disincentive will be levied.

The design team needs to weigh the mobility impact time with the cost for the project. Small adjustments to construction timeframes will have an impact on the construction cost.

The team should also not be too conservative with the estimate of construction timeframes. Longer construction times will lead to contractors requesting approval to change precast concrete elements to cast-in-place (CIP) concrete elements. If this happens on a project, the design team should re-evaluate and reduce the project schedule timeframes for future projects.

Table 2.3.1.4-1 contains construction timeframes for common ABC technologies. These values are approximate and greatly affected by the size of the project, size of elements, element details, site constraints, and traffic constraints. Two timeframes are given for each technology. The minimum timeframe is a reasonable lower bound on construction time. The second timeframe is a recommended timeframe to build a project fast without assigning excessive risk to the contractor.

ABC Technology	Minimum Construction Timeframe	Recommended Construction Timeframe
Bridge Deck Replacement using Precast Full Depth Concrete Deck Panels (1-3 spans including post-tensioning)	2 days (1 span) 3 days (2-3 spans	7-10 days
Bridge deck installation only on new girders using Precast Full Depth Concrete Deck Panels (1-3 spans including post-tensioning)	1.5 days (1 span) 2.5 days (2-3 spans)	4 -7 days
Precast Integral abutment installation assuming good access for excavation and pile/shaft installation	1 day (after installation of piles or drilled shafts)	3-4 days
Precast pier bent installation with precast spread footing assuming good access for excavation	3 days	5-7 days

ABC Technology	Minimum Construction Timeframe	Recommended Construction Timeframe
Precast pier bent installation with CIP concrete footing on piles or drilled shafts.	4 days	7-10 days
Precast cantilever abutment or cantilever retaining installation with precast spread footing assuming good access for excavation	3 days	5-7 days
Precast cantilever abutment or cantilever retaining wall installation with CIP concrete footing on piles or drilled shafts.	4 days	7-10 days
Superstructure replacement using modular deck/beam superstructure elements (1-4 spans)	2.5 days	7-10 days
Superstructure installation only using modular deck/beam superstructure elements (1-4 spans)	2 days	5-7 days
Superstructure replacement with a prefabricated superstructure system installation using SPMTs (1-2 spans)	1 day	2-5 days
Superstructure replacement with a prefabricated superstructure system installation using lateral sliding techniques (1-2 spans)	1 day	2-5 days

Figure 2.3.1.4-1. Approximate Construction Timeframes for Various ABC Technologies.

The information in Table 2.3.1.4-1 is a starting point. The agency should develop a detailed project-specific timeline for critical projects using critical path methods (CPM). The schedule should account for the following factors:

- Traffic management limitations.
- Mobilization and set-up of key equipment.
- Delivery of elements.
- Set-up time for temporary shoring systems.
- Rigging and placement time for each element.
- Placement of grouts and concretes including strength gain and cure times.
- De-mobilization of equipment and removal of shoring.

This type of scheduling would not normally be considered by the design team. If this effort is to be undertaken by the agency, the construction management staff should be involved along with the design team. Another approach is to enlist the services of a construction scheduling specialty firm.

2.3.2. Procurement and Fabrication Lead Times

The design and construction team need to know the realistic time required to procure prefabricated elements. Traditional lead times for materials can be reduced within reason. The following sections contain information on what can be done to expedite the procurement process.

2.3.2.1. How to Research What is Possible

The majority of prefabricated products in use today include precast concrete and prefabricated steel elements. Fortunately, there are several national industry organizations that can be contacted for information on element lead times. Other industries can provide prefabricated products such as FRP bridge decks, aluminum bridge deck panels, and timber deck panels. Information on these materials can be found on the FHWA website at www.fhwa.dot.gov.

The steel bridge industry has two organizations called the National Steel Bridge Alliance (NSBA) of the American Institute of Steel Construction (AISI) and the Short Span Bridge Alliance (SSBA) of the American Iron and Steel Institute (AISI). These two organizations are committed to providing prefabricated elements for ABC projects. They can offer assistance on the best way to procure steel products.

The precast industry is represented by the Prestressed Precast Concrete Institute (PCI) and the American Segmental Bridge Institute (ASBI). These organizations are also committed to providing prefabricated bridge elements. They can offer guidance on concrete element lead times in an area.

2.3.2.2. Shop Drawing Review

One of the most common causes of material procurement delays is the review and approval of shop drawings. Traditional review procedures include the submission of multiple copies of each drawing and review by the design and construction team. The plans are marked up and stamped, and in some cases, the plans require re-submission. It is not unusual for a set of plans to take more than 60 days to go through this process.

Modern electronic software technology and the internet can be used to dramatically reduce the time for shop drawing submission and review. Virtually all shop drawings are created using CADD software. Hand-drawn sheets can also be easily scanned into electronic format. Using these tools, all shop drawings can be produced electronically and shared among the project teams. The most common format for electronic plan submission is Portable Document Format (PDF), which most CADD and scanner software can produce.

Once plans are produced electronically, they can be shared using internet file sharing sites. Electronic file sharing is becoming more commonplace. These sites can be set up to manage the document submission and approval process.

It is possible to review and mark-up PDF files on a computer terminal. Some engineers have issues with review of drawings on computer screens. The latest generation of large, high resolution screens can remedy this issue. Another approach is to have reviewers print smaller format (typically 11x17-inches) plans, review them by hand, and then scan the marked up plans back into electronic format.

There are also legal issues in some states with regard to electronic signatures and approvals. Many agencies have developed electronic approval processes. If electronic approvals are not allowed in a jurisdiction, the electronic process can still be used to review and mark-up plans. Once the plans are acceptable, they can be printed and stamped by hand. This process will still reduce the shop drawing review time for typical projects.

Agencies should specify the required review times in contracts as well as the need for the use of electronic file sharing sites. Agencies should also dedicate resources to conduct timely reviews, either using in-house staff or through consultant support. Reducing review times will not only reduce the total contract time, but it will also reduce the risk to the contractor associated with projects that have ID clauses associated with them.

If the project is DB, the DB team can be given the responsibility for the review of the shop drawings. Once approved by the DB team, the drawings can be submitted to the owner for a cursory review and approval.

2.3.2.3. Fabrication

Prefabrication of elements is a critical step in an ABC project. There are two types of prefabricated products—ones that are fabricated in off-site plants and elements and systems that are fabricated near site. Fabrication of plant produced products needs to be coordinated with the on-site construction activities and schedules. Construction planners should be aware of typical lead times for various elements. "Just-in-time" (JIT) delivery of plant-produced products allows for direct placement from the delivery truck. However, if storage area at the plant is not available, it may be necessary to provide a temporary staging area on-site or near site for prefabricated elements and systems that cannot be stored at the plant and delivered "just-in-time." This approach will require additional handling (and possible additional temporary construction easements) and can increase construction costs.

Fabrication of steel elements has been a source of delays in the recent past. These delays were caused by global economic issues and the needs of the United States Department of Defense. In general, these issues have been resolved; therefore, procurement of steel products has returned to reasonable timeframes. For example, the Massachusetts DOT 93 Fast 14 project required the fabrication of 504 welded plate girder beams in less than four months, with the first beams delivered in less than three months.

One way to expedite fabrication of steel beams is to detail options on the plans so that different fabrication methods can be employed. For example, one might think that rolled products can be fabricated more quickly than welded products. This is true; however, rolling schedules of wide flange beams may not coincide with the project schedule. In this case a fabricator may choose to use an equivalent welded steel section in lieu of the rolled section. Offering this option on the contract drawings will give the fabricator the greatest flexibility, which will result in faster lead times.

Another way to reduce fabrication lead times for welded steel products is to minimize the number of plate thicknesses in a given project. This will reduce the material procurement time from the steel mill. Elimination of shop flange splices and minimization of transverse web stiffeners will also reduce fabrication times. Prismatic sections with minimal web stiffening can also be a cost-effective solution. NSBA and AISI can be helpful in assisting project teams with design decisions that will result in the fastest lead times.

The key to reduced precast concrete element cost and lead times is simplicity of details and repetition of shapes. Internal reinforcements can be customized easily, but complicated custom forming can lead to longer lead times. Some states and regional precast groups have standardized elements and details in an effort to minimize the number of “custom” precast elements. It is important to note that even custom elements can be fabricated in a reasonable amount of time by using wood forms versus steel forms.

2.3.2.4. Shipping

Section 2.1.1 describes different shipping and handling needs for prefabricated elements. The handling of over-sized and heavy elements may need specialized equipment and hauling permits. When planning a construction project, ample time should be allotted for the delivery of large prefabricated products. There are several issues that can cause delays in delivery.

The first issue is the availability of special hauling equipment. Extended trailers and steerable dolly trailers are common, but delays can occur if a larger number of elements need to be delivered in a short amount of time. Contractors prefer to deliver and store the elements on the trailers as opposed to off-loading the elements in a storage yard. The cost of handling an element increases every time it is moved. This requires cranes and rigging that need to be mobilized. If specialized equipment is anticipated, the construction schedule should be set to allow for ample delivery vehicles.

Delivery by rail or barge is also an option on some sites. If rail delivery is anticipated, the contactor should have an adequate location to either store the elements on rail cars, or to offload the elements onto trailers. Barge delivery also requires extensive coordination since moorings for barges can be limited.

Another potential time delay can be caused by the requirements for hauling by roadway. The design team on a DBB project does not know the haul route for elements; however, it can be assumed that hauling through multiple roadway jurisdictions is possible on most projects. Each roadway agency will typically have different hauling permit requirements. In some cases, these requirements can be in conflict. For instance, one agency may require hauling only during the daytime, while an adjoining agency may require hauling only at night. One agency may require escort vehicles, while another may require police escorts. The project specifications should allow ample time for the contractor to procure the hauling permits and to coordinate this effort with the various agencies.

Hauling by rail and by barge can have similar issues with regard to coordination. As with roadway hauling, sufficient time should be allotted for the contractor to coordinate with the various companies and agencies.

2.3.3. Establishing the Construction Sequence

Building a prefabricated bridge has been likened to building a purchased item like a grill. There is logical sequence of assembling the finished product. The sequence of construction of a prefabricated bridge is similar, except it can have the added complexity of traffic maintenance.

All projects should have a construction sequence plan in place that lists the planned sequence of events required to construct the bridge. The sequence can be broken down into stages, and can include activities which occur offsite and do not impact traffic. Including offsite activities helps the owner and subcontractors understand how all the activities relate and how delays in an activity can delay the project. Often, a separate detailed construction sequence or schedule is prepared for the critical periods when traffic impacts are highest. Typical items in the construction sequence include:

- Contract award date.
- Prepare and submit fabrication drawings.
- Approve fabrication drawings.
- Begin fabrication.
- Cure precast elements.
- Construct any foundations and complete any grading or CIP work required to assemble the precast elements.
- Construct crane pads.
- Mobilize cranes.
- Ship precast elements.
- Off-peak, short duration, lane, or shoulder closures used to stockpile precast elements and/or stage the area can accelerate the final construction.
- Set up MOT and close road.
- Follow the detailed erection sequence.

The detailed erection sequence should specifically identify all the required activities and the anticipated time frames. Typical items include:

- Duration and method of demolition.
- Exact crane locations.
- Defined elements to be placed from a single location.
- Every activity in detail that must occur during construction.
- The more detail provided at this stage helps everyone understand their role and can identify potential problems or areas where improvements can be made.
- Identification of contingency plans may not be required but can be a powerful tool to minimize any disruptions due to unexpected events.

2.3.3.1. Relate to MOT Plans

One of the benefits of ABC is the reduced impact on the traveling public. Thus, it is important to ensure that all activities in the sequence of work be coordinated with the MOT plan. To do so, three phases of MOT planning must be developed:

1. Pre-move traffic control: This phase focuses primarily on the possible impacts on traffic caused by the need to relocate or protect utilities along the travel path as well as the removal of obstructions and constraints to the bridge move. Conventional MOT planning is employed as these activities involve conventional construction processes.

2. Bridge move route closures: Once the major components of the old and new bridges are going to be moved, route closures, detours, and diversions must be planned to clear the travel path for the movement of these large structures. Public information planning is essential to ensure that the traveling public fully understands the impact of the closures. Additionally, special planning may be advisable to control the flow of spectator traffic to view the process.

3. Post-move traffic control: This phase involves restoring the normal flow of traffic while providing a safe work environment for the removal of temporary facilities and the repair or restoration of the road over which the heavy moves were made.

2.3.3.2. Soil Erosion and Sediment Control Restrictions

One of the important early project schedule activities is to evaluate the potential for sediment and soil erosion issues as a result of the ABC construction sequence. Local statutes and any permits will furnish the constraints that must be met in the sequence of work. Activities to construct temporary foundations, utility relocations, and other required excavations need to be planned with the appropriate prevention and remediation measures in mind. A subsequent plan is required to remove these preventive measures and restore the construction site to the contractual final condition.

2.3.3.3. Waterway/Environmental Restrictions

Conducting ABC operations over wet gaps such as rivers or streams adds another layer of planning to ensure that riparian environmental regulations are not inadvertently violated. For example, activities such as pile driving may have to be scheduled around fish spawning seasons. Additionally, contingency plans for flash flooding in areas prone to that event are also recommended. In navigable waterways, coordination with both the U.S. Army Corps of Engineers and the U.S. Coast Guard may be required to implement traffic control plans for both commercial and recreational boat traffic.

Some flexibility should be considered here for slight changes which the contractor may identify as more efficient. Agencies considering ABC will need to review potential detailed commitments made in early public meetings and the NEPA process to ensure they won’t create a detriment of the overall project. Additionally, ABC-specific subsurface investigation activities, such as taking cores to ensure that the pavement can handle the weight of the SPMTs or heavier type equipment needed for lifting bridge elements, will need to be included in early environmental clearance documents.

2.3.3.4. Other Restrictions

Lastly, considerations must be undertaken to ensure that local communities are not adversely impacted by ABC operations. In urban areas, this includes coordinating with local businesses in the project area as far in advance as possible to permit them to schedule freight delivery on the routes needed to complete the ABC project without interfering with either the construction or the businesses' need to bring in the stock necessary for their livelihood. ABC project schedulers should familiarize themselves with the dates for local events such as parades, festivals, and sporting events, and evaluate potential conflicts with the project's construction schedule. If a conflict is unavoidable, special MOT plans will need to be made to service both the project and the local event in a safe and effective manner. Incentives may be included to induce the contractor to avoid working on important local dates, or the solicitation.

2.3.4. Setting the Contract Terms

To achieve the benefit of a reduced construction schedule, the contract construction completion date must be established using a rational evaluation of the duration of ABC activities from contract award to ribbon cutting. Most agencies utilize some form of critical path method (CPM) scheduling, which is based on an activity-oriented scheduling algorithm. Sophisticated construction contractors plan their schedules using a production-based scheduling method, such as linear scheduling, to establish the critical path and then convert it to a CPM format to complete the detailed construction schedule. The main strength of a production-based schedule is that it ensures that major activities that drive the overall duration of a project are not inadvertently over-ridden by less important activity in the network's sequence of work logic.

2.3.4.1. Total Contract Term

To better understand the overall period required to complete an ABC project, the agency does not need a detailed construction schedule, but rather a schedule that rolls up groups of activities as work packages. PBES activities may be set inside a large schedule, so milestone hammocks may be needed to isolate these activities and to provide the expected level of benefit from PBES. As noted in other sections, the timing of the PBES events inside the master schedule need to have sufficient lead time to coordinate the required activities and submittals and to ensure all preparations have been made. The total contract term must allow for all fabrication, actual construction, and closeout. An effective strategy is to separate time before impacts occur, on-site construction time, actual time during traffic impacts, and closeout time.

2.3.4.2. On-Site Construction Time

Realizing the planned on-site construction period is the key to on-time project completion. As mentioned previously, this is a production-based consideration and will be highly dependent on a given contractor's means and methods. Hence, ABC projects delivered with either CM/GC or DB project delivery methods will have the benefit of direct input from the actual contractor after award. As a result, the agency will want to incorporate sufficient flexibility in pre-award planning and scheduling to permit the actual contractor to fine-tune the period after award. If the actual on-site construction time is an essential project success factor, then agencies should seriously consider using CM/GC delivery to be able to bring the bridge contractor into the process at the earliest possible date. If this is not possible, the agency should consider including ATCs in either the DBB or DB procurement to provide a mechanism for contractor input on the contract schedule before award.

At the same time, owners should be cautious in limiting on-site construction time. Many on-site activities can occur with minimal impact or disruption to traffic. An aggressive on-site schedule may make it more difficult to meet the critical road closure period since preparation tasks may overlap into the full closure period. Moderate limitations on on-site construction time are valuable to limit owner oversight costs, improve public perception of speed of construction, and minimize potential delays.

2.3.4.3. Road Closure Period

Developing an authorized road closure period is also an exercise in production-based scheduling. In many cases, it could be a fixed period that extends across a weekend and is expressed in terms of hours rather than days. To establish a realistic period, the agency may consider seeking input from a knowledgeable ABC contractor to validate the proposed period by conducting a constructability review of the proposed bridge movement plan and design. To gain access to this type of information, the agency may need to award the contractor a professional services consulting contract.

Owners should be as aggressive as possible in setting complete and partial closure limits. Loose closure times mute the effect of ABC and usually do not reduce owner costs. Partial closures can slow the overall construction time but may alleviate concerns on detour routes. On many projects where partial closures are not an option, a partial closure just before and after the full closure can minimize the full closure requirements. A partial closure option may allow the contractor to set up equipment or begin demolition without impacting traffic to the extent that a full closure does. It may also allow the contractor to do some dry run activities or get the process of lifting and setting elements finalized before any real impacts to traffic are required.

2.3.4.4. Incentive Date

Selecting a completion date for an incentive-based contract requires the agency to be able to justify both the amount of the incentive and the timing for its enactment. In theory, the amount of incentive should be related to the user delay costs saved by opening the project earlier than the contract completion date. Most State DOTs have an algorithm for computing user costs for use in conjunction with A+B contracts, and in most cases these serve as a good starting point from which to compute a reasonable daily incentive rate.

Selecting the timing of the "complete no later than" date should also be a rational process and the agency must validate that there is a tangible benefit to the public if the project completes before that date. One example of a possible date would be the start of a new school year in the local area where minimizing disruption to traffic would seem to be logical. Another possibility is a national holiday like Memorial Day or Labor Day where traffic is expected to spike due to holiday travel. A final example would be a major local event like a state fair where maximizing capacity will reduce congestion and decrease accidents.

2.3.5. Putting the Schedule Together

Developing the final construction schedule for an ABC project requires that the agency de-conflict all the activities on the project with one another. Often, it requires adjusting the logic to ensure that critical resource levels are not exceeded. It also requires input from all the project stakeholders. One effective method to generate the final schedule is to hold a scheduling conference where the owner, the designer, and the contractor all contribute items to the conference agenda and jointly develop the final sequence of work, agree on reasonable activity durations and commit to providing the requisite levels of resources to achieve the minimum required production rates necessary to complete the project on schedule.

2.3.5.1. Accounting for Items Above

The final schedule should act as a model for being able to build the project in virtual space before having to actually start construction. All the various components and outside influences are incorporated in the construction schedule, making it the project execution blueprint. To be effective, the personnel from all stakeholders who must execute their individual activities must be completely knowledgeable on the assumptions that were made to develop the final schedule.

It is also good practice to ensure that those personnel fully understand the consequences to subsequent tasks if their assigned work does not complete on schedule. One way to accomplish this is to use two- to four-week look-ahead schedules during weekly project progress meetings. These tools are valuable aids to adapting the as-planned sequence of work to the as-built sequence of work. They also provide a mechanism to identify potential issues and resolve them before they become problems.

2.3.5.2. Account for Construction Seasons

Highway construction is always weather-sensitive. Restrictions on ambient air temperatures drive the actual periods in which temperature-sensitive tasks like pouring concrete or asphalt paving can be conducted. Once a sequence of work is established, the schedulers need to review the calendar and identify those periods where seasonal climatic variations may have an adverse impact on timely project completion. If possible, activities that are weather-sensitive like earthwork or paving should be scheduled to occur during those times of the year when local climatological history shows the lowest probability of weather-related delay. If it is impossible to complete those activities before the weather becomes dicey, then consideration of extending the length of the daily shift and the work week is advised to reduce the potential for weather-related disruption of project progress.

2.3.5.3. Fiscal Issues

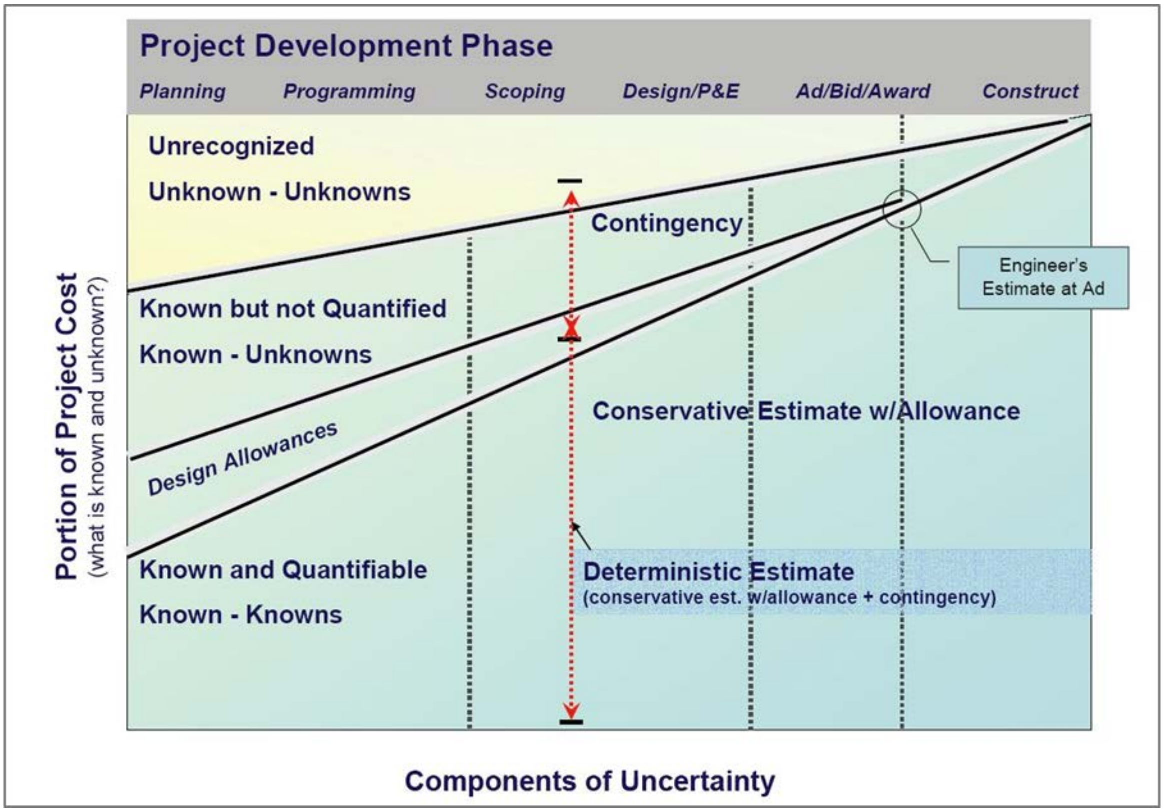
While normally not a sizeable problem, the agency should compute the cash flow requirements to achieve the final schedule and ensure that sufficient funding is available to support the as-planned rate of progress. If this is impossible, then the contract will need to be advertised using a "contingent upon availability of funds" disclaimer. This is particularly important for federal-aid highway projects. The U.S. federal fiscal year begins on October 1 and ends on September 30 each year. In recent history, the U.S. Congress has not reliably authorized the requisite funding for each fiscal year before it starts. Thus, the nation's federal-aid projects are directly impacted by continuing resolution and/or stop-gap federal funding. Thus, checking the schedule against the federal fiscal year to ensure the necessary revenue stream to fund the construction is very important to achieving accelerated highway construction.

2.3.5.4. Account for Advertising and Award Period

The last scheduling issue deals with the procurement period. ABC project schedulers must ensure that there is sufficient time to satisfy State and Federal open competition mandates as well as sufficient time to evaluate bids and award the contract. The fiscal year issue mentioned in section 2.3.5.3 also applies in this context. Since both State and Federal funding are authorized to be expended in specific fiscal years, the schedule must not only ensure time to advertise the project but also ensure that the contracts are all awarded before the end of the fiscal year in which the funding will expire. The schedule should allow time for production, review, and approval of shop drawings, prefabrication, shipping, and on-site preparatory work.

2.4. ENGINEERS CONSTRUCTION COST ESTIMATE

The decision to employ ABC methods often includes the study of cost implications. Often, project managers have used bid prices to compare the costs of ABC with conventional construction. To date, the bid price of many ABC projects has been higher than equivalent non-ABC projects. However, the use of bid prices alone may not reflect the true costs of relatively new but increasingly adopted technologies such as ABC. Moreover, the comparison of bid prices takes only the costs of direct bid items into account but fails to include the benefits associated with time savings through reductions in overall construction time. This section will cover the various aspects of project estimating that can be used in preparing more accurate cost estimates for ABC projects.



2.4.1. How to Estimate ABC Construction Contract Cost

Cost estimating is the critical component of the project development process. The estimating process begins with the identification of a need, development of a simple, less accurate conceptual estimate at the preliminary stage, and refinement into a more accurate, detailed estimate as the project development advances to the plans, specifications, and estimate (PS&E) stage.

At any stage in the project development process, a cost estimate should account for three types of project information:

- Known and quantifiable costs (known/unknowns).
- Known but not quantified costs (known/unknowns).
- Unrecognized, unforeseeable costs (known/unknowns).

Figure 2.4.1-1 is a chart showing the relationship between project costs and the level of uncertainty that are present at different times in the project development process. As the project moves through the development process, more information is available to the agency, which results in a more accurate cost estimate.

The total cost estimate set aside for a project includes both base costs and contingency to include the above mentioned costs.

Cost estimation is unique for each project; preparation involves the detailed consideration of project scope, all activities involved, design details and assumptions, schedule and unforeseen external factors such as varying site conditions, and market conditions. For ABC projects in particular, the estimated costs are needed to be optimized with schedule and technical aspects as well.

Estimators typically rely on two methods to prepare cost estimates:

- Historical bid-based estimating.
- Cost-based estimating.

Historical bid-based estimating is a method of developing estimates using historic bid prices from recently awarded contracts. Historical bid prices for unit costs of standard work items are typically stored in a repository for three to five years. Based on the availability, data is organized by project type, size, and location to provide better estimates. Historic unit prices are then adjusted for specific project conditions based on the project location, size of the project, project risks, quantities, general market conditions, and other factors.

In agencies with established ABC programs, sufficient data may exist to obtain reasonable cost estimates using historical bid estimating. However, in many areas there is a lack of historical data. Since ABC projects often employ specialized construction means and methods, the estimator must be careful about using historic unit prices without verifying each pay item price's applicability to the ABC project.

Cost-based estimating is a method of estimating using production rates and costs for work items/tasks necessary to complete the work. The cost items consist of six basic elements: time, equipment, labor, material, overhead and profit. This method involves estimating the cost of each component required to complete the work together with a contractor's profit and overhead. This approach takes into account the unique aspects of a project, schedule requirements, geographical location, market factors, and volatility of material prices.

Price volatility of materials/fuels may have a confounding effect on accuracy of cost estimation and owner budgets. Index pricing of key commodities, such as steel, cement, liquid asphalt, and fuel can be used to manage the negative effects of inflationary trends. Most agencies use construction cost indices to track changes in the prices of key commodities over time. Oregon DOT uses macroeconomic-based statistical models to forecast construction costs for four primary commodities used in road and bridge construction for fuel, materials, equipment, and labor. These models utilize Bureau of Labor Statistics indices such as Producer Price Index and Consumer Price Index for forecasting. The forecasting models are updated every six months.

Even with the best estimating tools, it is difficult to estimate the total cost of a project with an extended schedule. ABC can be used to reduce the uncertainties by reducing the overall construction timeframe. This reduces the uncertainty of the bid estimation and the risk associated with the bid. Both of these can potentially lead to lower bid prices.

Lump sum items are also used when an item of work can be easily defined but its quantity or components cannot be easily determined. Historically, lump sum amounts are used for pay items such as mobilization, traffic control/maintenance of traffic, clearing and grubbing, demolition, etc. Most lump sum items are very different from one project to another. Traditionally, these items are estimated on a percent of total construction cost basis. ABC projects are somewhat different than conventional construction when these items are considered. The following are factors that may affect lump sum bid items for ABC projects:

- More prefabrication will require up-front costs for executing early sub-contracts with fabricators.
- More and specialized equipment will lead to higher mobilization costs.
- Traffic management will be different than conventional construction. In most cases traffic management cost will be reduced due to shorter construction timeframes. Elimination of staged construction will also affect this item.
- Demolition costs can be reduced due to the efficiencies of productivity; however, the cost may increase due to the need to work overtime.

Agencies can adjust traditional lump sum bid percentages by investigating the impacts of the project on the items. The use of time, equipment, and material estimating can be helpful in developing a more accurate model of the actual costs. Agencies can use specialized estimating consultants that have experience in construction estimating from the contractor's side. This insight is critical to developing an accurate estimate for lump sum items.

2.4.1.1. Unit Pricing: Items That Lack Historical Data

Most agencies use historical bid prices for unit pricing of work items. Unit prices are typically established based on statistical averages of lowest, lower, few, or all bids of a given work item. Historical bid-based estimates are more suitable for routine work items such as asphalt concrete pavement, embankment, structural concrete, etc. However, for major work items of ABC, sufficient historical data is often not available to provide reliable estimates.

Even for routine construction projects, the historical bid-based unit prices must be validated for rationality, and adjusted if needed, based on project type, work involved, specific contract provisions, and prevailing market conditions. Various factors used in adjusting the unit prices include:

- Project site conditions.
- Permissible work hours (nights, weekends, etc.) that affect wage rates and production.
- Sequence of construction.
- Difficult work zones (stages or phased construction).
- Seasonal limitations.
- Regional conditions.
- Current market conditions.

- Quantity/price relationships.
- Inflation and risks involved in the project.

While the price adjustments can be done for newer work items or products associated with ABC, the rationale behind these adjustments may not be strong enough to provide reliable estimates, typically due to lack of experience with these items.

2.4.1.2. Cost-Based Estimating

Typically a small subset of work items accounts for a significant portion of the total costs (otherwise known as the Pareto Principle). The principle is based on the fact that on typical projects, 80 percent of the cost is associated with 20 percent of the items. Figure 2.4.1.2-1 shows a Pareto chart for a typical bridge cost estimate. Estimators should focus on the estimating accuracy of these major work items, which will lead to better accuracy in the overall cost estimate.

These major work items can typically be estimated based on determining the contractor's cost for materials, direct and overhead labor, equipment, hauling, subcontractor effort, and a reasonable amount of contractor profit and contingencies. The estimator can avail the in-house records of actual production rates and time from actual work performed on similar projects. However, for ABC projects, the owner has little or no historical data to aid in establishing cost-based estimates. Moreover, to establish cost-based estimates, the estimators must have a thorough understanding, working knowledge, and experience in ABC methodologies, including production rates, equipment, labor, mobilization, and scheduling. Often, the owner may have little or no experience with ABC to seek the advice of in-house experts.

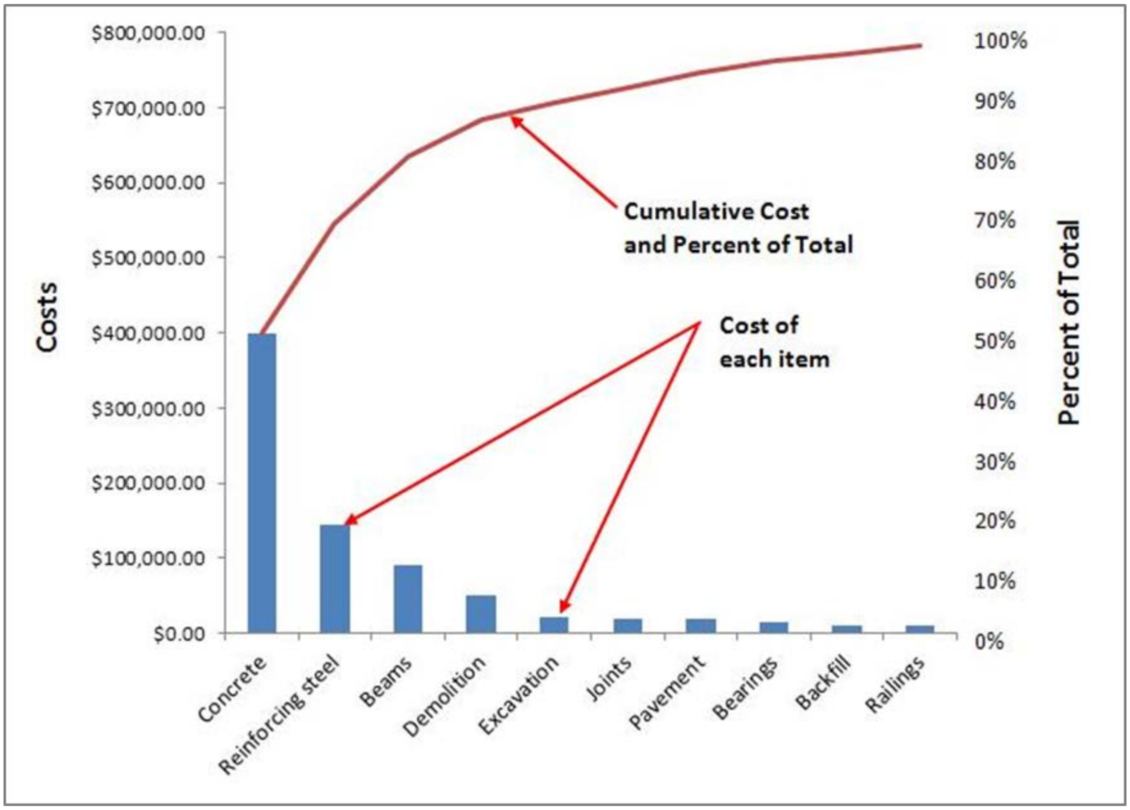


Figure 2.4.1.2-1. Pareto Chart for Typical Bridge Construction Item Costs.

Most agencies estimate these items by calling suppliers, specialized consultants, other highway agencies with ABC experience, industry associations, and contractors and asking for installed cost information. The cost inputs received from outside entities are then adjusted based on project location and current market conditions and validated for reasonableness.

In the event of obtaining information from suppliers or contractors, it is necessary not to rely on inputs from a single source, but rather seek inputs from multiple sources. Note that the procurement laws in some states may prohibit highway agencies directly contacting contractors about a specific job due to concerns about unfair bidding advantage among bidders.

When the owner is statutorily prohibited from contacting outside sources for pricing, the agency may consider delivering the project using CM/GC since this project delivery method can give the owner direct access to real-time pricing from an experienced ABC contractor during preconstruction. The Utah DOT, for example, used CM/GC on ABC projects in part for this reason.

Another way to solicit input is to hold an industry meeting for a specific project. This meeting can be organized through local contracting organizations. Specialty contractors can also be invited. The goal of the meeting would be to solicit input. The one problem with this approach is that contractors are hesitant to offer specific information in front of their competition. Participants should be encouraged to submit confidential information to the agency after the meetings. Confidential one-on-one meetings can also be used. The key is to open the process to all industry partners that show interest in the project or process.

All estimates prepared using external inputs must be carefully structured and reviewed to make sure no contract-related conflicts of interest arise.

There is a small amount of historical data for large-scale bridge moves. The Utah DOT uses unit costs for tracking the costs associated with the use of heavy equipment to move bridge systems (SPMTs and lateral sliding). The Utah DOT bid tabs for the item “move prefabricated bridge” varied from $125,000 to $500,000 in 2012. Their bid item encompasses all extras for the bridge move including engineering, temp supports, temp walls, excavation, etc. Bids for lateral sliding alone can range from approximately $40,000 for a small project to over $250,000 for complex projects. Every project is different and costs will vary depending on the complexity and site conditions. For instance, the Utah DOT projects all required deep foundations for the temporary supports.

The costs for large-scale bridge moves are decreasing. There is more competition in the market and contractors are becoming more familiar with the process and the risks associated with the work as more projects are built. Still, agencies should expect higher costs for initial projects until the contracting community gains more experience.

2.4.1.3. Specialized Sub-Contractors

In some instances, the prime contractor may procure the services of subcontractors who are specialized in ABC solutions. The estimator should include additional costs such as the prime contractor’s retainage fee and costs of financing to account for delayed payments and related cash flow issues. The estimator can call subcontractors to obtain reliable estimates, but should be aware of the procurement rules governing such contacts within the estimator’s jurisdiction.

2.4.1.4. Contingencies

Contingency is an estimate of costs associated with identified uncertainties and risks, the sum of which is added to the base estimate to complete the project cost estimate [7]. The contingency amount may vary depending on the phase of project. Contingency is inherently higher at the early stages of the project due to low scope definition, unknowns, and uncertainties. With refining project definition, as the refined elements are shifted from contingency to base cost category, the contingency decreases on a sliding scale in the later stages of project development.

Most DOTs have statutory constraints on the amount of contingency they can include in a project’s construction cost estimate regardless of the type of project. Therefore, it is important that agency personnel make every effort to accurately quantify the scope of work in its quantity survey and not rely on the contingency to cover those items that may have been missed. Owner’s contingency fund is primary for owner-requested items including scope creep, changes in scope, material price escalation, multiple contract coordination, project schedule, differing site conditions, additional environmental mitigation, etc. This fund does not cover the contractor's contingency to pay for issues relating to cash flow, quality, schedule, permits, insurance, subcontractor faults, material shortages and price increase, and labor availability. The contractor contingency is generally built into the bid in addition to direct expenses, overhead, and profit.

Typically, contingency is applied in terms of a predetermined percentage to the base amount either uniformly across all projects (say, 10 percent to all projects), or based on agency guidance or past experience based on specific project conditions, type, and project development stage. However, neither of these methods takes a proactive approach in managing project-specific risks and uncertainties identified based on rigorous assessment of project scope and conditions. Risk analysis is particularly imperative for novel approaches, such as ABC, to identify risks and uncertainties associated with the implementation of any newer technology.

Cost estimates should reflect the true nature of the risks of all stakeholders. In addition to owner's contingencies, the cost estimate should also incorporate contractor contingency for construction as well. Note that the designer contingency is first built into the cost estimate of the process but gets absorbed at different line items in the budget as project development progresses. For ABC projects, the estimating procedures must not only evaluate technical and nontechnical challenges in setting contingency, but also consider the experiences of both owner and contractor as well. The construction contingency is expected to be higher than normal due to increased risks and uncertainties. With sufficient experience and lessons learned, the contingency factor is expected to decrease to normal levels or even go lower than conventional construction if overall risk is reduced (fewer weather impacts, safer work zones, fewer worker injuries, etc.).

CM/GC project delivery uses an open-books project pricing structure where the owner and the CM/GC contractor jointly develop, assign, and retire contingencies during the preconstruction process. This furnishes a much higher degree of rationale than simply adding a fixed percentage to the bottom line and permits the owner to revisit design decisions that drive construction costs before the design is finalized. In some CM/GC projects, the agency locks in unit prices for major pay-items in the proposal phase, while allowing standard adjustment factors for price or quantity change. This may involve the estimation of approximate quantities of these pay-items in the preliminary engineering phase.

2.4.1.5. Risk Analysis

Complex projects, such as ABC, require special consideration of project risks in order to produce accurate contingencies and effectively control cost and schedule performance. As all knowns and unknowns of a project are reduced into costs as base estimate and contingency respectively, the risk elements should be identified, quantified, and managed through an effective risk analysis process. Experience has shown that inadequate risk analysis can be one of the root causes of poor project performance [8]. In other words,

each risk is associated with a dollar value, and failure to identify or properly manage risk may result in inaccurate cost estimating and cost escalation.
Risk analysis involves the following key steps [7]:

- Identify risks as opportunities and threats.
- Evaluate the probability of risk occurrence.
- Estimate the consequence of risk on cost and schedule performance.
- Incorporate the impact of opportunities and threats into the final cost estimate.
- Conduct a sensitivity analysis to identify the most critical risks.
- Develop risk mitigation or management plan.

Identification of risks involves a rigorous assessment of project-related factors including scope, elements, assumptions and conditions, and external factors, to identify potential opportunities (i.e. beneficial factors or events) and threats (i.e. adverse factors or events). The likelihood of risk occurrence and their impacts on cost and schedule are modeled using a risk-based probabilistic analysis. Quantitative risk analysis models, ranging between simple what-if analyses, spreadsheet estimates, Monte Carlo simulation, and sophisticated stochastic models, can be employed for this purpose.

The risks associated with ABC projects are similar to projects built with conventional methods. The variation is with the level of the risks and the potential impacts. ABC projects built with prefabricated elements place higher emphasis on fabrication, delivery, and erection of elements. Prefabrication of elements is not new in the industry; however, the level of prefabrication and the size of the elements bring on a new level of potential risks. Potential risks associated with prefabrication might include:

- Delay in fabrication schedule.
- Errors in fabrication (tolerances, mistakes, etc.).
- Delivery vehicle accidents.
- Erection accidents.
- Breakdown of erection equipment.
- Improper fit-up of prefabricated elements.

These risks exist with any prefabricated element such as beams; therefore, agencies and contractors are experienced with the handling of these risks. Other potential risks associated with conventional construction still exist on ABC projects, including environmental impacts, right-of-way problems, geotechnical unknowns and third-party issues such as utilities.

Any risks that have project schedule implications are also raised to a heightened level on ABC projects. Simple risks such as shop drawing review times can have dramatic impacts on the entire construction process. Contractors and agencies often do not have time to implement risk management mitigation strategies without impacting the project schedule. This, coupled with disincentive clauses, can make the management of these risks more difficult and expensive.

The outcomes of this analysis of both opportunities and threats are duly incorporated in developing the final cost estimates. Tools such as sensitivity analysis can be helpful in identifying the most critical risks. A risk response or management plan is devised to mitigate the negative effects of threats and enhance the benefits of opportunities. Risk analysis can also be used in bid analysis to screen for unbalanced bids.

The FHWA Guide to Risk Assessment and Allocation for Highway Construction Management [9] is a useful guide to management of risk on projects.

Washington State DOT (WSDOT) has also developed a process called Cost Estimating Validation Process (CEVP) [6]. Similar to a value engineering process, CEVP involves rigorous, due-diligence peer review of the project estimate and systematic risk modeling to more accurately define contingencies and allowances as distributions of cost and schedule. CEVP is performed by a multidisciplinary team of professionals from public and private sectors. WSDOT requires CEVP for projects over $100 million and a similar less-intensive process for projects between $10 and $100 million. This process is simple, less expensive, and does not require risk analysis experts. The CEVP has helped WSDOT to better understand uncertainties, quantify them as contingencies and allowances, and effectively manage them.

2.4.2. How to Estimate Other Project Costs

2.4.2.1. Contract Administration and Inspection (CA&I)

This includes the owner's indirect cost for construction engineering, inspection, and administrative oversight during construction. Typically, this cost is combined with preliminary engineering costs and marked up as a percentage of total contract value. The indirect costs will vary by type of work and total amount of the contract, which typically range from 10 to 20 percent of the total costs. With ABC, the construction administration costs may decrease substantially with time savings, manufacturing of products in a controlled environment, and supplier self-performance.

Some engineers have stated that construction inspection costs for ABC projects are simply shifted from the site to the fabrication plant. It is true that some shifting of work occurs; however, the efficiencies of a production facility also result in the efficiencies of inspection personnel. It is not uncommon for a project site to be dormant for periods of time. During these times, inspection staffs are often idled while waiting for construction to re-commence. In a plant environment, multiple projects can be in production at one time, thereby reducing the potential for "down time" of inspection staff. This enables staff to inspect more projects simultaneously.

Owners should incorporate the project time metrics into the cost estimate for CA&I and base the estimate on the level of effort required, rather than on a percentage of construction costs. These estimates should account for overall construction time and on-site construction time. The reduced costs for these indirect costs can then be used in the decision making process and for establishing construction project budgets.

2.4.2.2. Setting Incentive Values

Owners are interested in expediting construction to manage the overall impacts of construction delays and work zones. The public cost of delays and disruptions caused by work zone activities are monetized as road user costs. The benefits of expediting construction time are obvious: it minimizes inconvenience and disruption of the traveling public, improves the safety performance of both construction crew and traffic, minimizes the adverse economic impacts on local businesses, provides savings in direct agency costs, and minimizes the social costs of traffic delays and additional travel. The use of incentives and disincentives should be tied to these benefits. A source of information on incentives is the FHWA Technical Advisory 5080.10 entitled "Incentive/Disincentive (I/D) for Early Completion" [10].

Owner agencies have used liquidated damages clauses in traditional DBB projects to enforce construction completion on time. Liquidated damages are imposed to recover the additional construction oversight costs incurred by the owners if the contractor fails to complete the construction on time.

With increasing pressures to complete construction on time, owner agencies have turned to non-traditional, schedule-focused contracting methods for use in conjunction with liquidated damages. These methods utilize an I/D structure as means to motivate contractors to align with the owners' goal of early completion, with no compromise to product quality, before a target date/duration and within a target cost. These methods were evaluated under the FHWA's Special Experiment Projects No. 14 (SEP-14) and have been found effective in shortening the construction completion time.

To be objective and justifiable, I/Ds are determined on a project-by-project basis based on the anticipated work zone impacts caused by construction delay and the associated work zone road user costs and agency construction management costs. Both incentives and disincentives should be adequate enough to motivate the contractor to complete the work on or ahead of schedule. If there is no real incentive to accelerate production or if the owner-specified time for project completion is unreasonable, the use of I/D provisions will not produce the intended results. On the other hand, to justify their use, the I/D should not exceed the additional costs incurred by the owner agency and work zone road user costs.

2.4.3. Bid Items

2.4.3.1. Defining

A cost estimate typically includes direct costs, indirect costs, overhead, and contingency. The direct costs primarily include production costs of the precast panels and their installation. It will also include the costs for temporary construction works at the fabrication and bridge sites, cost for reinforcing or protecting subsurface utilities and structures during bridge moves, and cost for traffic control and road closure detour signage, etc.

The contractor's indirect costs includes shipping costs from the fabricator's yard to job site; mobilization/demobilization; and insurance, surety, and taxes. If the prime contractor performs the precast operation on-site in lieu of purchasing from a precast fabricator, cost reductions can be realized in shipping, precast fabricator overheads, and fees; however, the efficiencies of a fabrication facility is often lost.

The overhead includes fabricator's supervision and general and administrative (G&A) expenses, while the markup costs cover profit and contingency. If there is a subcontractor involved, the subcontractor's overhead and profit is also added. Both overhead and markup costs are typically market priced depending on factors such as competition, bidding conditions, and project complexity.

Bid items for ABC projects vary from agency to agency. Some agencies bid bridge items based on unit costs, while others use lump sum costs for entire bridges. The problem with lump sum bidding is that the cost of the ABC items is not available for future estimating efforts. Unit cost contracting offers a better way of tracking ABC costs. On unit cost contracts, items such as precast concrete elements can be bid using volumetric units. Items such as deck panels can be based on a square foot basis. The use of specialty equipment can be more difficult to quantify. Most agencies to date have either used lump sum contracting for the entire bridge or lump sum cost for the bridge system installation. The unit costs approach is preferred, since it will provide the agency historical data for future system installation projects.

2.4.3.2. Payment Methods

Progress payments are essential to maintain the cash-flow of the contractor. Delayed payments can incur additional expenses for the contractor for financing the project costs and erode their overall profitability. This can adversely affect the project progress and the mutual trust between both parties. A history of delayed payments increase the overall project costs as the contractors must shift the financing costs (i.e. the carrying costs) to the bid. Delayed payments also affect subcontractors, who in turn depend on their prime contractor's payments, thus causing friction among parties and increased sub bid costs for future projects with an owner or general contractor with a poor payment record.

ABC projects require a large capital investment by the contractor early in the project to arrange for the necessary equipment and precast components to be fabricated and delivered to the project to support the construction schedule. As a result, DOTs should evaluate the possibility of accelerating progress payments and implementing nonstandard pay items that permit the agency to make payments as quickly as practical to reduce the amount of carrying costs built into an ABC project. For example, bi-monthly progress payments rather than the usual monthly payments could be considered. Cutting the progress payment in half can theoretically cut the carrying costs added to the ABC project bid in half as the general contractor's need to finance work under construction becomes a two-week cycle rather than a four-week cycle. Additionally, the accelerated payment scheme can actually increase competition and allow emerging companies—whose line of credit would not support a major project with a four-week financing cycle—the opportunity to bid. This can be very helpful given the accelerated nature of the work. These projects can choke some competition if it is a drain on cash flow. Agencies may see more bidders with favorable payment terms.

Similarly, the retainage by owners to ensure satisfactory completion can increase the project costs as the contractor tends to increase the amount of financing costs included in the contractor's bid. There are a number of options that could be considered, such as matching the amount of retainage to the cost the owner would bear if a default occurred. Another is programming the release of retainage as an incentive for satisfactory progress and the absence of significant quality issues. A third is reducing the retained percentage as construction progresses.

2.4.3.3. Third Party Costs

Police: Many state highway agencies use uniformed police officers on highway construction projects. Officers' patrols are funded through various sources, including state highway construction and administration funds, law enforcement appropriation funds, or fines generated from work zone violations. Involving police officers in work zone management requires more lead time to coordinate.

The costs for law enforcement can be significant for construction of bridges in high traffic zones. By reducing the time for on-site construction activities, the costs for police can be greatly reduced. These costs should be factored into the decision making process for ABC.

Utilities: A utility coordinator, either employed by the owner agency or the prime contractor, is required to communicate and coordinate with utility owners on accommodation or relocation of utility lines. The ownership of utilities may range between local bodies, utility companies, or private entities.

Typically, the utility coordinator transmits plans and design documents to the utility owner, gets the transmittal reviewed, coordinates to identify, locate, and resolve potential conflict points, incorporate utility-related changes to plans and design documents, and develop special provisions. The utility coordinator is also responsible for obtaining utility coordination agreements and clearance letters from the utility owners.

In this process, many utility owners may not have adequate staffing to coordinate with contractors or agency staff multiple times. Setting up a master utility meeting for all interested parties would facilitate utility coordination better with Requests for Information (RFI) coordinated through the owner agency. Since utility agreements may take considerable time to get executed and funded, a timeframe for performance agreeable to all parties is recommended.

ABC can be used to reduce utility relocation costs for bridge replacement projects. Utilities are typically relocated from the old bridge to the new bridge through the use of staged construction. Half of the new bridge is built, the utilities are transferred over to the new half, and then the second half of the bridge can be constructed. If the construction of the bridge can be significantly accelerated, it may be possible to shut off some utilities for short durations. For example, natural gas systems in urban areas are typically designed to be redundant, so that construction work at one location will not result in a shut-down of the entire system. It is normally possible to shut down a natural gas main for a short time period during low demand periods such as summer months. By constructing the bridge rapidly using ABC methods, the cost of relocating the utilities off the ends of the bridge can potentially be eliminated.

Railroad Flagging: On federal-aid projects, owner agencies are required to identify any railroad facilities within or near the project limits and determine if construction activities will affect the facility. The owner agencies are required to coordinate with railroad operators.

Many owners are looking to the prime contractor to execute a Right of Entry (ROE) agreement with the railroads and provide separate railroad liability coverage based on a percentage of work down within a certain distance of the track. A clear understanding of the work is needed by the railroad operator and typically an ROE will not be granted until full plans are developed and approved. Track outages and timing need to be incorporated into the design to determine if temporary crossings and access from both sides of the track are feasible.

The owner agency or the prime contractor may need to purchase railroad protection insurance coverage and hire a flagger to help construction run smoothly.

Many railroad agencies require the use of railroad flagging in order to ensure safe operation of the rail system. Flaggers coordinate with railroad operations staff to warn contractors of approaching trains. They also oversee the construction process to ensure that the tracks are not fouled.

Flagging costs are a function of the amount of railroad traffic carried by the lines near the project site. Flagging costs may also depend on the requirements of the railroad companies. ABC and prefabrication can be used to significantly reduce flagging costs by reducing the amount of on-site construction time. On a busy line, the cost of railroad flagging can typically offset any potential cost increase brought on by ABC methods. For example, the Connecticut DOT had estimated flagging costs for a bridge project over a busy rail line to be in excess of $2 million. ABC was chosen to reduce the amount of time and cost for flagging, which offset the additional costs for prefabrication.

2.4.3.4. Pre-Payment of Fabricated Materials

The use of prefabrication can also lead to increased costs for elements that are fabricated, but not yet installed. Some agencies only pay for materials that are in their final position on the bridge. This approach leads to delayed payment for materials that are stored and awaiting shipment. Fabricators are then required to finance the cost of the materials and labor during the period between fabrication and shipment. Some agencies make use of partial payments for fabricated materials, which alleviates this pressure on the fabricators.

The owner agency may consider partial payment for fabricated materials to the prime contractor or vendors, especially for on-site fabrication. Upon making the prepayment, the owner agency would receive a transfer of title, and a certificate of insurance for the items. This is particularly helpful as the owner can retrieve the materials in the event the contractor or vendor goes bankrupt during the project.

Another approach to reducing fabrication costs is to bid separate early release contracts for fabricated elements. The Utah DOT uses CM/GC project delivery to accomplish this on ABC projects by requiring the contractor to bid out an early construction package to secure long-lead materials and to lock in those costs against escalation. This can be helpful for materials that require longer lead times that may not fit within an accelerated project schedule. At face value, this seems like a simple solution; however, there can be drawbacks. Delays in bidding subsequent projects can lead to claims for excessive storage of fabricated materials. Coordination of multiple contracts can also lead to complications and potential claims.

2.4.3.5. Mobilization Costs

Mobilization is a contract pay item established to compensate a contractor's preconstruction expenses and the start-up costs of preparatory work and operations [11]. This effort broadly includes but is not limited to movement of personnel, equipment, supplies, and incidentals to the project site; and the costs of obtaining surety bonds, insurance and permits required prior to beginning work at the project site. The contractor mobilization charges are generally estimated using a standard percentage that varies with project dollar size.

Contractors may require more upfront costs for mobilization in ABC than traditional projects as it involves hauling of precast elements or structures from the prefabrication site to the job site and the need for special equipment for hauling as well as installation. Other factors, including the location of the project, urban or rural area, offsite or on-site prefabrication, owner's payment schedule, construction phasing and staging, and other environmental restrictions may impact the mobilization costs.

Designers should be aware of the potential for higher mobilization costs when projects involve lateral movement of prefabricated bridges. The commonly used pieces of equipment that are used for lateral moves are SPMTs and specialized shoring systems. While these machines and materials are readily available in the U.S., they may not be available locally. Mobilization of this equipment can be costly since the transporters are commonly shipped, not driven to the project site. Designers should try to avoid multiple set-ups that are separated by a significant period of time (more than one to two weeks). Idle time can be costly, especially if the equipment is in high demand. The contractor would either need to de-mobilize and re-mobilize, or pay for idle time of the equipment. Both can lead to higher mobilization costs. The cost of mobilization of heavy equipment is generally included in the unit cost for the work; therefore, historical mobilization data is not available.

2.4.4. Delivery Methods

The project delivery method is the process by which a project is comprehensively designed and constructed for an owner—including project scope definition; organization of designers, constructors, and various consultants; sequencing of design and construction operations; execution of design and construction; and close-out and start-up [12]. The common project delivery systems are Design-Bid-Build (DBB), Design-Build (DB), and Construction Manager/General Contractor (CM/GC). No single project delivery method is appropriate for every project. Each project must be examined individually to determine how it aligns with the attributes of each available delivery method.

DBB has traditionally been used throughout the United States. Use of other delivery methods including DB and CM/GC is growing; however, not all jurisdictions have statutory authority to use DB and/or CM/GC.

An overview of the project delivery selection method is presented herein. The selection of an appropriate project delivery method begins with the review of project description, goals, and constraints [13]. Each project delivery method is rigorously evaluated against a set of selection factors to identify which delivery method is more appropriate for the project. The commonly used selection factors include, but are not limited to:

- Legislative/statutory constraints.
- Delivery schedule.
- Complexity and innovation.
- Level of design at the time of procurement.
- Cost.
- Project-specific factors including right-of-way, environmental clearance, geotechnical, utilities, railroad, HAZMAT, etc.
- Staff experience/availability (owner).
- Level of oversight and control.
- Competition and contractor experience.

A risk assessment should be performed for the desired delivery method to ensure that risks can be properly allocated and managed. The risk assessment involves assessing opportunities and obstacles associated with each of the selection factors. Based on the evaluation of selection factors and risk assessment, an appropriate project delivery method is selected.

2.4.4.1. Design-Bid-Build

DBB is the traditional project delivery method in which an agency designs or retains a designer to furnish complete design services, and then advertises and awards a separate construction contract based on the designer’s completed construction documents. The construction phase of DBB projects is generally awarded on a low-bid basis. In DBB, the agency “owns” the details of design during construction and as a result, is responsible for the cost of any errors or omissions encountered in construction [14]. DBB is viewed as the traditional project delivery method by owners, design consultants, and contractors.

Certain ABC construction methods are feasible with DBB. For instance, construction of bridges with prefabricated elements can be fully detailed in the same manner as prefabricated beams and girders. Specifications for fabrication and installation of the elements can be written to be similar to prefabricated beam and girder elements. The one change that is recommended is the specification requirement for the submission of an assembly plan. An assembly plan is similar to an erection plan, but with more detail. It includes the development of a timeline schedule and assembly procedure. The companion manual to this manual entitled “Engineering, Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems” includes more information on assembly plan specifications.

One issue that is problematic on a prefabricated bridge element project built using a DBB contracting mechanism is related to the size of the elements. The design engineers do not know where the element will be fabricated and how it will be shipped. Also, they do not know the size of the cranes that will be employed. In this scenario, there are two potential ways to detail the bridge in a DBB project:

- Detail the elements reasonably small based on past history of bridge girder installations. This can lead to more elements, increased shipping costs, and longer construction timeframes since more connections will need to be made.

- Detail smaller elements and optional construction joints. In most cases, this can be done without a need to re-design the elements. For instance, the width of a wall panel can be adjusted since the transverse internal reinforcing is distribution reinforcing and not required for load resistance. This approach allows the contractor to tailor the size of the elements to maximize the shipping and handling equipment that will be employed.

The one form of ABC that is more difficult to bid in a DBB environment is large-scale system installation. These projects require specialized equipment and temporary works. There are often multiple ways to lift and move a bridge. For instance, a lateral slide bridge can be moved using hydraulics, cable winches, and even SPMTs. Each of these methods has their advantages and disadvantages. On some SPMT bridge move projects, there are multiple staging areas that are available for SPMT moves, which makes detailing an exact construction method difficult. The design engineer does not know who will be building the bridge and what equipment will be used. On a DBB project of this type, the design engineer needs to make certain assumptions as to how the bridge will be moved, where it will be lifted, and what equipment will be used. This can lead to inefficiencies and the establishment of constraints that limit the flexibility of the contractor to provide the best value. Based on this, many large-scale bridge moves have been built using DB and CM/GC contracting methods.

2.4.4.2. Design-Build

DB is a project delivery method in which the agency procures both design and construction services in the same contract from a single, legal entity referred to as the design-builder [14]. The method typically uses Request for Qualifications (RFQ)/Request for Proposals (RFP) procedures. DB projects can and have been delivered using all three procurement methods: low-bid procurement, qualifications-based procurement, and negotiated GMP contracting. To date, all state DOTs, except Iowa, Nebraska, and Oklahoma, have legislative authority to pursue DB contracting.

Since the owner transfers responsibility for both design and construction, the design-builder has a higher level of control over the projects. The design-builder controls the details of design and is responsible for the cost of any errors or omissions encountered in construction. As a result, the DB has proven to be a highly successful project delivery method in compressing the project delivery schedule and “fast-tracking” projects.

DB and ABC work very well together. The issues described in section 2.4.4.1 are not present in a DB contract. The key is that the contractor can be directly involved in design development. Decisions regarding design details, element sizes, crane sizes and locations, and the use of specialized equipment can be included in the design process. This is especially true for large-scale bridge system installations. Having knowledge of the equipment to be used allows the DB team to tailor the design to match the installation process.

The owner agency still needs to identify certain parameters that will aid in the use of ABC. The agency should identify the time and traffic management constraints for the project prior to the start of the procurement process. These constraints can be used to define the limits of mobility impacts. I/D clauses can also be used to further reduce mobility impacts to travelers.

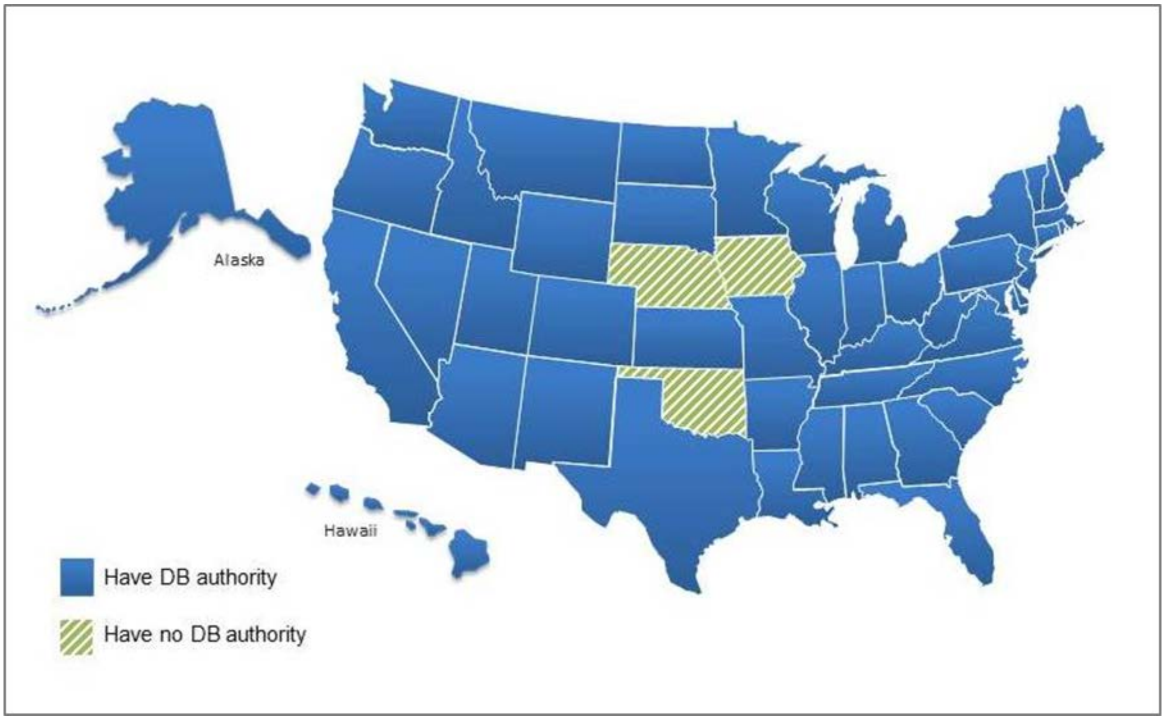


Figure 2.4.4.2-1. Map showing States with Design-Build Legislative Authority.

It is advantageous for the agency to obtain adequate right-of-way and work areas, address utility conflicts, and obtain environmental permits prior to procurement. Handing these issues off to a DB team is possible; however, it can add risk to the team and potentially result in delays during construction while the issues are worked out.

2.4.4.3. CM/GC

CM/GC is a procurement method that draws on the best attributes of DBB and DB. In a typical CM/GC scenario, the agency contracts with a designer in the same fashion as a traditional DBB project. The agency also contracts with a general contractor during the preliminary design phase to serve as the construction manager and to provide the agency with input on constructability, pricing, and scheduling. As the design nears completion, the agency, the designer, and the construction manager estimate the construction costs. If the agency and the contractor are able to agree upon a price for construction, the agency would then establish a construction contract and issue a notice to proceed. The construction manager would then become the general contractor and be given a notice to proceed with construction. To date, at least 15 State DOTs have the legislative authority to pursue CM/GC contracting, while four states may have the legislative authority but have not tested it.

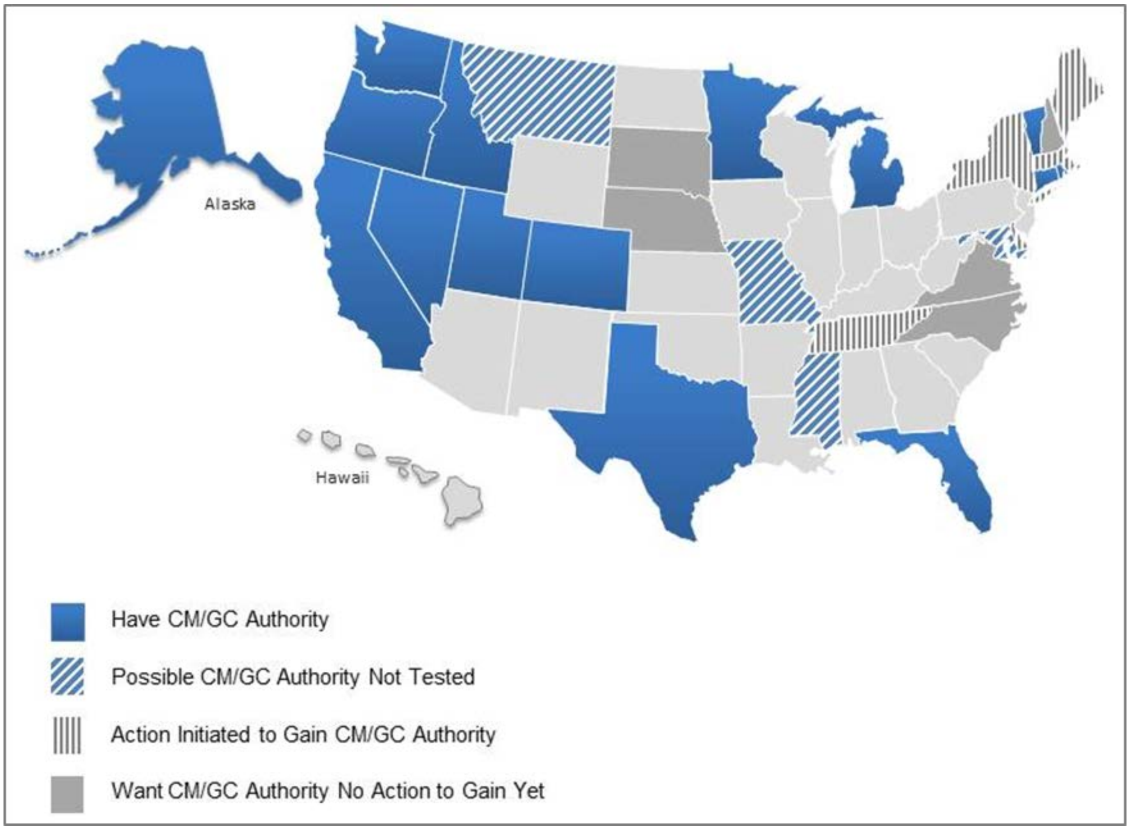


Figure 2.4.4.3-1. Map showing States with CM/GC Legislative Authority (Source: On-going NCHRP Project 10-85, Douglas Gransberg).

This process is somewhat different than in the vertical construction industry where the contractor is more of a manager than a constructor. Vertical construction typically involves many sub-contractors that are managed by the construction manager. On most transportation projects, the general contractor is required to perform a significant amount of the actual construction. This is the primary difference between Construction Manager at Risk (CRAR) and CM/GC. The contractor's role is both the construction manager (CM) and the general contractor (GC).

CM/GC allows both the agency and the CM/GC to play an active role in the design development process. The CM/GC team can analyze the risks associated with the project and assign them to the parties most able to mitigate them. The CM/GC is expected to provide realistic cost estimates in early phases of project development. CM/GC delivery uses the following project pricing structures:

- Lump sum – Guaranteed Maximum Price (GMP).
- Lump sum – no GMP.
- Unit price – GMP.
- Unit price – no GMP.
- Combination lump sum and unit price.

Some CM/GC contracts contain a provision in which the CM/GC stipulates a GMP above which the owner is not liable for payment if project scope remains unchanged. These contracts are characterized by incentive clauses in which the CM/GC and owner can share any cost savings realized below the GMP. The owner will enter into a contract with the CM/GC for providing construction services if a certain amount of the design is complete and the project is sufficiently defined, and if the CM/GC's price is competitive. Some State DOTs, such as Utah and Minnesota, require validation of the CM/GC's price with the Engineer's Estimate (EE) and the Independent Cost Estimate (ICE). If the CM/GC's price is not validated, and the variations go unresolved through negotiations, many State DOTs reserve the right to solicit competitive bids.

CM/GC contracts can contain provisions for the CM/GC to handle some aspects of design, but generally the owner retains the traditional responsibility by having a separate design contract and furnishing the CM/GC with a full set of plans and specifications. The CM/GC will usually be paid for furnishing preconstruction services such as cost engineering and constructability review.

CM/GC is particularly valuable for new non-standard types of designs such as ABC, where it is difficult for the owner to develop the technical requirements that would be necessary for DB or DBB procurement without industry input. The Utah DOT has successfully used CM/GC to introduce new ABC concepts to the local contracting industry, including the use of SPMTs, lateral sliding technologies, and prefabricated elements. Having the contractor on the design team gives the agency the opportunity to openly discuss the technology, the process, and the risks associated with the construction. This sharing of knowledge can result in lower prices since the contractor is integrally involved in the design development process.

Some agencies have expressed concern regarding the negotiated price concept and the lack of multiple bids. The initial bid price may be somewhat higher than a conventional DBB or DB project; however this can be offset by reduced construction change orders brought on by ambiguities and inconsistencies in the plans and specifications. These issues can be resolved during design development and before the development of the project cost.

2.4.5. Innovative Contracting Clauses/Methods

2.4.5.1. Incentives/Disincentives

FHWA's Contract Administration Core Curriculum (CACC) Manual defines I/D for early completion as "a contract provision which compensates the contractor for each day that identified critical work is completed ahead of schedule and assesses a deduction for each day that completion of the critical work is delayed" [15]. Under this clause, the contractor is required to complete the construction or a milestone by a specific duration (in terms of calendar days or set date) specified by the owner in the contract. The contractor is rewarded with incentive payments for completing the project ahead of schedule and penalized with disincentives for late completion. For some ABC projects, schedules can be shorter but the impacts of road closure during critical hours such as rush hours can be adverse. In such projects, I/D clauses can be based on hours rather than days.

The current FHWA recommendations for I/D clauses are based in part on the findings of the National Experimental and Evaluation Program (NEEP) Project #24 which showed that I/D provisions are a valuable cost-effective construction tool. Another source of information on this topic can be found in the document entitled “Alternative Project Delivery, Procurement and Contracting Methods for Highways” [16]. Another source of information on I/D clauses is the FHWA Technical Advisory 5080.10 entitled “Incentive/Disincentive (I/D) for Early Completion” [10]. In this document, the FHWA recommends a cap of five percent of the total contract amount for the maximum incentive payment, while no such cap is recommended on the maximum disincentive amount.

In practice, the I/D is determined based on some percentage (typically ranges from 20 to 100 percent) of work zone road user costs [17]. This is the portion of road user cost savings or expenses that an owner is willing to share with or recover from the contractor for early completion or delay, respectively. This percentage is established as an owner agency’s management decision by taking factors into account such as market conditions, confidence on the accuracy of work zone road user cost estimates, work zone factors, and time sensitivity of project completion.

Contractors have noted that incentive clauses can be one of the most significant factors affecting the speed of construction. In order for this to be true, a meaningful incentive value should be considered. The reality in many congested areas is that the roadway user costs will be significant, justifying a larger incentive value. While incentives can affect construction speed, excessively large disincentives can be detrimental to the project. Large disincentives can limit the number of bidders on a project due to high risks associated with the disincentives. In practice, both incentives and disincentives are generally set at the same level, and if they are different, the incentive daily rate should not exceed the disincentive daily rate.

2.4.5.2. Cost Plus Time (A+B) Bidding

Cost plus time bidding, also referred to as A+B bidding, is a procedure that selects the low bidder based on a monetary combination of the contract bid items (A)—the total dollar amount to perform the work and the time parameter (B)—the total number of calendar days required to complete the project. The number of days is multiplied by the owner-determined daily road user cost and then added to the dollar amount of contract items to determine the total bid value.

The contract evaluation is based on the lowest total bid value. The payment to the contract is based only on the dollar amount of contract items (A), not the total bid value. The contract time is the number of calendar days specified by the winning bidder, which may not necessarily result in the shortest (B) time. This method allows the contractor to provide the optimal combination of cost and time.

Generally, A+B bidding is combined with I/D, where the contractor receives incentives for early completion and is required to pay disincentives (and liquidated damages) for delaying beyond the completion date agreed in the contract.

A+B bidding is a form of "best value" contracting where the value is attributed to the impacts to the traveling public. A+B bidding is suitable for ABC projects that look to reduce impacts to road users, construction work zones, and environmentally sensitive areas. The use of high road user costs that are applied to the (B) term in the bid will encourage bidders to reduce the impacts to the road users. Typical projects include new or reconstruction, rehabilitation projects, simple bridge replacement projects, detour projects, intersection upgrades, and bridge rehabilitation projects.

A+B bidding is not required for non-critical, low impact projects such as signal systems, landscaping, and signing projects. If the (B) term of the bid is too low, there will be little incentive to accelerate the construction process. A+B may not be suitable for projects with potential for increased costs and may delay claims due to utility and third party coordination problems or lack of timely agency reviews.

2.4.5.3. A+B+C Bidding

A+B+C is a multi-parameter bidding method that adds a biddable quality or warranty parameter (C) to cost plus time (A+B) bidding. This method offers the owner agency a means of awarding contracts based on the potential quality of the finished product as well as the time and price necessary to construct such a product. The quality parameter would allow an agency to improve the quality delivered on future projects.

The total bid value is established based on the combination of cost, time, and quality. The quality factor (C) is established by combining anticipated or bid quality levels with appropriate quality pay factors. The contract evaluation is based on the lowest total bid value. The payment to the contract is based only on the dollar amount of contract items; however, the payment is increased or decreased depending on whether the contractor has achieved quality levels higher or lower than the quality specified in the contract.

As with A+B bidding, this contracting method can reduce construction timeframes with appropriate time parameters. The (C) parameter is consistent with the "Stay Out" portion of the Highways for LIFE mantra of "Get in, Get Out, and Stay Out." This contracting method places a focus on the quality that prefabricated elements can provide.

2.4.5.4. Warranties

A warranty is generally defined as a guarantee of the integrity of a product and the contractor's responsibility to repair or replace defects for a defined period and under certain conditions. The types of warranty used in highway construction include materials and workmanship, and performance warranty. Under a materials and workmanship warranty, the contractor is responsible for correcting defects in work elements due to the contractor's workmanship and materials during the warranty period but assumes no responsibility for defects due to design decisions.

Under a performance warranty, the contractor assumes full responsibility for product performance over a reasonably longer warranty period. Under a performance warranty, the contractor is responsible for all maintenance work to be undertaken during the warranty period with no additional cost to the owner. The contractor assumes responsibility for some or all design decisions.

For longer-term warranties, owners typically require a surety bond to cover contractor warranty obligations during the warranty period. A surety bond guarantees contractor performance throughout the warranty term. Should the contractor fail to perform, the surety covers the cost of remedial work to the limits of the bond. However, there are concerns over the surety industry's reluctance to issue long-term performance warranty bonds, especially for small- and mid-sized contractors.

2.4.5.5. Lane Rentals

Lane rental charges the contractor a rental fee for the time period a lane is closed to through traffic for construction activities. The rental fee is based on the road user cost estimated for the closure period. The lane rental fee is specified by the owner agency in terms of dollars per lane per time period. The fee may vary depending on the closure period, time of day, and the amount of traffic. Closures may be continuous or intermittent, restricted to off-peak hours, night work, weekend, or during the execution of specific tasks.

Lane rental is intended to minimize the disruption of the work zone traffic and to encourage minimal use of lanes for construction activities. Lane rental is effective for projects where the owner wants to encourage the work to be done during non-peak hours. It is generally suitable when detours are long, unavailable, or impractical, or when peak hour traffic is impacted adversely. It is well suited for multiple-lane roads with high-traffic volumes where there is flexibility for short, intermittent, or temporary lane closures to keep at least one lane open to traffic through the work zone. It is not suitable when full closure (i.e. all available lanes) or long-term permanent lane closure is inevitable. For long-term projects, lane rental may be combined with A+B bidding.

2.4.5.6. No-Excuse Incentives

No-excuse incentives provide a monetary incentive to complete the contract work on time or sooner than a stipulated date with no excuses for delay. The contract stipulates that the contractor complete a phase of work or the entire project by a "drop-dead date" in order to receive an incentive payment. If the work is not completed on time, the contractor is not charged with disincentives (liquidated damages may apply). No excuses are allowed for modifying this "drop-dead date," including weather, differing site conditions, utilities, permitting, third-party coordination, change orders, or any other reason short of a natural catastrophe. No-excuse incentives are suitable for time-critical and full closure projects such as in urban, business, tourist, or environmentally sensitive areas. They are well suited for larger projects with multiple phases where the pace-of-work progress needs to be controlled.

2.4.5.7. Alternative Technical Concepts

An ATC is a request by a proposer to modify a contract requirement, specifically for that proposer's use in the bidding or proposal process. The ATC must provide a solution that is equal to or better than the requirements in the Invitation for Bid or RFP document. If the ATC concept is acceptable to the contracting agency, the concept may be incorporated as part of the proposing team's technical and price submittal. Value engineering proposals and alternate bids are considered as ATCs.

ATCs are typically used on DB projects where the scope is significant and the contracting agency believes that the best-value selection may depend on the degree of innovation in the technical solutions offered by the teams. Many States have evaluated and benefitted from the use of ATCs on large DB or public-private partnership projects. A survey conducted by the on-going NCHRP Synthesis 20-05/Topic 44-09 study shows that 36 states have used ATCs on DB and CM/GC projects. There is relatively little experience with the use of ATC on DBB projects; only the Missouri DOT has evaluated this approach in a traditional DBB project and found it to be successful when thoughtfully added to appropriate projects.

The ATC process is very different for DBB projects. The owner issues an "invitation for bids" to its normal bidders list and makes copies of the construction documents available for review up to six months prior to the scheduled letting date. The agency then engages in confidential one-on-one meetings with those contractors that are interested in proposing an ATC. If the ATC is approved, the owner then advances the ATC design to the point where biddable quantities can be generated. Only the contractor with the approved ATC can use the concept in its bid. The contract is awarded to the lowest responsive bidder. However, like any DBB projects, the owner remains responsible for the design and any changed conditions, design errors, or omissions.

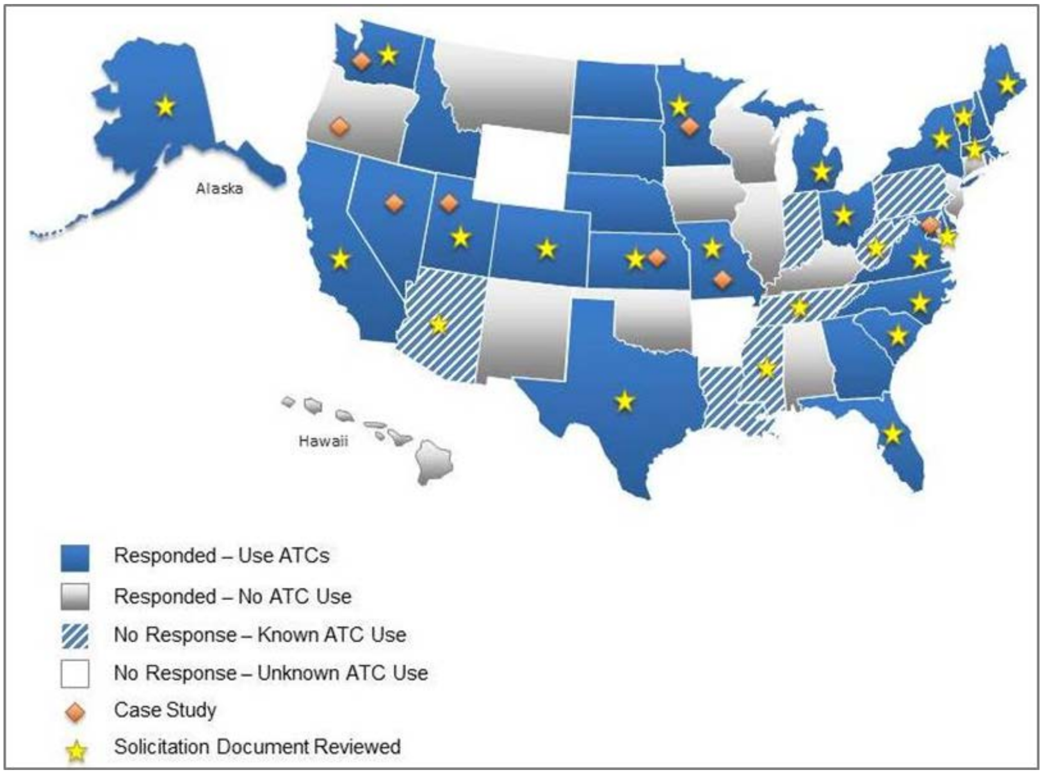


Figure 2.4.5.7-1. Map showing the use of ATCs. (Source: On-going NCHRP Synthesis 20-05/Topic 44-09 study, Douglas Gransberg).

There is no FHWA statute that directly addresses ATCs; however, the current policy in 23 Code of Federal Regulations Section 636.209 (b) allows proposers to submit proposals as a supplement but not as a substitute for the base proposal. Most highway agencies have depended on their state or local statutes for using ATCs.

The key to making ATCs work is confidentiality, objectivity, unbiased evaluation, fairness to proposers, and mutual trust. One-on-one meetings between the owner and the proposer are recommended but are not required. The ATCs not only encourage innovations and best-value solutions but help owner agencies get the best out of a competitive environment. ATCs provide the owner with the full value of the savings through competition.

As ABC experience increases, the owner agency may find itself in the position where industry will propose to replace conventional bridge construction with ABC as an ATC. This happened in the Nevada DOT's I-15 Mesquite Interchange DB project. Nevada DOT approved an ATC to substitute a slide-in bridge for the originally planned conventional bridge that was to be built in place. The net result was a cost savings of $13 million and a schedule reduction of six months.

The ATC must be complete and fully compliant with the RFP requirements for ATC submittals. An ATC submittal normally includes the following information:

- Description and conceptual drawings of the base configuration.
- Description and conceptual drawings of the proposed configuration.
- Location and description of how the proposed change will be used on the project.
- Identification of RFP design criteria deviations that must be approved to implement the ATC.
- Justification on why the proposed change should be allowed.
- Analysis of potential impacts on project cost and schedule, as well as impacts on right-of-way, environmental permitting, and other baseline design commitments.
- Analysis of potential performance of the facility including anticipated life, maintenance requirements, operational changes, and life cycle costs.
- Analysis of potential user impacts on work zone traffic, safety, environmental, and community impacts.
- Analysis of risk impacts to the owner agency and third parties.

To provide a fair and transparent environment in which to consider potential ATCs, many DOTs allow a two-step ATC process. The first step is a confidential meeting where a conceptual ATC is presented and considered by the DOT. The contractor is then told whether or not the concept would potentially be approved by the owner. This is done to minimize the expense the contractor must bear to propose an ATC. If the first step is positive, the contactor then makes a formal ATC proposal in accordance with the terms for ATC submittal contained in the project's solicitation document.

The two-step ATC process also creates an incentive to innovate by minimizing the cost and effort necessary to bring an idea to the table that completely changes the baseline design, as was seen in the Nevada DOT project. The ATC to replace conventional construction with ABC construction literally changed the footprint of the project as well as many other ancillary features of work. By allowing the contractor to present the idea to the DOT without having to completely fulfill the requirements for a formal ATC submittal, the agency created an environment where competitors felt comfortable suggesting bold alternatives.

2.4.5.8. Insurance Requirements

Owner agencies require contractors to submit liability insurance for all damages and losses assumed under the contact. Insurance includes but is not limited to worker compensation, general liability for property damage and bodily injury, automotive insurance, railroad protection, and any third-party requirements such as utilities. The prime contractor is responsible for verifying subcontractors' insurance coverage.

Workers' compensation provides the contractor coverage for its obligation to pay for employees' bodily injuries that occur on the job. Most states require contractors to purchase workers' compensation insurance. General liability protects a contractor against claims of bodily injury (to the general public or other contractor's workers) and property damage arising from the contractor's work. Automotive insurance is required to cover bodily-injury and property-damage exposures arising from the construction vehicles. The contractor also undertakes insurance to protect railroads for acts or omissions arising out of the “work” at the “job location” [18].

The impact of ABC on insurance rates is not well defined at this time. FHWA has had discussions with the insurance industry regarding the potential effects of ABC on insurance costs. In general, there is a potential increase in exposure to property loss for projects that involve moving large elements and systems. Damage to a beam element has an associated cost to repair or replace. Damage to a larger element or bridge system could potentially result in larger repair or replacement costs. Some agencies require the development of a bridge assembly plan, designed by a professional engineer for ABC projects built with prefabricated elements. Assembly plans include detailed erection and falsework designs. The level of engineering effort that goes into the development of an assembly should result in a higher level of quality control that may offset the increased exposure to property loss brought on by moving larger elements and systems.

The total exposure on property loss is unclear at this time, but the effects of ABC on personal injury and casualty are clearer. Exposure to personal injury and casualty are primarily a function of construction time. The reduction in work zone time will result in less exposure to the workers and the traveling public. The reduction in on-site construction work will also reduce the amount of time that workers are exposed to potential fall situations.

Based on the discussion above, it appears that the use of ABC and PBES will not have a significant effect on the insurance requirements for projects; however, there has not been definitive research on this topic. Depending on the specifics for a project, insurance may actually be reduced through the use of ABC and PBES.

2.4.5.9. Bonding Requirements

The FHWA CACC Manual classifies bonding requirements as follows [15]:

- *Bid bond*, or proposal guaranty, is a bond, certified check, cashier's check, or other negotiable instrument which is submitted with the bid as assurance that the bidder will, upon acceptance of his bid, execute such contractual documents as may be required within the time specified.
- *Performance bond* is a bond executed in connection with a contract to assure fulfillment of all the contractor's obligations under the contract.
- *Payment bond* is a bond executed in connection with a contract to assure payment, as required by law, to all persons supplying labor and material in the execution of the work provided for in the contract.
- *Warranty bond* is a bond executed in connection with a contract to assure that a warranted item survives the warranty period in the prescribed condition.

A bid bond is released when the contractor enters into a contract with the owner agency at the bid amount. Bid bonds are generally nominal and may not be different for traditional and ABC projects.

Performance and payment bonds are collectively taken together to ensure the fulfillment of contractual obligations. While these bonds are typically required for all projects, the evaluation criteria used by the surety companies in the underwriting process may be different for ABC projects. Even for the same contractor, different premiums may apply for traditional and ABC projects based on project-specific risks and threats.

The surety underwriters typically use the following criteria in determining the premium charged to the contractors: (a) project specifics, (b) contractual risks, and (c) the contractor's organizational practices [19]. The project specifics include the project type, contract price, contractor's experience with construction, quality of subcontractors, stipulated contract length, etc. The specific characteristics of the project are also taken into account. Contractual risks are evaluated to ensure that the contractor is familiar with the project delivery method and that the clauses in the contract are acceptable. The contractor's organizational practices include an assessment of their ability to perform different management practices for the proposed project. All these factors may influence the underwriting process in determining the surety premium for ABC projects.

Obtaining surety bonds for major projects is an issue especially for small- and mid-sized contractors. The major reasons cited include the insufficient net worth and working capital, and the firm's ability to succeed under such conditions as an increase in project size, a change in geographical area or the type of construction undertaken, replacement of key personnel, and overall contractor profitability [18].

For ABC projects, some owner agencies may require performance warranty for the installed product from contractors over a reasonably longer period. While the surety industry is generally positive toward the concept of performance bonds, there are longstanding concerns over the longer term performance bonds, especially when the warranty duration is more than three years. Long-term performance warranty bonds tend to be more expensive and difficult to obtain for small and mid-sized contractors due to the inherent issues relating to the certainty of the contractor's ability to stay in business.

To overcome the concerns relating to longer term surety, several strategies are being considered in the construction industry:

- Obtaining warranty for shorter periods (1 to 2 years) and renewal at the end of warranty expirations.
- Using a pay-for-performance system in lieu of a bond, in which the contractor is paid periodically on a graduated scale during the life of the warranty based on expected performance.
- Using a prequalification system by tying the contractor performance of required remedial work to qualification for future work.

2.4.5.10. Electronic Data—Sharing Model Data with Contractors

The highway construction industry, including owners, designers, and contractors, is moving toward adopting electronic plans and 3D design models. With 3D models, design and construction teams can connect virtually to develop, test, and alter project designs throughout the design and construction phases. Intricate design features can be viewed geospatially from multiple perspectives, and simulations can be run to detect design flaws before construction begins. It allows designers and contractors to run alternative scenarios quickly and more easily alter one's models to suit their process flow.

Data for roadway surfaces, exported from the 3D models, can be transferred to a GPS control that guides and directs construction equipment like bulldozers and excavators. The connectivity allows workers to receive and work with the most accurate, up-to-date models even if mid-cycle design changes are made. The 3D models-GPS combination helps complete highway projects faster with improved quality and safety.

Significant issues regarding the implementation of 3D models are yet to be resolved. Electronic drafts of 3D models are now used in conjunction with 2D models signed by the authorized professional engineer (P.E.). Despite its benefits, legal liability is one of the pending issues for both the agency and the industry. While the licensing boards of some states are evaluating the P.E. liability issue, there are a few suggested workarounds such as adding a disclaimer about the legal liability of 3D models, electronic signing, or making the bidders sign waiver agreements.

There is no standard data format for the 3D model data feed into the construction equipment. Equipment models available in the market are pre-wired for specific data formats by the manufacturers. There are three xml types: xml, land xml and trans xml; these data formats are not compatible or inter-convertible with each other. Therefore, lack of a standard data format is another key issue impeding the full-scale implementation of 3D models in highway construction.

Another potential electronic data sharing format is referred to as Bridge Information Modeling (BRIM). This involves detailing the bridge elements in full 3D. In theory, the 3D model can be shared with fabricators and used to develop shop drawings and computer numerical controlled (CNC) machinery. A full 3D model of elements can be used to identify potential fit-up and erection issues with prefabricated elements. The effect of tolerances can also be studied by adjusting the dimensions of various elements.

This approach has been used in the vertical construction industry, but has found limited use in the bridge industry. This may be due to the inherent complexities of bridges that are commonly designed with skews, vertical curves, and horizontal curves. Typical bridge detailing involves the use of plan, elevation, and sections to depict the bridge structure. The complexity of detailing reinforcement and complex joint areas are typically left up to the contractor to develop on the shop drawings or in the field. The complexity and time required to develop a full 3D bridge model for typical bridges could potentially limit the use of BRIM. The application of this tool on large-scale design build projects may justify the modeling and set-up time.

CHAPTER 3. BIDDING AND EXECUTING THE CONTRACT—THE AWARD PHASE

3.1. PRE-BID MEETINGS

Pre-bid meetings provide an opportunity for the owner to provide project-related information and key contract special requirements to competing firms before their submission of bids and proposals.

Pre-bid meetings can be open in nature, with all competing firms or private one-on-one meetings with each competing firm. Pre-bid meetings can be mandatory or optional depending on the owner's policy or project-specific decisions. The issues discussed during the pre-bid meetings are not considered contractual. Any exchange of information at pre-bid meetings must be consistent with State procurement integrity requirements. If the owner agency has an interest in considering ABC methods via ATCs on a given project, a pre-bid meeting provides an opportunity to gauge the industry's interest in the idea.

The open pre-bid meeting provides an information-exchange forum to all concerned entities to discuss key project-related issues, answer project-related or submission-related questions, and clarify any concerns. The open pre-bid meeting will be attended by project managers, and technical, legal, and contract administration staff of the owner agency. The open pre-bid meeting will typically invite the FHWA local division staff and other third-party entities including utility owners and railroad companies. The presence of third-party entities will facilitate both an open discussion on project requirements or constraints (such as utility conflicts) and an information exchange that would provide a better understanding of the risks to competing firms. Minutes of the meeting are shared with all prequalified firms in a timely fashion, and all private information exchanged between the owner and firms is documented.

3.2. RESPONSIBILITY AND RESPONSIVENESS

3.2.1. Prequalification of Contractors

Contractor prequalification is the screening and evaluation of contractors by the owner agency based on a given set of criteria to determine their competence to perform on a given project. Some agencies are forbidden by their statutes from prequalifying construction contractors.

According to NCHRP Synthesis 390: *Performance-Based Construction Contractor Prequalification,* there are three types of contractor prequalification systems in use in the U.S. transportation industry [20]:

1. *Administrative prequalification*: a process whereby a contractor submits a set of financial, equipment, and experience information, which, when approved, admits that entity to the agency's list of prequalified bidders.

2. *Performance-based prequalification*: a process that expands the administrative prequalification procedure to include a linkage to a given contractor's record of performance on past projects. Generally, this process results in a determination of how much work the contractor is allowed to bid at any given point in time.
3. *Project-specific prequalification*: a single project prequalification process that seeks to ensure that only highly competent contractors with specific sets of skills and past project experience are allowed to bid on a given project. This is most often found in CM/GC and DB projects.

In DBB projects, contractors are typically only required to administratively prequalify. To be included on an owner's approved bidders list, the contractors submit documents to demonstrate their ability and capacity to perform on a given project, in accordance with the owner's set of procedures and forms. The submittals typically include financial statements, bonds, sureties and insurance, available equipment and personnel, and prior work experience. This approach seeks to establish a benchmark for a contractor's financial capacity but does not consider their technical capability and past performance. This approach does not differentiate between consistently poor-performing contractors from those contractors that deliver high quality work.

Some State DOTs, such as Florida, have implemented a more comprehensive evaluation based not only on the financial criteria and organizational capabilities but also their technical ability, past performance, safety performance, prior litigations, and project management skills. This information may be provided on a project-by-project basis or on a specified periodic basis. This approach can be used for projects using both traditional and alternative project delivery methods. The performance-based prequalification process takes the following factors into account:

- Performance criteria.
  - Major project experience.
  - Quality and workmanship.
  - Available equipment.
- Financial criteria.
  - Financial capability describing the company's current finances.
- Management criteria.
  - Technical ability describing expertise and experience in constructing technically complex projects.
  - Past illegal behavior including disqualification or failure to complete a project.
  - Key personnel experience.
  - Managerial ability to control project tasks, in-house resources, and subcontractors.
- Bonding, sureties, and insurance.

In addition, there may be other project-specific factors such as quality management, traffic control, and safety plans taken into account in the contractor prequalification evaluation. Owner agencies also evaluate the contractor’s responsiveness to complaints and disputes, client orientation, partnering, and communication on past projects.

Because of the unique means, methods, and materials used in ABC projects, project-specific prequalification is desirable to establish the competing contractors’ technical abilities, prior experience, and ability to perform the work. However, it is cautioned that owners may not always be able to find contractors with significant ABC experience in their region.

3.3. SELF-PERFORMANCE REQUIREMENTS

Major elements such as prestressed beams and fabricated steel elements should be fabricated in a certified plant. Initial PBES projects were bid with specification that required the same certified fabrication facilities for all prefabricated elements. This can be challenging in regions where fabrication facilities are few and far between. Shipping of elements over long distances is a cost factor that can reduce savings achieved in other areas. Understanding the accessibility of the site to fabrication facilities is an important factor to consider in developing specifications and cost estimates. Self-performance of prefabrication can be used to address this issue.

A number of states also have experienced resistance to the use of prefabricated elements on the part of the contracting community. To them, prefabrication is perceived as a loss of business when it replaces site work such as cast-in-place concrete with prefabricated elements. Self-performance of prefabrication is one way to respond to this resistance.

Supplier prequalification requires certification from the owner or owner-approved agency that the precast concrete products are manufactured and erected to nationally accepted standards, comprehensive quality systems, and audits that are in place to ensure quality and compliance. The certification process is a formal assessment and verification by an authorized agency of the supplier’s fabrication and erection methods, personnel training, and quality control systems, in accordance with established requirements or standards.

The American Institute of Steel Construction (AISC) provides certification programs relating to fabrication and erection of steel elements. Information on these programs can be found at http://www.aisc.org.

Certification programs relating to fabrication, erection, and grouting of precast, prestressed or post-tensioned products can be found at:

- Precast Prestressed Concrete Institute (PCI) Personnel Training and Certification: http://www.pci.org/pci_certification/personnel_certification_programs/.
- Post-Tensioning Institute (PTI) Certification Program: http://www.post-tensioning.org/certification_program.php.
- American Segmental Bridge Institute (ASBI) Grouting Certification Program: http://www.post-tensioning.org/page/certification

PCI offers certification programs for fabrication and erection of precast prestressed products. PTI offers certification programs for unbonded or bonded post-tensioned products, while ASBI's program is for grouting operations on post-tensioned structures.

The national organizations for precast concrete products recommend that the products be fabricated in a certified plant; however, a few owners—for instance, Utah DOT—allow the setting up of temporary precast plants to cast at or near the project site but require obtaining applicable certifications from national organizations and the agency's pre-qualification before placing any precast elements in their final location. This does not typically apply to prestressed products that should be fabricated in certified fabrication plants.

Under Utah DOT's prequalification program, the suppliers of precast prestressed products are required to pass the agency inspection prior to acceptance as a pre-qualified fabrication plant [21]. Utah DOT will schedule an initial plant certification inspection visit at the request of the supplier to check if the plant, production process, and personnel are in accordance with the agency's Precast/Pre-stressed Concrete Structures Quality Management Plan. Based on the inspection results, a written report documenting all deficiencies observed will be submitted to the fabricator to address before requesting another inspection. Upon completion of a deficiency-free inspection, Utah DOT Central Materials will issue a letter of certification and unannounced annual audits.

It should also be noted that all materials used in the fabrication process for use in federal-aid projects are subjected to the FHWA's current Buy America requirements of 23 CFR 635.410. FHWA has the discretion to grant a waiver to these requirements on a project-by-project basis.

CHAPTER 4. CONSTRUCTING THE PROJECT—THE CONSTRUCTION PHASE

4.1. PLANNING THE CONSTRUCTION PHASE

Accelerated bridge construction requires accelerated planning for all phases, but nowhere is it more important than in the construction phase itself. To accelerate construction successfully demands that all resource requirements are satisfied and that issues like environmental constraints, third party stakeholder involvement, and the ability to expeditiously pass through the quality assurance process are fully resourced and will not create unnecessary delays. The owner agency must carefully examine its construction project delivery processes to identify and address potential shortfalls in required staffing to keep pace with the construction. It also must ensure that the contractor has allocated sufficient resources to those tasks on the project's critical path before the owner issues construction notice to proceed (NTP). Therefore, the next sections will discuss the planning required to ensure that the ABC product is delivered in the desired timeframe.

4.1.1. Owner Agency Staffing/Needs

Owner agencies are not normally able to swiftly expand and contract their roster of public agency personnel just to meet a short-term demand imposed by an ABC project. Additionally, agencies are often organized around geographic areas of responsibility that make it difficult to cross-level within the agency when demands spikes in one residency. Hence it is important that a detailed analysis of staffing requirement be made for every ABC project. This might involve developing a schedule of the resource-loaded critical path method for agency resources to identify those periods in which the agency's ability to meet staffing requirements is exceeded.

Typically, when an agency's resource capacity is exceeded, it has the following three options:

- *Bring temporary in-house staff from another agency unit.* This option often requires additional expenditure of travel funding to support temporary staff throughout the duration of their stay. It also involves the need to build a "training/familiarization" period into the schedule to ensure that temporary personnel are able to fill the need with the required knowledge of project conditions, etc. One potential source of additional staff might be from the agency design office. The Utah DOT has had success with staffing project field offices with the actual designers of the project. This can be helpful with the rapid resolution of problems in the field, and with the training of the design staff in typical construction processes.

- *Out-source for temporary staff from a consultant.* This option obviously involves an additional cost to the agency, which might be subject to agency competitive procurement rules and constraints. Thus, the decision must be made early enough to award a contract using routine procurement processes.

- *Use only the available staff and choose to accept increased risk of noncompliance with the terms of the ABC contract.* This is the least cost option in terms of personnel costs, but could potentially become the source for a delay if the staff on hand is not able to keep up with the faster pace of construction administration.

Agency project managers must remain cognizant of the potential disruption that having sufficient staff can cause and seek to set processes in place that are realistically planned. No matter which of the three options is chosen in making this decision, the agency will remain at risk for accomplishing its due diligence duties on 23 CFR 637.207(a). Ensuring adequate resources for both oversight and acceptance operations is one way to facilitate a successful ABC project completion.

4.1.1.1. Plant Inspection (Including Contractor Produced)

Given the off-site nature of ABC projects, ensuring that sufficient staff is allocated to QA tasks like checking the calibration of batch plants and other production elements is mandatory to achieving quality in the finished product. Determining the staffing level is a function of completing an inventory of QA program requirements for activities conducted in the plant. Tasks such as checking precast construction tolerances, ensuring that the proper grade of steel is being used, and random material sampling are typical resource requirements at the plant.

Some agencies may choose to rely on existing QMP programs for certain materials and contractor-produced products. However, since ABC projects often incorporate materials and production techniques that are unique to the specific type of bridge, these standing programs may not be sufficient, or worse—they may not cover the exact materials, means, and methods required in an ABC project. Hence, QMP programs must be checked to ensure their applicability at an early stage of construction planning. The other issue with these programs is validating that the equipment used in the plant is properly serviced during construction to ensure that it operates in the manner necessary to achieve quality requirements.

Lastly, a plan for periodic re-inspections and random oversight visits must be developed to keep the plant operating at a level that satisfies both the contractor's production needs and the contract quality requirements. The owner agency must be brutally honest with itself regarding the technical expertise of its staff and their ability to properly conduct plant inspection and bring in outside expertise for those specialty areas with which the inspection staff are not properly trained or may have no experience.

4.1.1.2. Field Staff

An ABC project puts on field staff additional demands that are not present in routine bridge construction projects. For example, the use of slide-in bridges creates a period where a high level of productivity must be sustained for a period of up to two or three days. Agency field staff may be subject to work rules that do not permit them to work the same schedules as the contractor's workers. This creates a need to increase field staff during these extended periods of ABC activity. Additionally, because of the on-site/off-site nature of ABC projects, sufficient field staff will need to be assigned to more than a single location.

To achieve the aggressive schedule desired in an ABC project, field staff will need to ensure that they are cognizant of project control tools like “witness-and-hold” points. This technique requires the contractor to notify the engineer in advance of reaching one of these points in production to permit the agency the opportunity to conduct inspections and/or observe a specific construction operation. This technique is often used in utility construction prior to backfill or in concrete construction prior to each major pour. Other techniques of this nature are available and the staffing plan should be developed around these options.

4.1.1.3. Office Staff

An old cliché says that “cash is the fuel of construction progress.” Hence, an accelerated bridge project must ensure that contractor cash flow does not impede the contractor’s ability to achieve the production rates necessary to complete the project on schedule. Sufficient office staff must be on hand to expedite the processing of periodic pay estimates. If field staff is charged with the development of progress payments, the agency should consider augmenting it with office staff regularly for each progress payment.

The second major area where allocating sufficient office staff is critical is the review and approval of construction submittals. Accelerated projects are always highly susceptible to delays in the submittal process. The contractor must wait to order materials until its submittals are reviewed and approved. Therefore, the use of routine boilerplate review provisions is not recommended. Construction planners must evaluate the amount of time available in a given project for submittal review and assign the required number of design personnel to the office staff to complete these reviews in a compressed period. If insufficient staff is available for peak submittal periods, retaining additional capacity via a consultant is recommended.

4.1.1.4. Consultant Support

The use of consultant support generally takes one of two possible paths. The first is to retain the consultant that produced the design through the construction phase to provide construction engineering and inspection. This option brings a person to the project who is theoretically familiar with its details and any technical issues that must be addressed during construction. This person also is the author of the requisite quality standards and understands the intent of various design features.

If the design has been completed by agency personnel, however, the above solution is not an option. The agency will then augment its field and design staff with additional consultant resources. It is important to focus the consultant on specific construction phase tasks rather than merely bring more bodies to the field or office. ABC projects are conducted in a series of clearly defined phases of construction. So one possible approach is to assign consultant personnel to phases with which the agency has little or no experience, thus covering both the need for additional technical expertise as well as additional personnel.

4.1.1.5. Decision-Making Process

The decision process for ABC staffing requirements is essentially a matter of balancing the risk of noncompliance with the available resources. The agency should develop a project work breakdown structure that is based on the severable work packages it expects the contractor to utilize during construction. Given those basic elements of work, a conceptual schedule is then developed and the requisite staffing resources are assigned to each contractor work package. Those resources are then accumulated over time and compared to actual resource availability. Periods where the resource requirement exceeds the agency's resource capacity are identified and addressed as discussed above. The final staffing plan is then reviewed against the ABC project's risk register to check that resources appear to be sufficient to address other risks in a timely manner.

4.1.2. Contractor

The ABC contractor will have completed much of its construction planning prior to being awarded the contract during the bidding phase of the project. Thus, the contractor's preparations are primarily implementing the construction sequence assumed in the bid and coordinating the myriad details that must be arranged to smoothly construct the bridge.

The contractor must plan for pre-erection, erection, and post-erection activities. Depending on the ABC technique to be used, pre-erection activities can entail a wide range of tasks, ranging from developing a site for a bridge farm to verifying that crane reach and pick capacities are compliant with the actual siting for the cranes and that the structural members have been designed to withstand the construction loads that will occur during erection. The design of the rigging and load spreading apparatus must be completed or checked by the engineer that designed the structural members, including validating that pick points have been provided for in the design. These are but a few examples of the construction engineering design requirements that the contractor must include in its final sequence of work.

ABC projects are highly dependent upon precise horizontal and vertical geometric control. Construction geometric control for differential camber, skewness, and cross-slope are a key to ensuring proper fit-up of prefabricated elements and systems. Hence, some ABC contractors will use two separate survey crews to ensure that tolerances of as little as one-quarter of an inch are achieved during pre-erection and erection.

The contractor is typically responsible for erection plans and calculations. The erection plan must be comprehensive and consider such aspects as available right-of-way, underground and overhead utility conflicts, the bearing capacity of soils under the crane set-up site and SPMT routes, access routes for delivery trucks, and temporary marine structures like mooring points for float-in erections. When crane capacity limitations are being approached, physically measuring the actual reach at the set-up site may be required. Heavy modules might require the erection of temporary bridging consisting of standard preassembled trusses to prevent large erection stresses. Dynamic dead load allowances need to be included in the construction engineering plan to account for the inertial effects during handling. Bracing must be designed to safely transport structural members from the point of assembly to the point of final positioning.

The final aspect of construction planning is to ensure that the contractor and the owner agency have coordinated the cross-organization communications process during construction. Items like the allocation of decision-making authority, decision oversight, communication protocols during erection, and reporting relationships in the field should be preplanned to manage the work effectively and avoid costly delays when unforeseen circumstances occur during erection.

4.1.2.1. Safety

Construction safety planning for ABC is not materially different than a traditional bridge construction project. The main difference is that the pace at which construction will proceed is faster, which increases the hazard level. A thorough job site hazard analysis must be made for the entire process. Specific attention must be paid to the fabrication and transportation of structural members. Safety plans must include nontraditional considerations unique to ABC projects such as providing a safe area where the general public can assemble to watch an SPMT bridge move.

Traffic control is always a safety issue in highway construction and nowhere is it more key to project success than in an ABC project. FHWA's avowed objective for implementing ABC is to "Get in, Get out, and Stay out" by accelerating construction disruptions to the traveling public. Past ABC projects have been allowed to completely shut down urban interstate highways for brief periods of time to take advantage of the means and methods available in ABC. Special detour planning including detour route congestion analysis and impact to the surrounding business community is often required to achieve these closures.

Because of the enormity of the construction loads, construction personnel may require additional training to ensure that they fully understand the dangers inherent to these means and methods. The plan for the construction sequence must have a parallel plan for safety to ensure the project is completed without the potential delay imposed by an accident. Security of and controlled access to and from the project site must also be included in the safety plan to prevent potential accidents by both the curious and the nefarious. Safety is always "job one," but in ABC projects it is a large job that extends the boundaries across which the safety plan must reach. Speed is often the culprit in construction accidents and ABC projects are initiated because of a need for speed. Contractors must make sure that safety plans can operate at the increased speed of the ABC project.

4.1.2.2. Risk Management/Contingency Planning

The contractor should invite the owner to participate in any risk management exercises to provide the owner with the information on how anticipated risks will be addressed and, more importantly, to create an open environment where the owner can volunteer to manage risks that it can best control. The starting point for construction risk planning is the construction sequence. Each work package in the contractor's work breakdown structure should be reviewed and provide input as appropriate to the project risk register. The process will follow standard agency risk management procedures that are used to identify, allocate, mitigate, and retire project risks. Potential impacts of each risk should be developed to provide input to contingency plans. Once the risk register is complete, it should be categorized into pre-erection, erection, and post-erection risks to allow planners to associate various risks with the project's timeline.

The next step is to categorize the risks by their probability of occurrence and the impact if they occur. Essentially, this develops the following list:

- High probability-low impact risks.
- High probability-high impact risks.
- Low probability-low impact risks.
- Low probability-high impact risks.

The high probability-high impact risks will require an in-depth analysis and a detailed plan for preventing them from happening and mitigating their impact if they are realized. Specific focus is given to the timeline and maximum emphasis is placed on retiring those risks as soon as practical in the construction sequence. A similar approach is taken with the low probability-high impact risks except that prevention plans will usually be far less detailed. The two remaining categories are also addressed, but in much less detail since the impact is not high. However, the final analysis should include an evaluation of how various risks may be interrelated, with an eye toward understanding how a low impact risk could be the trigger for a high impact risk if it occurs.

4.1.2.3. Getting Third-Party Stakeholders on Board

Third-party stakeholders can influence the ability to achieve the aggressive schedule set for an ABC project in a number of ways. As a result, they cannot be ignored and the risks associated with these parties should be included in the above risk analysis. The best way to quantify the risk of third-party interference is through creating an information-rich environment where open communications can occur in a timely manner. This is the purpose of developing a public information and communications plan. If done well, the agency and its contractor will complete the project and be able to leverage the positive sentiment created by a job well done. If done poorly, public sentiment could effectively remove ABC from the agency's menu of bridge construction options.

Some stakeholders are easier to deal with than others. The contractor must identify which stakeholders require special care and handling. Railroads and utility companies will be primarily concerned with the possibility that the ABC means and methods will damage or disrupt their facilities. These issues must be addressed in design by the agency. However, the contractor should meet with each stakeholder and furnish the information they require about the actual construction process. It should also capture their primary concerns about construction operations and use that list to structure the risk management planning. Contingency plans must also be devised with the stakeholder's assistance so that if a given risk is realized, its impact can be mitigated expeditiously.

Previous ABC projects have included public information meetings to advise travelers about what impact the project will have on the routes they normally use. These meetings can propose strategic detour routing during closures, including the placing of variable message boards as far upstream as practical to notify travelers that would not have normal access to local public information media. Notifying commercial trucking companies that depend on the given route of planned closure dates as far in advance as they are known permits those entities to plan for potential delays and expensive reroutes in a manner that minimizes the short-term disruption. The local business community must be involved so that it can plan alternate routes for routine delivery of merchandise and other goods during disruption periods. Establishing local business councils for the duration of the project provides a conduit where timing and sequencing decisions can be made, recognizing the impact to public goodwill.

4.1.2.4. Project Scheduling

The ABC project will have its typical project schedule against which actual progress will be compared to evaluate contractor performance. These schedules are normally developed using the day as the unit of time. While that is certainly adequate for construction administration purposes, those schedules do not contain the detail necessary to control actual construction progress during high production periods like bridge moves that demand to be scheduled using a finer unit of time of an hour or minute. The solution is to pull fragmentary networks of the critical erection periods from the official baseline schedule and increase the level of detail for each of the activities. This is best done in a collaborative manner where the contractor, owner, and engineer of record are all present to mutually develop the detailed schedule for these periods.

A detailed scheduling conference is the usual vehicle for achieving a mutually acceptable erection schedule. The conference normally starts with a straw-man detailed schedule provided by the contractor. Next, the engineer-of-record is asked to identify those activities where construction loads are expected to be high. The contractor then explains its plan for dealing with those high-stress situations. If necessary, adjustments are made to satisfy both the engineer and the owner. Next, the owner is asked to identify those periods where it believes problems may occur. Again, explanations are made, contingency plans are developed, and the schedule is adjusted accordingly. Finally, the contractor's scheduler runs the revised schedule to determine the time impact of the adjustments and if a satisfactory answer is returned, the revised fragmentary network is folded back into the baseline to determine how the revisions impact the overall project. When satisfied, the contractor publishes a detailed timeline for each critical period that can be used by project personnel to monitor the progress of construction.

Any changes made to the baseline schedule must be evaluated to determine if the fragmentary networks are extended or negatively impacted. All potential changes to the contractor's sequence of work must also be checked to ensure that critical periods are not disrupted.

4.1.2.5. Submission Review Process

The contractor's construction/erection plan should be completed and submitted for review and approval by the engineer in accordance with the terms of the contract. Prior to its submission, the contractor should call a meeting of all major participants, including subcontractors, fabricators, and others to present the plan and identify any conflicts or issues that need to be resolved prior to implementing the plan. The detailed erection schedule discussed above should be presented in this meeting to validate that assumptions made for durations of each activity are indeed realistic and that members of the bridge erection and support teams understand the timeframes in which they are expected to complete their work. Contingency plans that flow out of the risk analysis are covered next to ensure the team knows how to react if a given risk is realized. Finally, a thorough review of the safety plan with specific attention to the high-risk job hazards finishes the meeting's content.

The contractor should have someone take minutes of the meeting. Those minutes should be reduced to action items with milestone dates that can be tracked to assure that issues and conflicts are resolved before bridge erection begins. If desired, the contractor can use those minutes to furnish the content of a cover letter to the owner for the construction plan regarding the primary issues that concern the contractor and its subs and suppliers.

4.2. CONTRACTOR SUBMITTALS

4.2.1. PBES: Assembly Plans

Prefabricated bridge elements and systems are an important technology for accelerating bridge construction. Like most technically complex assemblies, PBES must include a thorough plan for assembling the bridge elements to ensure the final product will perform as designed. The companion FHWA manual to this manual entitled "Engineering, Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems" contains more information on specification requirements for assembly plans.

Typical assembly plans will include the following information:

- Narrative and graphic depiction that demonstrates how the assembly will comply with applicable environmental permits.
- MOT plan that complies with timeframe constraints specified in the contract.
- Handling and erection bracing requirements design in accordance with Chapter 5 of the PCI Design Handbook.
- A work area plan, depicting items such as utilities overhead and below the work area, drainage inlet structures, and protective measures.
- Details of the equipment to be used to lift substructure elements, including cranes, excavators, lifting slings, sling hooks, and jacks. Include crane locations, operation radii, and lifting calculations.

- Detailed sequence of construction and a timeline for all operations, including setting and cure time for grouts, grouted splice couplers, and concrete closure pours.
- Methods to provide temporary support of the elements, including methods of adjusting and securing the element after placement.
- Procedures for horizontal and vertical geometric control to meet specified tolerance limits.
- Details of the installation procedure for connecting the grouted splice couplers, including pre-grout and post-grout applications, methods for curing grout and closure pour concrete, proposed methods for installing non-shrink grout, and the sequence and equipment for the grouting operation.
- Mock-ups for grout voids.
- Methods of forming closure pours, including the use of backer rods.
- A list of personnel who will be responsible for the grouting of the reinforcing splice couplers, with proof of completion of two successful installations within the last two years.

4.2.1.1. Shipping and Handling

The major logistical problem that must be overcome on ABC projects is the shipping and handling of precast structural elements. The shipping of some elements may require special road hauling permits. The contractor should factor in the time required to obtain these permits in the project schedule. Some ABC projects have had problems with obtaining these permits in a timely fashion. Project specifications should include requirements that these permits be obtained a minimum of 14 days prior to shipping.

One might think that the agency would play a significant role in the issuance of shipping permits. This may be true for most projects with in-state fabrication facilities; however, there is the possibility that the elements will be fabricated out of state. If the fabrication and shipping are both in state, the agency can work to expedite the review of the permit applications. If the fabrication is out of state, the contracting agency will not have control over the permit process. In some cases, agencies have been known to work together in a cooperative manner to expedite trucking permits for ABC projects.

4.2.1.2. Erection Plans

The erection plan must be comprehensive and site-specific. Erection plans are typically included in the assembly plan submission. A typical erection plan includes the following information:

- Crane and pick locations with appropriate crane charts.
- Panel erection and sequence.
- Minimum clearances of reinforcing to panel edges.
- Cables and lifting equipment.
- Details of vertical adjusting hardware.
- Details showing the erection and installation of the proposed deck panels.

- A proposed method for forming the camber strips and installing the structural non-shrink grout, sequence, and equipment for grouting operation.

4.2.1.3. Lifting Calculations and Element Stresses

The ultimate objective that must be reached is to handle all the bridge elements without damage. Considering that in many cases the largest stresses the element will experience are those induced during shipping, handling, and installation. The construction engineering that must be completed to achieve this requires a careful analysis of the element itself, the method for its transportation, the means and methods used to lift, position, and install it, and other factors such as the need to post-tension. The design of crane picks must be accomplished from the ground up and include an analysis of the load distribution system to transfer the lifting loads to the earth.

The contractor must develop a set of lifting plans that include calculations to verify that the required factors of safety specified in the contract will be met or exceeded. Calculations for each element should also be included and compared to the allowable stresses included in the design. The design of crane rigging and spreader-bars should also be included to furnish the necessary information for the engineer of record to verify that each pick can be made without exceeding allowable stresses.

The companion FHWA manual to this manual entitled “Engineering, Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems” contains more information on the requirements for lifting and handling of prefabricated bridge elements.

4.2.1.4. SPMT: Temporary Works Plans

The ABC contractor is required to thoroughly plan the bridge move and often is required to submit sealed working drawings that depict the means and methods required to complete construction of the bridge. The project plans typically indicate which submittals are necessary based on site-specific requirements. The following are examples of items that may be included in submittals:

- Improvements to ground conditions at the bridge staging area and along the travel path, such as terrain leveling, grade adjustments, replacement of soft soils, etc.
- Evaluations of structures along the travel path that will be encountered during the move, such as bridges or drainage structures to be crossed, retaining walls, utility lines, etc.
- Temporary support structures, including the temporary abutments upon which the superstructure is cast, and the SPMT blocking, plus additional temporary support structures such as ramps, jacking towers, strand jacks, etc.
- Details of the SPMT system including the configuration of SPMT units, the movement plan, contingency items, and emergency plans.

The companion FHWA manual to this manual entitled “Engineering, Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems” contains more information on the design and specification requirements for large-scale bridge moves using SPMTs.

4.3. QUALITY ASSURANCE DURING CONSTRUCTION

The FHWA motto for ABC and PBES is “Get in, Get out, and Stay Out.” The first two portions of this motto clearly refer to ABC. The third portion, “Stay Out,” refers to the use of quality to extend the service life of the bridge. There is no reason to sacrifice quality for speed of construction. It does not help to build a bridge fast and have to come back 20 years later to build it fast again. Agencies strive to design bridges that will have a 75- to 100-year service life. Another goal is to have a bridge that required minimal maintenance during the service life.

There are two basic types of quality control in an ABC bridge. The first is quality control during fabrication of prefabricated elements. The second is quality control in the field during assembly of prefabricated elements.

This section will discuss how to achieve quality on an ABC project. The goal is to have equal or better quality than that of bridges built using conventional construction.

4.3.1. Quality Assurance in Design-Build Contracting

Most agencies have well established quality assurance procedures and manuals for both the design and construction processes. These are based on the fact that the agency is under contract with the designer, and under a separate contract with the contractor. The agency manages the design consultant or the in-house design staff during design development and also manages the contractor during construction.

In a DB environment, the agency typically relinquishes some control over the management of the design and in some cases the construction. This is done in order to expedite the project delivery. During the bid phase of the project, the design builder needs to develop the design concept, details, and specifications. This is done based on the requirements of the agency RFP.

QA during construction is often placed under the DB team since the team includes both the designer and the builder. Many agencies require that the DB team develop and submit a Quality Assurance Manual as part of the submission process for the project. This manual typically covers both the design and construction aspects of QA. The construction portion of the QA program for DB projects can include the following elements:

- Construction Quality Control (QC).
- Owner Agency’s Acceptance.
- Independent Assurance (IA).
- Dispute Resolution System.
- Qualified/Accredited Laboratories.
- Qualified/Certified Inspection and Testing Personnel.

Once submitted and approved, the program is put in place and used to manage the quality of the project. This type of program places the QA responsibilities on the DB team.

Agencies may elect to play this role in the construction using typical DBB procedures. Agencies may also take on the responsibility of construction acceptance in an oversight role.

4.3.2. Prequalified Products

The companion FHWA manual to this manual entitled “Engineering, Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems” covers the various materials and specifications used in ABC projects built with PBES. The following sections contain a synopsis of the information in that manual and how it applies to the construction of the bridge.

4.3.2.1. Grouts

Grouts are a common material used to connect prefabricated elements. The most common form of grout that is specified is non-shrink grout. Low shrinkage grouts are required in order to minimize the potential for formation of shrinkage cracks in the connections during curing of the grouts. On very fast ABC projects, these grouts are also called upon to gain strength rapidly. Durability is the third basic requirement for connection grouts.

Other grouts that are commonly used in prefabricated connections include grouting for bonded post-tensioning systems. These grouts must provide additional characteristics such as flowability, pumpability, and resistance to the development of bleed water near the anchorages and high points in the duct.

Some agencies have developed non-proprietary grout mixes and specifications; however, most of these do not meet the rigorous demands stated in the previous text. This has led to the need for specialized proprietary grouts. There are two ways to specify these types of grouts:

1. The agency can develop a pre-qualified list of approved grout manufacturers based on a pre-defined set of parameters.
2. The designer can specify the grout using a pre-determined performance specification.
3. The designer can develop a specification with a list of at least three equal products.

The first option provides the most flexibility in that companies can get pre-qualified before or even during the construction of the bridge. Once a list is established, the designer can simply specify that the grout must be on the pre-qualified list.

The second option is desirable for specialty projects that have strict performance demands that common grouts may not be able to attain. For instance, if a construction schedule requires a grout that can attain a high strength in a short amount of time, only certain grouts may be able to meet the demands of the project. In this case the designer can specify the performance demands of the grout and require that the contractor submit a certified test report that demonstrates the performance.

The third option is desirable if there are only several known suppliers that can provide a grout that can meet the demands of the design. The problem with this approach is that it is almost inevitable that additional grouts will be submitted for approval during construction. This can place a certain amount of effort on the designer to review the material, which may be detrimental to the project schedule on rapid delivery projects.

4.3.2.2. Mechanical Connectors

Many of the connections for prefabricated elements that are used in the U.S. make use of mechanical connectors. Mechanical connectors can be used as a substitute for a reinforcing steel lap splice or they can be embedded devices that can transfer forces from one element to the adjacent element.

Mechanical reinforcing steel connectors have been in use for many years. They are commonly used at stage construction joints adjacent to traffic where extended reinforcing steel would interfere with the traffic and/or excavation support system. Most of these connectors are not applicable to prefabricated element connection since at least one side of the connection is embedded in cast-in-place concrete. There are several connectors that can be embedded in precast concrete and connected to protruding reinforcing steel via a socket type device. The elements are jointed together by inserting reinforcing steel from one element into the connector in the adjacent element. The connection is completed by filling the device with a material that completes the connection. These connectors are relatively easy to specify. The AASHTO Design Specifications [5] define a mechanical connection device as one that can develop a minimum 125 percent of the specified yield strength of the adjacent reinforcing steel bar. The ACI building code [22] has specifications for a higher level of mechanical reinforcing bar connector that requires strength equal to or greater than 100percent of the specified tensile strength of the connected reinforcing bar. This higher level of strength is used for seismic resisting moment frames made with precast concrete.

Embedded mechanical connectors are more complicated than mechanical reinforcing steel connectors in that they are commonly called upon to resist forces in multiple directions (as opposed to bar connectors that only resist axial forces). In this case, the designer cannot use an approved product list. He/she will need to specify the forces that the connector is required to resist. These forces should be clearly stated to be factored ultimate resistances. Another option is to specify a minimum of three connectors that can resist the forces.

4.3.2.3. Maintenance and Upkeep of Pre-Qualified Products Lists

As discussed in the previous section, the use of proprietary approved products lists is one of the best ways to incorporate proprietary products into an ABC project. In order for this process to function well, the agency needs to maintain the approved product list. This can be done in several ways:

1. The agency can perform the material testing and approval process using in-house staff.

2. The agency can use an on-call materials testing company to assist with evaluation of the materials.
3. The agency can require that the material suppliers submit certified test reports that can demonstrate the performance of the material.

The three methods have their advantages and drawbacks. The first option gives the agency total control over the acceptance of the material; however, it can place a heavy workload on the agency, especially if the material is manufactured by many suppliers. The second option takes the pressure off the agency for testing and acceptance; however, it can be costly if there are many products in the market. The third option is the easiest for the agency; however, the agency relinquishes control of the testing to an outside entity.

Agencies should evaluate each material for inclusion in an approved product list and choose the appropriate acceptance criteria for each material. Different criteria can be used for different materials. For instance, mechanical couplers that are approved primarily on strength can be approved based on a certified test report. Items such as grouts that require multiple tests may be best evaluated using in-house staff or hired testing firms.

Some products are subject to potential variation over time. For instance, grouts may contain cements and aggregates that are obtained from various sources that may vary over time. For these types of products, the agency may choose to re-test products on a regular basis or require certified test reports that were completed within a certain timeframe.

4.3.3. Use of Certified Plants versus Contractor Fabrication

Most agencies require the use of certified fabrication plants for prefabricated beams and girders. They have well established requirements for certifications for this work. The same certifications can be applied to prefabricated elements.

The certification of fabricators of prefabricated products is a subject that has seen much debate in the last five years. Prior to the increased use of prefabricated elements, agencies and contractors agreed that elements such as beams and girders would be fabricated by certified fabrication plants. The advent of more prefabricated elements—especially precast concrete elements—has opened the debate regarding the allowance of self-performance of precast products by general contractors. The theory is that contractors are experienced with forming and placement of reinforcing steel and concrete and that they have the ability to self-perform the fabrication process. The following sections describe the two methods that can be used for fabrication and the implications of each.

4.3.3.1. Fabrication Plant Certifications: Are They Necessary?

There is a difference between prefabricated beams and girders and other prefabricated elements. In most cases, the prefabricated elements will be connected in the field using mechanical connectors or narrow joints.

Prefabricated beams are specified to be fabricated to certain tolerances; however, there is normally room for adjustment in the field if a beam is slightly out of tolerance. The use of mechanical connections and narrow joints can create significant fit-up problems if the elements are fabricated out of tolerance. The companion FHWA manual to this manual entitled "Engineering, Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems" describes the role that tolerances play in the detailing of the joints between prefabricated elements. In general, larger tolerances require larger joints. If the tolerances are set too large, the joint can get wide, which is not as desirable from an aesthetic and durability perspective.

Many of the connections that are used in precast elements place a greater emphasis on tolerances and fit-up, which reinforce a position to use the highest level of fabrication accuracy. Below are several prefabricated bridge element projects in which the fit-up of elements was a problem:

- The Utah DOT had a project in which the precast concrete full depth deck panels were fabricated out of tolerance. There were fit-up problems with the panels, which ultimately had to be re-cast prior to installation.

- The Michigan DOT had similar problems with a prefabricated bridge deck panel project. The skew of the panels led to fit-up problems and necessary re-casting of the panels.

The need to re-cast a panel is always problematic. The problems are less critical if discovered prior to the actual roadway closure. Recasting of panels might delay the start of construction, but will not necessarily change the impacts to the traveling public. Problems discovered during the actual construction are much more disruptive to the project and the traveling public. Re-casting of the elements in question is one option. Another is substituting cast-in-place concrete for the precast element. Both will most likely lead to delays, resulting in the potential loss of incentives and possibly the imposition of disincentives. In the worst cases, the parties may need to settle the issue in court. None of these scenarios are desirable for the agency, the contractor, or the fabricator. Because of this, most agencies require the same certification with precast elements as with beam and girder elements to ensure that the highest degree of fabrication quality is applied to the project.

4.3.3.2. Certifying Contractors for Precast

The previous section described the need for accurate fabrication of elements and the justification for the use of certified fabrication plants. This works well in a developed region of the country where certified fabrication facilities are close to the construction site. The fact is that in some parts of the country, the locations of certified fabrication facilities may be few and far between. Specifying certified fabrication plants can lead to increased cost for shipping of the elements. The agency may choose to allow fabrication of elements by the contractor in order to keep costs in check.

The Utah DOT allows contractors to self-perform the fabrication of non-prestressed element such as deck panels, footings, wall stems, and columns. The contractor is allowed to fabricate elements in a fabrication yard, or in some cases adjacent to the bridge. This is often referred to as near-site fabrication. This approach can dramatically reduce the number of times that an element is handled, which reduces the chance of damaging the element and reduces the cost of shipping and handling of the elements.

Self-performance or near-site fabrication by the general contractor should not eliminate the need for certified fabrication work. The same quality control procedures that are followed in a certified fabrication facility could be applied to the fabrication of elements by contractors. The Utah DOT requires that the contractor obtain the same plant certification as a conventional fabrication facility.

If an agency chooses to use this approach, they should consider the volume of work that is intended to be let in the region. The cost and time required to obtain certification is significant. If this is applied to one project, the cost of this effort will lead to high construction costs. If a program of projects is planned, the contractors will be able to spread the cost of the certification over multiple projects.

4.3.4. Grouting Technician Certifications (Post-Tensioning)

Construction of bridges using bonded post-tensioned concrete is becoming more common in the U.S. Certain forms of ABC make use of bonded post-tensioning including full depth precast concrete deck panels and segmental piers. Problems have arisen in the last 20 years with bonded post-tensioning systems. These problems have included:

1. Accumulation of excessive bleed water at the tendon high points, causing corrosion of tendons and anchorage assemblies.
2. Segregation of grout, leading to the development of low-quality paste at the tendon high points causing corrosion of tendons and anchorage assemblies.
3. Discovery of excessive chlorides in the grout, leading to concerns over the long-term durability of the tendons.

The third problem has been addressed by the industry through better quality control. The first two problems relate to both the grout materials and the installation procedures. Over the last 20 years, the quality of grouts has improved significantly, including the introduction of thixotropic grouts with admixtures to improve performance. The final solution to these problems is with regard to the installation procedures for the grout in the tendons. There are several publications that cover grouting methods and quality control for grout installations in bonded post-tensioning systems. They include:

1. Post-Tensioning Tendon Installation and Grouting Manual [23].
2. Specification for Grouting of PT Structures [24].
3. Guide Specification for Grouted Post-Tensioning [25].

These documents can be helpful; however, hands-on training is often the best way to learn a process. The American Segmental Bridge Institute (ABSI) offers a certification course for supervisors and grouting technicians for post-tensioned structures. The following text is taken from the ASBI training website: (http://asbi-assoc.org/index.cfm/grouting/training).

The purpose of the ASBI Grouting Certification Training is to provide supervisors and inspectors of grouting operations with the training necessary to understand and successfully implement grouting specifications for post-tensioned structures.

Individuals who successfully complete the ASBI Grouting Certification Training and provide verifiable documentation of three years of experience in construction of grouted post-tensioned structures, will receive a certificate as an "ASBI Certified Grouting Technician." The certificate will be valid for a period of five years, and will be renewable at the end of that time through participation in an online recertification examination.

Agencies may choose to specify this training for all contractor supervisors and inspectors on post-tensioning projects. This training is typically held once a year, which may make it difficult for staff to complete the training. The participant must also have three years of experience in grouting procedures, which also complicates the process. Based on this, an agency should plan in advance the need for this certification and consider a program of projects that can be used to justify the effort and cost of obtaining this training. Until more technicians become certified, the agency may choose to consider that the staff be trained under this program, but not require the actual certificate. As the program matures, the specification requirements can be adjusted to match the availability of technicians in the local market.

4.3.5. Grouted Reinforcing Splice Couplers

Grouted reinforcing splice couplers consist of a steel casting that is placed over two reinforcing bars that are to be joined. The final connection is made by injecting grout into the void within the coupler. The grouting of couplers is not a very complicated process; however, maintaining quality control during installation is critical to obtain satisfactory performance of the coupler. There are several manufacturers of these couplers, and each has a different installation procedure.

Specifications for these couplers should require that the installation follow the manufacturer's written installation procedures. An added level of assurance can be obtained by requiring training and/or experience for the installation crew foremen. Some agencies have specified that a representative from the coupler manufacturer be present during grouting of the couplers. This is not normally feasible due to the number of projects that are being built each year. In lieu of this, specifications can require training within a certain amount of time (6 to 12 months) prior to the start of construction. This training can be in person, online, or through videos.

Construction inspectors have noted that practice installations are very helpful in training construction staff on the proper installation procedures. Designers may choose to specify that a connection mockup be built and a connection made prior to the actual construction. The mockup could contain two pieces of precast concrete and several couplers. The same hardware and grout ports should be used as in the finished construction.

Some agencies have expressed concern over the acceptance for grouted reinforcing splice couplers. Testing has shown that the success rate of the couplers is very high. If additional verification testing is needed, the agency can specify that a "sister splice" be made during each grouting operation. The sister splice can be two bars joined with a coupler that is not embedded in concrete. The grouting crew can simply inject grout into the "sister splice" sleeve and cure it alongside the precast elements. Once cured, the "sister splice" can be sent to a testing laboratory for a standard tension test.

4.3.6. Repair of Damaged Elements

The fabrication, lifting, and handling of large prefabricated elements can lead to damage prior to installation. Common damage to precast elements consists of corner spalls, honey comb area, broken reinforcing bar protrusions, and minor cracking. Damage to steel elements typically is limited to bent plates and, in rare cases, cracked welds.

The Precast/Prestressed Concrete Institute has published a bridge member repair manual [26]. This manual can be used to give guidance on the repair of damaged precast concrete bridge elements. The manual offers guidance on the cause of common problems, recommendations on how to eliminate the problems in future pours, and recommendations for repair of the damage.

Repair of steel elements is typically covered in agency specifications. Repair of bent plates can be done using heat straightening. In the worst cases, the portion of the element can be removed and replaced. The AASHTO/AWS Bridge Welding Code [27] contains repair procedures for steel elements.

4.3.6.1. Repair Provisions

Provisions for element repair should be established prior to construction, especially for fast-tracked construction projects. This will expedite the repair process during construction, which will help to prevent delays in element delivery. It is recommended that the documents listed above be references in project specifications. By using these documents, the designer may not need to be involved in a repair process in most cases. Simple repairs can be addressed by the on-site inspector and the fabricator.

4.3.7. Surveying and Layout

The companion manual for this manual entitled "Engineering Design, Fabrication, and Erection of Prefabricated Bridge Elements and Systems" contains a chapter on element tolerances and how to detail a bridge to accommodate tolerances. This manual details the importance of specifying various tolerances for prefabricated bridge projects. Two of the tolerances that are critical to the successful construction of prefabricated elements are the horizontal and vertical erection tolerances. Once a project moves into construction, the application and management of these tolerances are in the hands of the contractor and the construction management staff.

Erection tolerances are based on the use of working lines, working points, and bench mark elevations. All measurements should be made from these data points and lines. Layout of elements by using "center to center" can lead to a build-up of measurement errors. For instance, if five elements are laid out with center-to-center spacing that is one-quarter in too far apart, the last element can be up to one in out of tolerance, which may be enough to make a connection impossible.

Project specifications should require that the contractor provide an independent survey of all layout and element erection tolerances. It is recommended that the agency also complete independent checks of the contractor's survey. The cost of providing multiple surveys can be considered inexpensive insurance for the successful construction of a prefabricated bridge.

Larger prefabricated elements and systems may require off-site fabrication that requires additional survey. In these cases, the same approach should be used, by establishing working points, lines, and an elevation datum. Bridge superstructure systems and some modular deck/beam elements should be built by blocking the beams in the same configuration as in the finished structure. Each bearing location should be set to the same relative elevation and location. The top of deck should also be verified to the same relative elevation as in the finished bridge.

4.3.8. Monitoring Erection Stresses (System Moves)

The lifting and movement of bridge systems can induce very large stresses in the bridge. Bridges installed using SPMTs are typically more critical than bridges installed using lateral slide methods. This is due to the fact that on most SPMT bridge moves, the lifting points are located away from the beam ends in order to accommodate the width and travel path of the SPMTs. Figure 4.3.8-1 shows a typical SPMT bridge move configuration. The end cantilevers of the span can be significant if the bridge site has unfavorable terrain. Figure 4.3.8-2 shows an SPMT bridge installation in Utah. The single span bridge has perched stub abutments that are located at the top of a slope. Even with the installation of temporary soil nail walls, the cantilever of the beam ends is significant. These large cantilevers can induce large negative bending moments in the bridge that can lead to deck and barrier cracking.

There are several ways to accommodate these cantilevers:

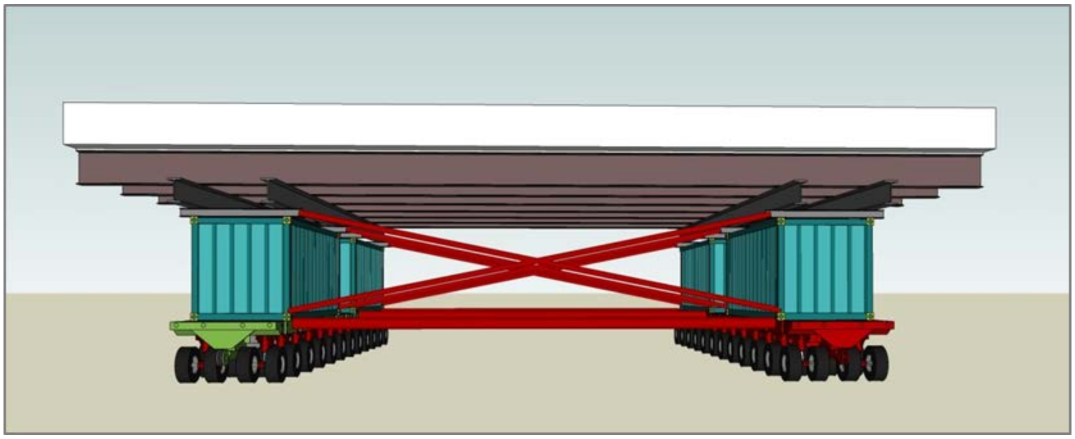


Figure 4.3.8-1. Schematic SPMT Bridge Move Configuration.

Figure 4.3.8-2. Actual SPMT Bridge Move.

1. The deck reinforcing can be designed to resist the negative moments. This approach is similar to the methods used for the design of continuous span bridges.
2. The cantilevers can be reduced (if possible) to limit the amount of bending moment.
3. Lightweight concrete can be used in the deck and barriers. The reduced weight will lead to reduced negative bending moments without sacrificing concrete strength.
4. The bridge can be supported on the lifting points during deck casting. The bridge shown in Figure 4.3.8-2 was supported in this manner. As a result, the deck was in zero tension during the bridge move. Once set in place, the deck was pre-

compressed by the positive moment that was applied to the bridge when it was set.

A number of bridge system installations in Utah have included provisions for monitoring of erection stresses by means of strain gages. This was done to verify the assumptions made during the bridge move. The gages were also used to measure dynamic effects during the move. The results of these moves were studied by Utah DOT and Utah State University. The results indicate that dynamic effects can be estimated to be within 15percent of the dead load stresses. The lifting stresses were also found to be within the range estimated by computations. Based on this, the Utah DOT no longer requires stress monitoring of bridges during bridge moves.

The NCHRP and the AASHTO Bridge Sub-committee has recently initiated a research project that will investigate the lifting and handling stresses in bridges during large scale bridge moves. The goal of this research is to define design provisions for bridge analysis prior to these moves. This research should further justify the elimination of bridge monitoring in the future.

When bridges are moved using SPMTs or lateral sliding technology, the bridge is designed to be well within the elastic range of the materials being used. This means that stress can accurately be equated to deflections. The heavy lift engineer employed by the contractor can determine the allowable deflection and twist that the structure can safely accommodate. Contract specifications for large-scale bridge installations typically require that the contractor establish a deflection monitoring system. These systems can be sophisticated—using lasers and video monitoring devices—or quite simple, using string lines. Both approaches have been successfully employed.

4.4. ACCELERATED MATERIALS TESTING

Rapid construction will inevitably lead to the need to accelerate materials testing. Construction projects that are measured in hours are not congruent with typical testing protocols. This is especially true for testing of cementitious materials such as concrete and grouts. The following sections describe measures that can be taken to accelerate the materials testing process.

4.4.1. On-site Material Testing Equipment

Testing of concrete and grout is typically done in laboratories that are located away from the construction site. In extreme situations where the strength gain of concrete is critical, it may be beneficial to have the testing facility on site during construction. It is relatively easy to set up a simple trailer with concrete testing equipment that can be used to measure compressive strength. The need for on-site testing equipment should be evaluated on a project-by-project basis.

4.4.2. Interim Strength Materials Testing

The companion manual for this manual entitled "Engineering Design, Fabrication, and Erection of Prefabricated Bridge Elements and Systems" explores the concept of assembling a prefabricated bridge using interim materials strength. The basic idea is to check the required strength of materials that will allow for the assembly of the prefabricated elements to move forward. This is based on the fact that most of the materials will not see their full design load until after the bridge is opened to service.

The contractor assembly engineer can determine the required interim strength for each step of the construction. For instance, a concrete closure pour in a footing may only require strength of 2,000 psi in order to support the weight of the substructure and beams. Once the closure pour concrete reaches this strength, the erection of the beams can commence.

Typically, testing of materials is based on the final specified strength. This testing, which is normally done by the agency (or a designated testing company) is still required on ABC projects. The testing of interim strength is normally done by the contractor. This is done so the contractors can test the materials at their convenience. The contractor would be responsible for determining the number of required samples and the timing of the testing of the samples based on the intended construction sequence and the project construction schedule.

4.4.3. Grout Testing

There are several ASTM testing specifications for grouts. Some of the testing is used for product evaluation as opposed to construction operations. An example of this is ASTM C 827 - Standard Test Method for Change in Height at Early Ages of Cylindrical Specimens of Cementitious Mixtures [28]. This test is used for the measurement of non-shrink grout height change.

Identifying grouts using these specifications does not necessarily guarantee acceptable performance. The reason for this is that the test specimens are cured in an unrestrained condition; therefore, the test may not be indicative of grout placed in a confined space. ASTM C 827 is an effective means of measuring the relative shrinkage of various grouts. Agencies may wish to further test grouts in a test pour mockup that is indicative of the actual field conditions. The grout can then be evaluated for flowability and shrinkage based on the actual geometry of the closure pour.

The testing of grouts for strength is included in ASTM C 1107 - Standard Specification for Packaged Dry, Hydraulic-Cement Grout (Non-shrink) [29]. Cylinder samples are not normally used for compression testing of grouts. Compression testing is done using 2x2x2-in cubes. This specification is written for hydraulic cement grouts; however, many agencies use this test for epoxy grouts as well.

The testing of grouts used in bonded post-tensioning systems is somewhat more complex. The companion manual for this manual entitled “Engineering Design, Fabrication, and Erection of Prefabricated Bridge Elements and Systems” describes the specification requirements for tendon grouts. The FHWA Post-Tensioning Tendon Installation and Grouting Manual” [11] also contains recommendations for grout testing including:

- Setting time.
- Grout strength.
- Permeability.
- Volume change.
- Pumpability and fluidity.
- Simulated field high temperature fluidity testing.
- Bleed.
- Corrosion.
- Wet density.

Most of these tests are used for material pre-qualification. On-site testing is typically limited to strength and wet density.

4.4.4. Maturity Meters

The previous FHWA ABC manual entitled “Accelerated Bridge Construction – Experience in Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems” [4] contains the following description of the concrete maturity method:

A maturity method has been developed to assist in the testing process for cast concrete. The maturity method equates a maturity index to the concrete strength of a mix. The concept is based on the proven assumption that concretes of equal maturity will have equal strengths. The maturity index is a function of the age and temperature of the concrete. During mix development, multiple tests are run on samples in order to develop a strength-maturity curve. This method does not normally replace the requirement for concrete cylinder testing; however, it can aid in the determination of when to test the cylinders. In order to use this method, temperature sensors need to be embedded in the placed concrete. Temperatures need to be measured during the entire curing process. From these readings, the maturity index can be calculated and the concrete strength estimated based on the mix development curve.

The intent of this method is not to eliminate the need for compressive strength testing. The benefit of this method is that the timing of the actual compression test can be optimized. The testing can be done when the estimated strength is reached based on the maturity index, as opposed to testing on a set timeframe such as seven days and 28 days. This can be used to reduce the overall construction time by eliminating wasted time waiting for concrete to be tested at regular intervals.

It should be noted that some agencies do not allow the use of maturity meters, so this will be a state-by-state case. It is also important to note that the maturity method requires a significant amount of pre-construction testing in order to develop the maturity index curves. The cost of this is significant; therefore, it should only be used on large projects or time-critical projects.

4.5. SAFETY

4.5.1. Work Zone Safety—Transportation Management Plan

In accordance with the Work Zone Safety and Mobility Rule, State and local agencies are required to develop a transportation management plan (TMP) to effectively address potential safety and mobility impacts on significant projects. As defined in the rule, a significant project is "one that alone or in combination with other concurrent projects nearby is anticipated to cause sustained work zone impacts that are greater than what is considered tolerable based on State policy and/or engineering judgment" [30].

A TMP consists of a set of coordinated strategies laid out to manage work zone impacts of a road construction project. A TMP includes temporary traffic control (TTC) measures and devices, public information (PI), and transportation operations strategies. TTC is often referred to as traffic control plans or maintenance of traffic plans. A TMP will include TTC measures and devices for all projects; on significant projects, a TMP must include strategies for PI and TO.

Despite the shorter time duration for construction, the projects using ABC require developing and implementing TMP strategies based on anticipated work zone impacts. Developing a TMP involves an 11-step, iterative process that might occur during planning, preliminary engineering, and design phases (see Figure 4.5.1-1). However, the scope, content, and level of detail of a TMP may vary based on the anticipated work zone impacts of a project as well as the agency's work zone policies and procedures [31].

The FHWA Work Zone Mobility and Safety Program has developed several guidance documents to help State and local agencies on developing and implementing TMPs. Examples include:

- Developing and Implementing Transportation Management Plans for Work Zones, Report No. FHWA-HOP-05-066 [31]. Appendix B includes a list of potential strategies for TTC, PI, and TO with discussion on consideration factors, and potential advantages and disadvantages for each strategy. Note that innovative construction techniques using ABC is identified as one of the strategies for effective management of traffic and safety impacts in work zones.
- Work Zone Impacts Assessment: An Approach to Assess and Manage Work Zone Safety and Mobility Impacts of Road Projects, Report No. FHWA-HOP-05-068 [32].
- Traffic Analysis Tools Volume IX: Work Zone Modeling and Simulation - A Guide for Analyst, Report No. FHWA-HOP- 09-001 [33].

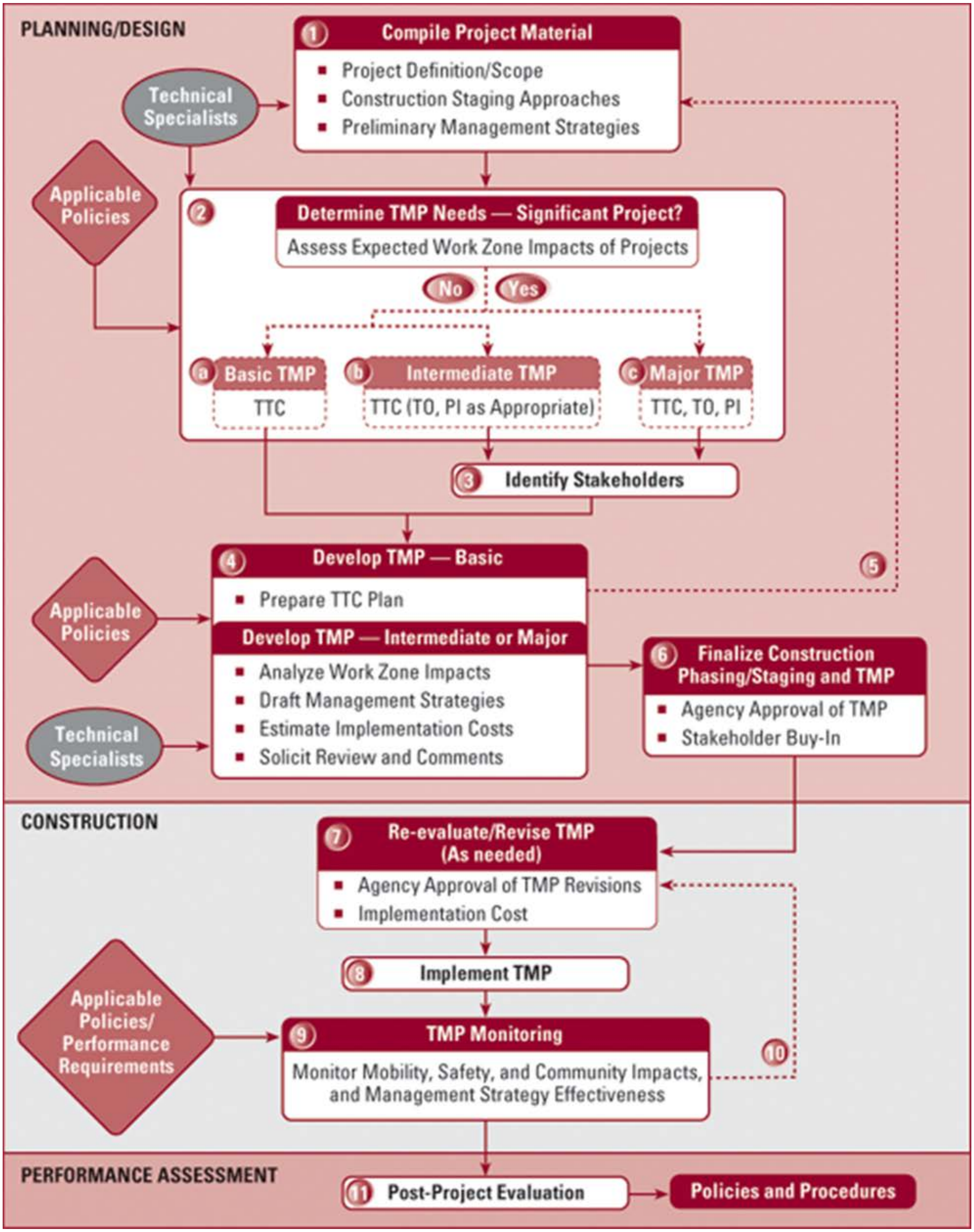


Figure 4.5.1-1. Steps involved in TMP Development. (Source: FHWA, 2005 [31]).

4.5.1.1. Improvements With ABC Projects

By reducing the construction period, the use of ABC greatly reduces exposure of construction crew, agency inspectors, and the traveling public. The reduction in adverse work zone impacts is realized not only through shortening construction duration but also with associated traffic control strategies.

Many owners and entities require multiple full closures when performing critical tasks on traditional projects to reduce exposure of the public. Critical tasks include girder placement, deck forming, deck pours, and form removal. Depending on the type of ABC project, the full closures can range from hours (a small lateral slide, SPMT, or crane lift project moving completed bridges into place) to several weeks for complex projects with multiple activities.

Recent projects where public impacts are a critical aspect for the project received input from the public that a short duration total closure is preferable to a longer phased construction project. Full closures offer the safest work environment. Full closures allow contractors complete access to the site and allow most or all of the construction to be completed in a single closure. Complete closures should always be considered when planning the project.

4.5.2. Construction Safety

In general, construction safety is greatly improved in ABC projects. Recognizing that not all ABC projects would have the same level of reduction in safety risks, the typical ABC project includes these construction-related safety improvements:

- Eliminate or reduce temporary shoring.
- Move fabrication to controlled environments or more accessible locations.
- Limit time spent exposed to traffic.
- Permit off-site daytime construction.
- Increase flexibility in scheduling off-site construction, allowing girder setting to occur in optimal conditions.
- Off-site construction or complete closures permit optimal crane placement.
- Limits major on-site construction activities to times when the road is closed.
- An effective TMP emphasizes the necessity of coordination between the agency and contractor personnel, review of TMP plans, and periodic assessment of work zone performance.

4.5.2.1. Project Specific Safety Orientation

Pre-construction coordination typically is performed during the contractor kick-off meeting to review and refine TMP plans, resolve any coordination issues, and agree on action items to be undertaken during construction [32]. The pre-construction meeting involves active participation of agency, contractor, and third parties, which may include agency construction and contract management staff, inspection staff, project design staff, technical specialists, FHWA, contractors, subcontractors, utility and railroad companies, law enforcement, marketing/public relations staff, businesses, the local community, and other stakeholders.

During the pre-construction meeting, an existing TMP will be reviewed for effectiveness of the proposed strategies as well as compliance to applicable work zone policies, policy provisions, and performance goals/requirements. Either the contractor or the agency can propose changes to the TMP upon review. The TMP is refined informally if the changes are minor and mutually agreeable. If the proposed changes are major, the existing TMP is modified through value engineering proposals or partnering between the agency and contractor.

During construction, the project team meetings are recommended on a regular basis to assess work zone performance and crew safety and to refine TMP strategies as needed [31]. If necessary, the agency may require the construction crew to undergo safety training to ensure compliance with safety procedures, understand project-specific risks, identify site-specific safety hazards, and maintain a high level of safety awareness.

4.5.2.2. Fatigue: Management of Staff Shifts

Rapid renewal projects, such as ABC, typically involve execution of several complex and dynamic activities at a faster pace. Unlike 8- or 10-hour work days associated with conventional construction, ABC projects typically involve extended night work or continuous weekend operations. This rapid pace of construction operations tends to increase cognitive and physical fatigue in workers and results in unintentional and intentional effects such as mistakes, violations, lapses, and slips [34]. These adverse effects can be expensive, causing workforce safety risks such as injuries and fatalities, reduction in quality, and/or reduction in construction productivity. The contractor must undertake countermeasures to prevent worker fatigue. Examples of such countermeasures include frequent rotation of shifts, increased crew size, frequent breaks, team work, and partnering.

Both the agency and the contractor have a shared responsibility in ensuring worker safety through effective management of fatigue-related risks. The agency must ensure the compliance of appropriate OSHA, federal, and state regulations relating to worker fatigue at the job site. Additionally, SHRP2 Reliability Project R03 has produced a guidance document that focuses on developing a fatigue risk management guide for rapid renewal highway construction projects [35].

4.5.3. Coordination with Police and Safety Personnel—Transportation Management Plan

Traffic/incident management and enforcement strategies are an integral part of an agency's TO management. These strategies focus on improved detection, verification, response, and clearance of crashes, mechanical failures, and other incidents in work zones and on detour routes [31].

4.5.3.1. Traffic Management and Monitoring

Work zone traffic management in high-volume, urban corridors can be challenging. Agencies use a wide array of strategies to minimize traffic delays, maintain accessibility and connectivity, and improve work zone safety. These strategies include setting up traffic management centers to coordinate projects at corridor or network level, speed management and enforcement in work zones, use of intelligent transportation systems (ITS) in work zones, and effective traffic incident management.

Most State DOTs use traffic management centers to facilitate the coordination among construction projects and improve traffic operations at the corridor or network. These centers coordinate with construction engineers on a regular basis to discuss work zone performance and related uses. These centers also collect traffic data to monitor performance at work zones as well as corridors, and initiate control strategies when needed. Performance measures such as travel delay time, queue length, and incident clearance time, are used to monitor work zone, corridor, or network level performance. Highway agencies also implement ITS solutions to traffic management, such as dynamic message boards, closed circuit cameras, and traffic sensors. Work zone speed management strategies include the use of law enforcement officers, and automated enforcement techniques such as speed photo radars, speed advisory systems, and variable speed limit systems.

The Work Zone Traffic Management website of the FHWA Work Zone Mobility and Safety Program presents a comprehensive collection of documents focusing on traffic management guidance, specific strategies, examples, and case studies [36].

4.5.3.2. Traffic Law Enforcement

Traffic law enforcement is one effective strategy for traffic and incident management. The presence of uniformed law enforcement offices in work zones is believed to improve driver behavior, maintain appropriate traffic speed, and increase driver awareness and alertness, resulting in improved mobility and safety performance in work zones. Federal Register 23 CFR Part 630 identifies the following conditions as criteria for determining the need for the presence of law enforcement officers [37]:

- Worker presence near high-speed traffic without positive protection devices.
- Traffic control setup or removal that presents significant risks to workers and road users.
- Complex or very short-term changes in traffic patterns with significant potential for road user confusion or worker risk from traffic exposure.
- Night work operations that create substantial traffic safety risks for workers and road users.
- Existing traffic conditions and crash histories that indicate a potential for substantial safety and congestion impacts related to the work zone activity, and that may be mitigated by improved driver behavior and awareness of the work zone.
- Work zone operations that require brief stoppage of all traffic in one or both directions.

- High-speed roadways where unexpected or sudden traffic queuing is anticipated, especially if the queue forms a considerable distance in advance of the work zone or immediately adjacent to the work space.
- Other work site conditions where traffic presents a high risk for workers and road users, such that the risk may be reduced by improving road user behavior and awareness.

Per federal regulations, the cost of law enforcement is reimbursable on a project-by-project or program-wide basis through the federal aid program. Also, the law enforcement officers can be paid by the contractors when the costs are included as a pay item in the construction contract. Penalties and fines collected from work zone violations can also be used as a funding source for law enforcement.

4.5.3.3. Incident Management

Any incident, such as vehicle crashes or breakdowns, can result in immediate reduction in work zone capacity and worsen traffic congestion and safety risks. Swift response is necessary to clear an incident from the travel lanes and restore roadway capacity. Traffic incident management (TIM) is defined as the coordinated, preplanned use of technology, processes, and procedures to reduce the duration and impact of incidents, and to improve the safety of motorists, crash victims, and incident responders [38]. TIM involves five primary phases:

1. Detection/verification.
2. Response.
3. Site management.
4. Clearance.
5. Information management.

Effective traffic incident management requires involvement of the agency, contractor, law enforcement, incident responders, and other stakeholders in the pre-construction phase of a project to devise strategies and implementation procedures. It is essential to establish the roles and responsibilities of each active participant in this process. An incident or emergency management coordinator is recommended to develop incident and/or emergency response plans, coordinate among parties, and monitor incident and/or emergency response activities. As a part of TMP or MOT, agencies should have alternative routes for handling traffic incidence. Potential issues, such as information-sharing bottlenecks, should be clearly discussed during the pre-construction meeting. The agency may conduct training of both incident responders and on-site construction personnel on techniques and procedures to be followed at the incident scene.

The FHWA report entitled "Traffic Incident Management in Construction and Maintenance Work Zones" identifies strategies and techniques for improving incident detection, response, clearance, site management, and information dissemination [38]. This report may serve as a reference document for practitioners in developing or improving incident management strategies.

4.6 PUBLIC INVOLVEMENT DURING CONSTRUCTION

ABC techniques are often utilized to reduce project impacts and durations, and these benefits should be promoted to the public. Although the duration of impacts may be shortened due to ABC techniques, many projects still require road closures or other impacts to the public. Public involvement and outreach during a construction project includes the general public, communities, businesses, appropriate public entities, and other identified stakeholders in understanding project impacts and changing behaviors to reduce them. In early project planning, public meetings and canvassing may be required to help define any problems and identify issues that need to be addressed. The goal of this preliminary process is to identify project stakeholders and their needs. Informing these stakeholders of project activities and impacts while highlighting innovations will ensure public support and reduce problems during construction. Public involvement is critical to the success of an ABC project for several reasons. It can identify and resolve issues before they become problems or project delays. Public involvement can create behavior changes necessary to reduce traffic impacts often associated with ABC techniques. Finally, a strategic public involvement plan can promote the positive benefits of the project, showcase owner efficiency and innovation, and foster goodwill among the traveling public and local residents.

4.6.1. Project Naming and Logos

Naming the project allows the owner to set the tone for the project. If professionals do not name the project, the local media may provide one by default resulting in the owner losing the ability to set the tone for the project. Project names promote the different aspects of a team in stakeholders and contributors. The name and logo make the project instantly recognizable and can improve the impact of public messages and announcements. Select a name and slogan that either describe the project or highlight its positive aspects.

For example, Utah DOT's "Innovate 80" project highlighted the ambitious nature of the project and promoted the owner's use of innovation (see Figure 4.6.1-1). The logo and tagline "12 bridges in 2 months" became well-known across the state. The project name and tagline promoted the scope of the project clearly, highlighted positive project benefits, and announced the owner's intent to the public. This well-crafted brand created a positive connotation with the project and the owner.

Figure 4.6.1-1. Logo for Utah DOT's "Innovate 80" project.

4.6.2. Public Meetings

Public meetings allow the public to become involved and foster ownership and pride in the project. Consistent meetings help direct various comments and unknown problems to the project team to determine the appropriate course of action. Public meetings during an ABC project allow for the owner to demonstrate to the public the benefits of the ABC efforts. Clear, concise, and consistent messaging is also key. Reviewing the project's key messages with the project team before a public meeting ensures message accuracy and team consistency. Attending local community events such as farmer's markets or arts festivals can also be effective ways to engage the public.

4.6.3. Managing Stakeholders

Consistent communication can ease the concerns of major stakeholders. The PI team should be trained to recognize the ABC project's target audience and create a strategic and effective communication plan for those audiences. Providing regular and consistent public involvement professionals for stakeholders helps resolve issues at the lowest possible level, reducing conflict and improving public perception and the project's reputation.

Businesses: A proactive approach with the local businesses results in fewer problems. Giving the affected businesses an early start on preparing for construction impacts can make all the difference. Providing the businesses with advance notification of a project provides them the opportunity to start building their clientele in order to withstand the impacts. Coupons, special deals, added signage, and even website updates help the businesses maintain customers. Consider forming a business advisory team that meets monthly throughout a project. This team can serve as ambassadors for a project and provide information to their peers.

Local Officials: Involving government officials in the construction process and educating them about the benefits of ABC builds a strong reputation for the owner. Consider inviting the elected officials to the construction site to learn about the innovative techniques being used (see Figure 4.6.3-1).

4.6.4. Advertising and Media

Working with the media has become an integral part construction projects. Proactive relationships with the media can assist owners in sharing impact information with the public, and building trust and positive impressions. Reactive relationships with the media are difficult to manage and often lead to negative impressions. Since ABC techniques are often used to reduce impacts to traffic, but can also involve full roadway closures, it is vital to share planned impacts to traffic with the traveling public in advance. When managed strategically and pro-actively, media coverage of traffic impacts can also highlight the ways in which ABC techniques reduce long-term impacts on the public. Use media strategically to promote the owners' intent, reduce project impacts, and to help build positive perceptions with the public

Figure 4.6.3-1. Involve local officials in the ABC construction process to learn about the innovative techniques being used.

Traditional Media and Press Conferences: A standard news release can be a helpful way to communicate to the public. A significant portion of Americans still gets their news from local media outlets via their television feeds, in print, and online. Press conferences can be a great way to highlight innovative ABC techniques used on a project while discussing construction impacts. Press conferences are also a great way for the owner to show the public a human "face." Having a project representative provide technical information can personalize the project for the public and show that the owner has a human side.

Figure 4.6.4-1. Allow the media an opportunity to be at the construction site.

Social Media and the Internet: Social media and the internet have become vital communication methods. The public expects instant communications via the Internet, Twitter, Facebook, YouTube, and other means for sharing information in real time. Transportation agencies serve a public that expects accurate and timely information on demand. Social media and the internet are great ways to interact with a segment of the public that may not utilize more traditional media. The information you put online or on social media is available for your stakeholders when they choose to view it, increasing your reach with minimal effort. Depending on the size of your project, we recommend you develop a project website or a dedicated page on the owner's website.

Utilizing the owner's social media feeds or creating project specific feeds if the project is large enough is recommended. Social networks like these allow you to launch highly segmented advertising campaigns targeting specific user groups and profiles. Age, gender, and geography can all be segmented, as are affiliations with interest groups or pages. You can create ads that directly reach your audiences for a matter of cents. Don't ignore social media and social networks in your outreach strategy. Consider creating messages and targeting participants in social networks and investigate the power of cost-effective advertising using these media.

4.6.6. Organized Site Visits

Organized site visits open to the public, media, and government officials allow the community to be safely involved during a construction project. This hands-on experience can build project allies and help maintain positive relationships for the owner. Many community members have expressed their gratitude after watching a bridge as heavy as 300 elephants, moved into place. Even government officials have found the experience quite exciting. Pointing out the various milestones and letting the public participate in those steps makes for a successful project.

Celebrating Project Milestones: Celebrating project milestones in the public eye helps keep morale up for the affected public as well as the project team. Taking the time to recognize each milestone lets the stakeholders recognize that we are one step closer to finishing the project. Strategically plan your celebration to ensure that it is appropriate and efficient. A large party with a speech from an elected official may be appropriate for one project, while another may only warrant a press release. Be sure to align your celebration with the owner's overall strategy to ensure success.

Public Viewing Opportunities: Many ABC projects feature impressive engineering and equipment. Setting aside areas for public viewing and encouraging the public to attend can be a powerful tool to enhance owner approval ratings and build positive support for the project. Be sure to consider crowd control, pedestrian access, parking, and safety when determining locations for public viewing.

Figure 4.6.6.1-1. Photo from 4500 South showing the public watching the bridge move.

Figure 4.6.6.1-2. Allow community members to participate in an escorted site visit.

CHAPTER 5. COMPLETING THE PROJECT—THE CLOSEOUT PHASE

5.1. LESSONS LEARNED PROGRAM

Winston Churchill once said, “Those who don’t study history are doomed to repeat it.” This cliché can be applied to ABC projects as well as many other subjects. Capturing lessons learned, evaluating them, and acting on the knowledge is the key to continuously improving an owner agency’s ABC program. Not only does the agency want to avoid making the same mistakes twice, but more importantly, it wants to be able to replicate success and leverage the knowledge of what worked well on future projects.

Capturing lessons learned involves both a top-down investigation that seeks to identify system and process issues that caused success and drove deficiencies, and a bottoms-up investigation to identify the true impact of processes, programs, and decisions made during project execution. Project personnel should capture lessons learned as they occur to provide input to the final evaluation and to ensure that they are not forgotten as the project progresses. An effective technique is to create a one-page form for documenting potential lessons learned that project personnel from both the agency and the contractor can submit electronically to be held for future reference.

Developing a lessons learned program essentially involves assembling project stakeholders and asking a series of questions regarding the project. The following is a typical set:

- What went wrong? How was it handled? What was the final impact?
- What worked well? Why did it work well? How can this success be carried over to future ABC projects?
- What would the team change in the project if it had to do it all over again?
- Were there serious conflicts? How were they resolved?
- What risks were realized? Did the contingency plans for these risks work? How was the project impacted?
- Which risks did not materialize? What was the impact to the project?
- Was the team properly staffed and resourced?

Construction projects need to orient lessons learned on the following five areas:

- Quality.
- Cost.
- Schedule.
- Contractual instruments.
- Project management.

5.1.1. Document Successes

Being able to definitively point to project successes requires documentation. The best means for describing success is to be able to measure it. This is particularly critical when new technology is introduced and must be compared with existing systems to determine if the promised benefits of the new technology were actually realized. To do so requires advance planning in order to create meaningful metrics and collect supporting data during project execution. In ABC, metrics such as total closure or traffic disruption time relate directly to the reason for implementing ABC. These metrics need to be balanced by factors such as total cost and cost growth after award or schedule time and schedule growth. Both cost and schedule growth can be negative, indicating a cost or time savings.

To make the ABC metrics meaningful, a benchmark must be established for the existing or traditional technology to provide a standard to measure against. Most owner agencies have project performance metrics in use for their routine bridge construction projects, and in many cases these will suffice. However, if the necessary information isn't available, it may require a specific effort to develop the benchmarks.

Since one aspect of ABC is to minimize impact on the traveling public, validating whether that goal has been achieved may require that a survey is completed of the impacted population. Other techniques, such as accumulating calls from the public to complain or ask for information, are available.

Finally, once project successes have been documented, the information about why these became successes must be recorded and disseminated. A typical example is changing a long-standing policy for lane closures to accommodate ABC techniques. If the change in policy worked well on the ABC project, perhaps a permanent change in that policy would enhance non-ABC projects as well. The Missouri DOT permitted full closure of rural bridges for up to 30 days when it implemented ABC for its "Safe and Sound" bridge replacement program. That agency learned that the traveling public was willing to accept full closures without compliant as long as it saw the contractor working every day. Once the contractor vacated the site or if the closure lasted more than about a month, the complaints began.

5.1.2. Study and Address Deficiencies and Share Them

Construction of any project is a complex undertaking and as such, many things can and will go wrong. The aim of studying deficiencies in an ABC project is to differentiate between those things that went wrong that were under the project personnel's control and those that were not. Unusually severe weather is certainly not anyone's fault, but a careful analysis of its impact should identify potential contingencies that could have been implemented to mitigate its overall impact.

Failing to review and return construction submittals in a timely manner is under the agency's control. In this instance, a forensic evaluation of the submittal process should be made to determine the source of the problem. Possible causes would range from failure to properly resource the submittal review process to personal negligence by a reviewer by deliberately neglecting this responsibility in favor of other less critical activities. The purpose here is not to assign blame but rather to determine how the process can be fine-tuned to reduce the probability of having the same issue on future ABC projects.

Systemic issues like ambiguous specifications or contract clauses must be elevated to agency management once they are identified as the root of a particular deficiency. Personnel issues that are specific to a given individual or team should be separated from those that relate to the sufficiency of the ABC project staffing and resource plan. The first issue must be addressed by agency leaders. The second must be brought forward to the next ABC project so that additional resources can be allocated to avoid a future deficiency.

REFERENCES

1. *Decision-Making Framework for Prefabricated Bridge Elements and Systems (PBES),* U.S. Department of Transportation, Federal Highway Administration, Publication Number FHWA-HIF-06-030, May 2006.

2. *Manual on the Use of Self-Propelled Modular Transporters to Remove and Replace Bridges,* U.S. Department of Transportation, Federal Highway Administration, Publication Number FHWA-HIF-07-022, June 2007.

3. *Connection Details for Prefabricated Bridge Elements and Systems,* U.S. Department of Transportation, Federal Highway Administration, Publication Number FHWA-IF-09-010, March 2009.

4. *Accelerated Bridge Construction – Experience in Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems,* U.S. Department of Transportation, Federal Highway Administration, November 2011.

5. *AASHTO LRFD Bridge Design Specifications,* American Association of State Highway and Transportation Officials, Washington, D.C., 7th Edition .

6. *Project Risk Management – Guidance for WSDOT Projects,* Washington State Department of Transportation, July 2010.

7. Molenaar, K., S. Anderson and C. Schexnayder. *Guidebook on Risk Analysis Tools and Management Practices to Control Transportation Project Costs,* National Cooperative Highway Research Program, NCHRP Report 658, Transportation Research Board, Washington, D.C. 2010.

8. Molenaar, K.R. and C.R. Wilson. *A Risk-Based Approach to Contingency Estimation in Highway Project Development*. 2009 Construction Research Congress, American Society of Civil Engineers, Seattle, Washington, 2009, pp. 786-795.

9. *Risk Assessment and Allocation for Highway Construction Management,* U.S. Department of Transportation, Federal Highway Administration, Publication Number FHWA-PL-06-032, October 2006.

10. *Incentive/Disincentive (I/D) for Early Completion,* Department of Transportation, Federal Highway Administration, Technical Advisory T 5080.10, February 1989.

11. *A Practical Guide to Estimating, AASHTO Technical Committee on Cost Estimating, American Association of State Highway and Transportation Officials, Washington, D.C., 2009.*

12. Gransberg, D.D., J.E. Koch, and K.R. Molenaar. *Preparing for Design-Build Projects: A Primer for Owners, Engineers and Contractors*, American Society of Civil Engineers, Reston, 2006.

13. Molenaar, K., C. Harper and D. Tran. *Guidebook for Selecting Project Delivery Methods and Alternative Contracting Strategies*, Technical Memorandum #1, Next-Generation Transportation Construction Management Transportation Pooled Fund Program Study, October 1, 2012.

14. Touran, A., D.D. Gransberg, K.R. Molenaar, P. Bakhshi, K. Ghavamifar. *A Guidebook for Selecting Airport Capital Project Delivery Methods*, Airport Cooperative Research Program, ACRP Report 21, Transportation Research Board, Washington, D.C., 2009.

15. FHWA, *Contract Administration Core Curriculum Participant's Manual and Reference Guide*, Office of Program Administration, Federal Highway Administration, Washington, D.C., 2006.

16. Molenaar, K., Yakowenko, G. *Alternative Project Delivery, Procurement and Contracting Methods for Highways,* American Society of Civil Engineers, Reston, Virginia.

17. Mallela, J. and S. Sadasivam. *Work Zone Road User Costs - Concepts and Applications*, Report No. FHWA-HOP-12-005, Office of Operations, Federal Highway Administration, Washington, D.C., 2011.

18. Russell, J.S. *Surety Industry: Overview, ACSE Journal of Management in Engineering*, Vol 6. No. 3, American Society of Civil Engineers, 1990.

19. Awad, A. and A.R. Fayek. *Developing a Framework for Construction Contractor Qualifications for Surety Bonding*, Construction Research Congress 2010, American Society of Civil Engineers, 2010.

20. Gransberg, D.D. and C. Riemer. *Performance-Based Construction Contractor Prequalification,* NCHRP Synthesis 390, Transportation Research Board National Academies, Washington, D.C., ISBN 978-0-309-09828-1, 2009, 101pp.

21. UDOT. *Prequalification of Precast Products*, Technical Bulletin MT-05.03A, Utah Department of Transportation, Salt Lake City, November 1, 2011.

22. Building Code Requirements for Structural Concrete (ACI 318-08), American Concrete Institute Committee 318.

23. Post-Tensioning Tendon Installation and Grouting Manual, U.S. Department of Transportation, Federal Highway Administration, May 2004.

24. *Specification for Grouting of PT Structures, Publication Number PTI M55.1-12,* Post Tensioning Institute, Farmington Hills, MI.

25. *Guide Specification for Grouted Post-Tensioning Publication Number PTI/ASBI M50.3-12*, Post Tensioning Institute, Farmington Hills, MI and The American Segmental Bridge Institute.

26. *Bridge Repair Manual, MNL-137-06*, Precast/Prestressed Concrete Institute, Chicago, IL.

27. *AASHTO/AWS Bridge Welding Code, D1.5,* American Association of State Highway and Transportation Officials, Washington, D.C., Sixth Edition 2010.

28. *ASTM C827-10 Standard Test Method for Change in Height at Early Ages of Cylindrical Specimens of Cementitious Mixtures*, ASTM International, West Conshohocken, PA.

29. *ASTM C1107 / C1107M - 11 Standard Specification for Packaged Dry, Hydraulic-Cement Grout (Nonshrink),* ASTM International, West Conshohocken, PA.

30. FHWA, *Work Zone Safety and Mobility Rule*, 23 CFR Part 630, Federal Register Volume 69, Number 174, Federal Highway Administration, Washington, D.C., 2004. http://www.gpo.gov/fdsys/pkg/FR-2004-09-09/html/04-20340.htm.

31. FHWA, *Developing and Implementing Transportation Management Plans for Work Zones*, Report No. FHWA-HOP-05-066, Federal Highway Administration, Washington, D.C., 2005. http://ops.fhwa.dot.gov/wz/resources/publications/trans_mgmt_plans/index.htm.

32. FHWA, *Work Zone Impacts Assessment: An Approach to Assess and Manage Work Zone Safety and Mobility Impacts of Road Projects*, Report No. FHWA-HOP-05-068, Federal Highway Administration, Washington, D.C., 2006. http://ops.fhwa.dot.gov/wz/resources/final_rule/wzi_guide/index.htm.

33. Hardy, M. and K. Wunderlich, *Traffic Analysis Tools Volume IX: Work Zone Modeling and Simulation - A Guide for Analyst,* Report No. FHWA-HOP- 09-001, Office of Operations, Federal Highway Administration, Washington, DC, 2009.

34. Hallowell, M.R. *Worker Fatigue: Managing Concerns in Rapid Renewal Highway Construction Projects*. Professional Safety, American Society of Safety Engineers, Des Plaines, IL, 2010. http://www.asse.org/professionalsafety/pastissues/055/12/018_026_F1Hallo_1210Z.pdf.

35. Sanquist, T., J.E. Jackson, J.L. Campbell, M.C. McCallum, E.B. Lee, H.P.A. Van Dongen, P. McCauley, H. Minor, *Fatigue Risk Management Guide for Rapid Renewal Highway Construction Projects*, Prepublication Draft, Renewal Project 03, Strategic Highway Research Program, Transportation Research Board, Washington, D.C., 2013.
http://onlinepubs.trb.org/onlinepubs/shrp2/SHRP2prepubR03Guide.pdf.

36. FHWA, Traffic Management, Work Zone Mobility and Safety Program, Federal Highway Administration, Washington, D.C.
http://www.ops.fhwa.dot.gov/wz/traffic_mgmt/.

37. FHWA, *Temporary Traffic Control Devices*, 23 CFR Part 630, Federal Register Volume 72, Number 233, Federal Highway Administration, Washington, D.C., 2007. http://www.gpo.gov/fdsys/pkg/FR-2007-12-05/html/E7-23581.htm.

38. Balke, K., *Traffic Incident Management in Construction and Maintenance Work Zones*, Report No. FHWA-HOP-08-056, Federal Highway Administration, Washington, D.C., 2009.
http://www.ops.fhwa.dot.gov/publications/fhwahop08056/fhwahop08056.pdf.

APPENDIX A—ACCELERATED BRIDGE CONSTRUCTION DEFINITIONS

ACCELERATED BRIDGE CONSTRUCTION (ABC)

ABC is 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.

ABC improves:

- Site constructability.
- Total project delivery time.
- Material quality and product durability.
- Work zone safety for the traveling public and contractor personnel.

ABC reduces:

- Traffic impacts.
- On-site construction time.
- Weather-related time delays.

ABC can minimize:

- Environmental impacts.
- Impacts to existing roadway alignment.
- Utility relocations and right-of-way take.

A common reason to use ABC is to reduce traffic impacts because the safety of the traveling public and the flow of the transportation network are directly impacted by on-site construction-related activities. However, other common and equally viable reasons to use ABC deal with site constructability issues. Often, long detours, costly use of a temporary structures, remote site locations, and limited construction periods present opportunities where the use of ABC methods can provide more practical and economical solutions to those offered if conventional construction methods were used.

CONVENTIONAL BRIDGE CONSTRUCTION

Conventional bridge construction is bridge construction that does not significantly reduce the on-site construction time that is needed to build, replace, or rehabilitate a single bridge or group of bridge projects. Conventional construction methods involve on-site activities that are time-consuming and weather dependent.

An example of conventional construction includes on-site installation of substructure and superstructure forms, followed by reinforcing steel placement, concrete placement, and concrete curing, all typically occurring in a sequential manner.

One of the reasons to minimize on-site construction activity is because the long-term presence of contractor-related equipment, labor, and staging areas can present driver distractions and traffic disruptions that reduce the safety and mobility efficiencies of the transportation network.

Time Metrics for ABC

To gauge the effectiveness of ABC, two time metrics are used:

On-site Construction Time

This is defined as the period of time from when a contractor alters the project site location until all construction-related activity is removed. This includes, but is not limited to, the removal of MOT items, construction materials, equipment, and personnel.

Mobility Impact Time

This is defined as any period of time the traffic flow of the transportation network is reduced due to on-site construction activities.

Tier 1: Traffic Impacts within 1 to 24 hours.
Tier 2: Traffic Impacts within 3 days.
Tier 3: Traffic Impacts within 2 weeks.
Tier 4: Traffic Impacts within 3 months.
Tier 5: Overall project schedule is significantly reduced by months to years.

<u>Note</u>*: "Total project" time is the period of time from when project planning begins until the time that all bridge work is completed. Total project time adds a planning time component to the on-site construction time period. It is not a focused metric because planning time is needed regardless of whether a project is planned using ABC or conventional construction methods. Owners recognize that the use of ABC may require varying degrees of planning effort and resource allocations, but choose the ABC approach due to the site constraints, the many benefits of ABC, or a combination of the two.*

PREFABRICATED BRIDGE ELEMENTS AND SYSTEMS (PBES)

Use of PBES is one strategy that can meet the objectives of an ABC. PBES are structural components of a bridge that are built off-site or near the site of a bridge, and include features that reduce the on-site construction time and mobility impact time that occur from conventional construction methods. PBES includes innovations in design and high-performance materials and can be combined with the use of "fast-track contracting" methods. Because PBES are built off the critical path and under controlled environmental conditions, improvements in safety, quality, and long-term durability can be better achieved.

Regardless of the reason(s) to choose PBES, on-site construction time and mobility impact time are typically reduced in some manner relative to conventional construction methods.

Elements

Prefabricated elements are a category of PBES which comprise a single structural component of a bridge. Under the context of ABC, prefabricated elements reduce or eliminate the on-site construction time that is needed to build a similar structural component using conventional construction methods. An element is typically built in a prefabricated and repeatable manner to offset costs. Because the elements are built under controlled environmental conditions, the influence of weather-related impacts can be eliminated and improvements in product quality and long-term durability can be better achieved.

Deck Elements

Prefabricated deck elements eliminate activities that are associated with conventional deck construction, which typically includes on-site installation of deck forms, overhang bracket and formwork installation, reinforcing steel placement, paving equipment setup, concrete placement, and concrete curing, all typically occurring in a sequential manner.

Examples of deck elements include:

- Partial depth precast deck panels.
- Full depth precast deck panels with and without longitudinal post-tensioning.
- Lightweight precast deck panels.
- FRP deck panels.
- Steel grid (open or filled with concrete).
- Orthotropic deck.
- Other prefabricated deck panels made with different materials or processes.

Beam Elements

Prefabricated beam elements are composed of two types: “deck” beam elements and “full width” beam elements.

Deck beam elements eliminate conventional on-site deck forming activities as noted above. To reduce on-site deck forming operations, deck beam elements are typically placed in an abutting manner.

Examples of deck beam elements include:

- Adjacent deck bulb tee beams.
- Adjacent double tee beams.
- Adjacent inverted tee beams.
- Adjacent box beams.

- Modular beams with decks.
- Other prefabricated adjacent beam elements.

<u>Note</u>*: Although not preferred under the context of ABC, a separate construction phase (performed in an accelerated manner) may be required to finish the deck. A deck connection closure pour, overlay, or milling operation using innovative materials can be used to expedite the completion of the deck. In some situations, the placement of overlays can be accomplished during off-peak hours after the bridge is opened to traffic.*

Full-width beam elements eliminate conventional on-site beam placement activities. They are typically rolled, slid, or lifted into place to allow deck placement operations to begin immediately after placement. Given their size and weight, the entire deck is not included.

Examples of Full-Width Beam Elements include:

- Truss span without deck
- Arch span without deck
- Other prefabricated full-width beam element without deck

Pier Elements

Prefabricated pier elements eliminate activities that are associated with conventional pier construction, which typically includes on-site form installation, reinforcing steel placement, concrete placement, and concrete curing, all typically occurring in a sequential manner.

Examples of Pier Elements include:

- Prefabricated caps for caisson or pile foundations
- Precast spread footings
- Prefabricated columns
- Prefabricated column caps
- Prefabricated combined caps and columns
- Other prefabricated pier elements

Abutment and Wall Elements

Prefabricated abutment and wall elements eliminate activities that are associated with conventional abutment and wall construction, which typically includes form installation, reinforcing steel placement, concrete placement, and concrete curing, all occurring in a sequential manner.

Prefabricated abutment and wall elements may be built in a phased manner using conventional construction methods, but under or near an existing bridge without disrupting traffic.

Examples of abutment and wall elements include:

- Prefabricated caps for caisson or pile foundations.
- Precast footings, wing walls, or backwalls.
- Sheet piling (steel or precast concrete).
- Prefabricated full height wall panels used in front, behind, or around foundation elements.
- CIP concrete abutments and walls used with or without precast elements if built in a manner that is accelerated, or has no impact to mobility.
- MSE, modular block, or proprietary walls.
- GRS abutment.
- Other prefabricated abutment or wall elements.

Miscellaneous Elements

Prefabricated miscellaneous elements either eliminate various activities that are associated with conventional bridge construction or compliment the use of PBES.

Examples of miscellaneous elements include:

- Precast approach slabs.
- Prefabricated parapets.
- Deck closure joints.
- Overlays.
    - Includes overlays that can be placed in an accelerated manner that complements or enhances the durability and rideability of the prefabricated element other prefabricated miscellaneous elements.

<u>Note</u>*: Any cast-in-place concrete or overlay placement operation should be performed in a manner that reduces the impacts to mobility. This may require work that is performed under "Fast Track Contracting" methods with incentive/disincentive clauses, nighttime or off-peak hour timeframes, or work done entirely off line. Innovative materials may be needed to expedite placement times such as the use of rapid-set/early-strength-gain materials or ultra-high-performance concrete (UHPC) in closure pours.*

Systems

Prefabricated systems are a category of PBES that consists of an entire superstructure, an entire superstructure and substructure, or a total bridge that is procured in a modular manner such that traffic operations can be allowed to resume after placement. Prefabricated systems are rolled, launched, slid, lifted, or otherwise transported into place, having the deck and preferably the parapets in place such that no separate construction phase is required after placement. Due to the manner in which they are installed, prefabricated systems often require innovations in planning, engineering design, high-performance materials, and "Structural Placement Methods."

Benefits of using prefabricated systems include:

- Minimal utility relocation and right-of-way take (if any at all).
- Minimal or no traffic detouring over an extended period of time.
- Preservation of existing roadway alignment.
- No use of temporary alignments.
- No temporary bridge structures.
- Minimal or no traffic phasing or staging.

Superstructure Systems

Superstructure systems include both the deck and primary supporting members integrated in a modular manner such that mobility disruptions occur only as a result of the system being placed. These systems can be rolled, launched, slid, lifted, or transported in place, onto existing or new substructures (abutments and/or piers) that have been built in a manner that does not impact mobility.

Examples of superstructure systems include:

- Full width beam span with deck.
- Through-girder span with deck.
- Truss span with deck.
- Arch span with deck.
- Other prefabricated superstructure systems.

Superstructure/Substructure Systems

Prefabricated superstructure/substructure systems include either the interior piers or the abutments, which are integrated in a modular manner with the superstructure as described above. Superstructure/substructure systems can be slid, lifted, or transported into place onto new or existing substructures that have been built in a manner that does not impact mobility.

Examples of superstructure/substructure systems include:

- Rigid frames with decks and parapets.
- Other prefabricated superstructure/substructure systems.

Total Bridge Systems

Total bridge systems include the entire superstructure and substructures (both abutments and piers) that are integral with the superstructure that are built off-line and installed in a manner to allow traffic operations to resume after placement. This excludes projects that are built off-line and, once complete, traffic “shifted” to the new alignment. Total bridge systems typically require innovations in designs, high-performance materials, and “structural placement methods” with or without the use of “fast track contracting” methods.

Examples of total bridge systems include:

- Total bridges of any kind, rolled/launched/slid/lifted into place.
- Rigid frames with decks, parapets, and integrated substructures.
- Other prefabricated total bridge systems.

The following pages contain examples of the most common prefabricated bridge elements and systems:

Table A1. Deck Element Examples.

Deck Elements	Examples
Partial-depth precast deck panels	

Deck Elements	Examples
Full-depth precast deck panels with and without longitudinal post-tensioning Lightweight precast deck panels	 
FRP deck panels	

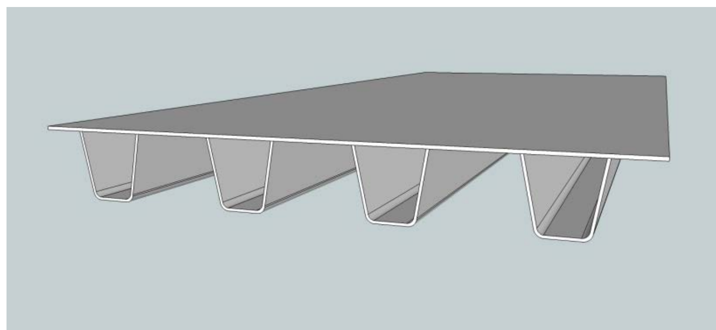
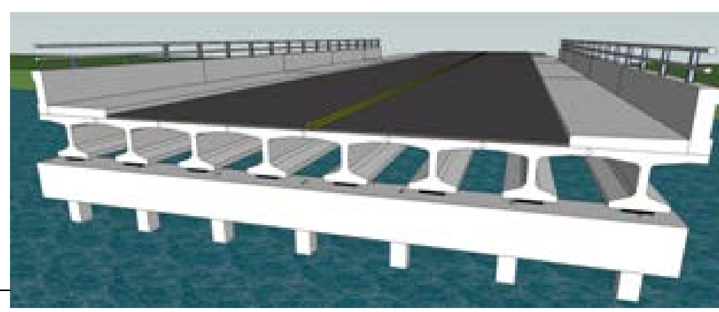
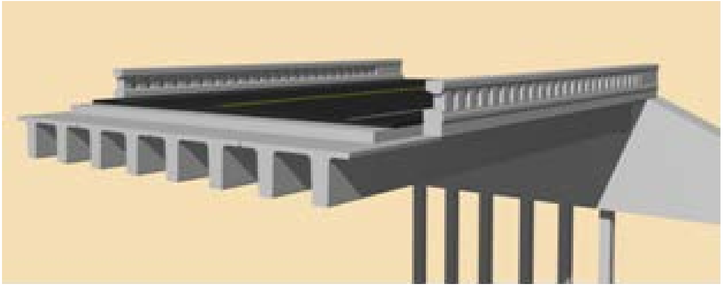
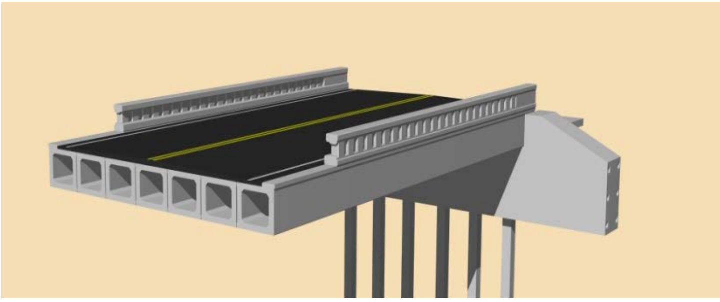
Deck Elements	**Examples**
Steel grid (open or filled with concrete)	
Orthotropic deck	

Table A2. Deck Beam Element Examples.

Deck Beam Elements	Examples
Adjacent deck bulb tee beams	

Deck Beam Elements	Examples
Adjacent double tee beams	
Adjacent inverted tee beams	
Adjacent box beams	

Deck Beam Elements	Examples
Modular beams with decks	

Table A3. Full Width Beam Element Examples.

Full Width Beam Elements	Examples
Truss span without deck	
Arch span without deck	

Table A4. Pier Element Examples.

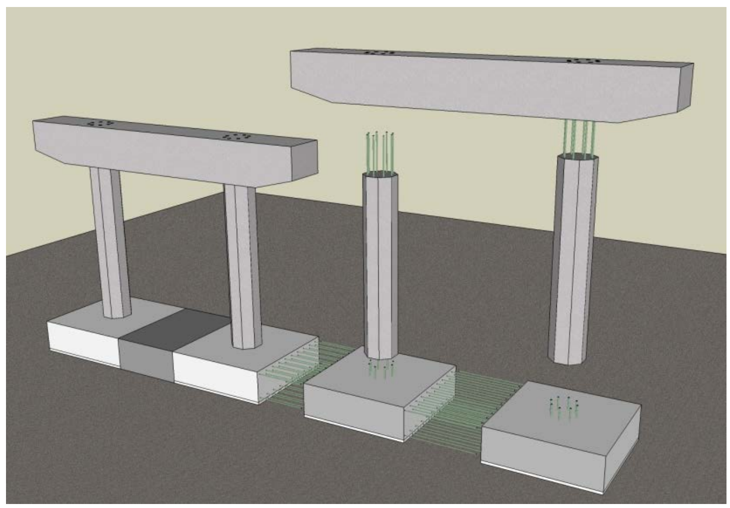
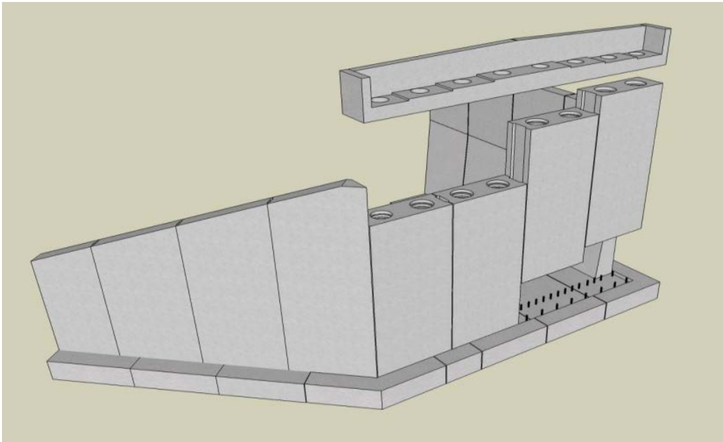
Pier Elements	Examples
Prefabricated caps for caisson or pile foundations	
Precast spread footings Prefabricated columns Prefabricated column caps	

Table A5. Abutment and Wall Element Examples.

Abutment and Wall Elements	Examples
Prefabricated caps for caisson or pile foundations	
Precast footings, wing walls, or backwalls	
Sheet piling (steel or precast concrete)	

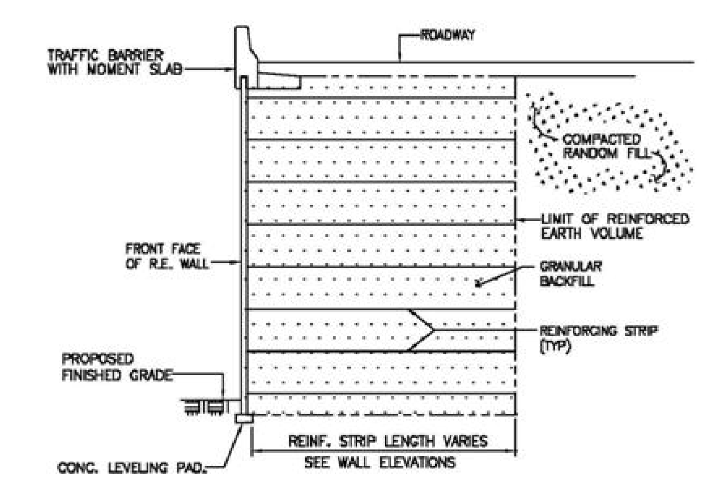
<table>
<tr><th>Abutment and Wall Elements</th><th>Examples</th></tr>
<tr><td>Prefabricated full height wall panels used in front, behind, or around foundation elements</td><td></td></tr>
<tr><td>MSE, modular block, or proprietary walls</td><td>
</td></tr>
<tr><td>Geosynthetic Reinforced Soil (GRS) abutment</td><td></td></tr>
</table>

Table A6. Prefabricated System Examples.

System	Examples
Superstructure Systems Full-width beam span with deck	 
Total Bridge System Total bridges of any kind rolled/launched/slid/lifted into place	

APPENDIX B—GLOSSARY OF TERMS

The following terms may be used in this document. The description of each term is written in the context of this document.

Term	Description
accelerated bridge construction	Construction methods that result in an overall decrease in construction time when compared to the historic construction methods used to build bridges.
additives	Substances (typically chemical) that are added to a grout mixture to counteract the natural tendency of grouts to shrink.
air release grouts	A type of grout that does not rely on a chemical reaction to achieve expansion. The additive reacts with water to release air and cause expansion of the grout.
anchor rods	Steel rods that are used to transfer loads from the superstructure to the substructure. Often referred to as “anchor bolts,” anchor rods differ in that they do not have a hexagonal head. Anchor rods are normally specified according to ASTM F1554.
approach slabs	Structural slabs that span between the bridge abutments and the approach fill. They are used to span across the potential settlement of the approach roadway fills directly behind the abutments.
backwall	A structural wall element that retains the backfill soils directly behind the beam ends on a bridge abutment.
barrier	A structural wall element that is used to contain aberrant vehicles. They can be used on the bridge (parapet), or on the approach roadway.
batching	The process of combining and mixing the materials to form concrete.
bearing	A structural element that connects the bridge superstructure to the substructure, while allowing for movements such as thermal expansion and contraction.

benefit-cost analysis	The comparison of benefits over time and of costs over time for proposed projects. BCA is a tool used to aid in public investment decision-making by measuring the efficiency of spending from the viewpoint of the net benefit to society.
bleed water (grout)	Water that seeps out of the surface of a grout due to expansion of a grout in a confined or semi-confined area.
blockouts	Voids that are cast in prefabricated concrete elements that are used in connecting the elements in the field.
bottom up estimating	A process of construction estimating that breaks the individual tasks into discrete segments where the cost for time, equipment, and materials can be determined for each segment. The total of all segments are then combined for the total construction estimate.
breastwall	A wall that is typically non-structural that covers the beam ends at the corners of the bridge abutments. Sometimes referred to as "cheekwalls" by some states.
bridge deck	A structural slab that spans between support elements (typically beams and girders) on a bridge. Bridge decks can be made of many materials, including reinforced concrete, steel, timber, fiber reinforced polymers, etc.
cable restrainers	Structural elements that are used to restrain a bridge superstructure from excessive lateral movement during seismic events. The goal is to prevent the superstructure from falling off the substructure, which is a very common form of failure during seismic events.
camber	A geometric adjustment of a bridge beam that is designed to compensate for the vertical deflection of the beam when subjected to dead loads. Camber is typically built into steel beams during fabrication. Camber is an inherent side effect of prestressed girder construction.
carbon fiber	A material used in fiber reinforced polymer elements (FRP) to provide the structure performance. These fibers are oriented parallel to the direction of stress.
cast-in-place concrete	Concrete that is cast on site (as opposed to cast in a fabrication plant).

cheekwall	A wall that is typically non-structural that covers the beam ends at the corners of the bridge abutments. Sometimes referred to as “breastwalls” by some states.
cofferdam	An enclosure used to retain water and support excavation in order to create a dry work environment. Typically used for bridge substructure construction in rivers and along river banks.
composite beam action	The process of connecting the bridge deck to the beams or girders to form a combined structural element.
composites	The combining of multiple structural materials to form a structural element.
compressive strength	The value of uniaxial compressive stress reached when a material fails.
concrete	A construction material that consists of cement (commonly portland cement), coarse aggregates (such as gravel limestone or granite), fine aggregates (such as sand), and water. Often, other materials are added to improve the structural properties such as chemical admixtures and other cementitious materials (such as fly ash and slag cement).
concrete/steel hybrid decks	A structural bridge deck system that combines structural steel elements with composite concrete to create a prefabricated deck system.
confinement steel	Reinforcing steel used to contain the concrete core of a column when subjected to plastic deformations brought on by seismic loading.
consistency	The state of a mixture of materials where the formulation is of uniform quality.
constructability	The extent to which a design of a structure provides for ease of construction yet meets the overall strength and quality requirements.
construction joints	Joints in structures that are used to facilitate the construction of a portion of the structure. Construction joints typically have reinforcing steel passing from one side of the joint to the other, providing continuity of the joined elements.

construction stages	A process of building a bridge in segments in order to maintain traffic during construction.
continuity connection	A connection used to connect two longitudinal bridge elements (beams) to form a continuous bridge system. Typically, these connections are only designed to resist live load.
continuous spans	A structural system where the beams span across more than two supports without joints.
contraction joints	Joints in structures that are used to allow the concrete elements to shrink without causing excessive cracking. Contraction joints typically do not have reinforcing steel passing from one side of the joint to the other.
controlled density fill	See "flowable fill."
conventional bridge construction	Construction methods that do not include prefabrication. Methods that employ non-adjacent butted girders that have CIP concrete deck and CIP concrete substructures.
cover concrete	The specified minimum distance between the surface of the reinforcing bars, strands, post-tensioning ducts, anchorages, or other embedded items, and the surface of the concrete.
critical path	The portion of the sequence of construction activities which represents the longest overall duration. This in turn determines the shortest time possible to complete a project.
cross frame	A transverse structural element connecting adjacent longitudinal flexural element used to transfer and distribute vertical and lateral loads and to provide stability during construction. Sometimes synonymous with the term "diaphragm."
crown	The apex of the roadway cross slope.
curing compounds	Chemical compounds that are used to prevent the rapid evaporation of water from concrete during curing.
curb	A structural element that is constructed at the edge of the bridge deck that is used to contain rain water runoff. Curbs are often combined with structural railings to retain vehicles.

debonding	The process of disconnecting prestressing strand from the surrounding concrete in a prestressed concrete element. This is done to control stresses in prestressed elements (typically at the ends of the element).
deck	The structural portion of a bridge that is directly beneath the wheels of passing vehicles.
dewatering	The process of removing water from an excavation that is below the water table or surface of adjacent water.
diaphragm	A transverse structural element connecting adjacent longitudinal flexural element used to transfer and distribute vertical and lateral loads and to provide stability during construction. Sometimes synonymous with the term “cross frame.”
differential camber	A variation on the camber of two adjacent beams. See “camber.”
dimensional growth	The phenomenon that results in the change in overall structure width or length when multiple elements are butted together. This is brought on by a build up of element side variations or tolerances that are a result of the fabrication process.
distribution direction	A direction that is normally parallel to the supporting members and is perpendicular to the direction of beam action in reinforced concrete slabs that are designed for one-way slab action.
drilled shafts	A deep foundation unit, wholly or partly embedded in the ground, constructed by placing fresh concrete in a drilled hole with or without steel reinforcement. Drilled shafts derive their capacity from the surrounding soil and/or from the soil or rock strata below its tip. Drilled shafts are also commonly referred to as caissons, drilled caissons, bored piles, or drilled piers.
dry pack grout	A form of grout that has very stiff consistency that is placed by packing the material into voids by hand and hand tools.
effective prestress	The stress or force remaining in the prestressing steel after all losses have occurred.

elastomeric bearing pads	A type of structural bearing that is comprised of virgin neoprene or natural rubber. Sometimes combined with internal steel plates, fiberglass sheets, or cotton duck sheets.
emulation design	A design method where a prefabricated connection is designed and detailed to act as (or emulate) a conventional concrete construction joint.
epoxy adhesive anchoring systems	A method of embedding reinforcing rods into hardened concrete to form a structural connection. The process involves a drilled hole and a chemical adhesive. *Note: Epoxy adhesive anchoring systems should not be used in sustained tension applications.*
epoxy grouts	Grout materials with chemical adhesives used in place of cementitious materials.
ettringite expansive grout	Ettringite is crystal that forms as a result of the by-product of reactive chemicals that can be interground into the cement in expansive grouts to produce non-shrink grout.
exodermic bridge deck	A bridge deck system that is composed of a steel grid deck combined with a top layer of concrete to form a composite system. This system differs from filled grid decks in that the concrete is placed above the top of the grid to maximize the composite action between the steel and the concrete.
expansion joints	Joints in structures that are used to allow the concrete elements to expand and contract with temperature variation without causing excessive cracking. Expansion joints are similar to contraction joints except they are normally wider and often include a compressible material to allow for thermal expansion. They also do not have reinforcing steel passing from one side of the joint to the other.
fiber reinforced polymers (FRP)	A structural matrix of materials used to produce a structural element. FRP is commonly made of reinforcing fibers that are combined with polyester, epoxy, or nylon, which bind and protect the fibers from damage and transfers the stresses between fibers. FRPs are typically organized in a laminate structure, such that each lamina (or flat layer) contains an arrangement of unidirectional fibers or woven fiber fabrics embedded within a thin layer of light polymer matrix material. The fibers, typically composed of carbon or glass, provide the strength and stiffness.

filled steel grids	A bridge deck system that is composed of a steel grid deck combined that is either fully or partially filled with concrete.
flowable fill	A material used to rapidly fill a void in embankment backfills or under structures without compaction. It normally has high flow characteristics. It is commonly made up of sand, water, and a minor amount of cement. It is also referred to as "controlled density fill."
flying wingwalls	Walls used to retain embankment soils at the corners of abutments that are cantilevered from the end or rear of the abutment, as opposed to being supported on a footing.
foam block fill	A material made with expanded polystyrene (EPS) used to rapidly fill embankments where low unit weight materials are desired. This is often used over highly compressible soils such as clays. This material is also referred to as geofoam.
full-depth precast concrete deck slabs	A bridge deck system that is composed of reinforced concrete elements that when placed, make up the full structural deck system.
gantry crane	A crane type that is characterized by two or more legs supporting an overhead beam with a traveling trolley hoist.
gas generating grout	A type of non-shrink grout that expands due to the production of gas during the curing process. The gas is generated by adding reactive materials to the mix (often aluminum) to produce the gas.
general zone	Region adjacent to a post-tensioned anchorage within which the prestressing force spreads out to an essentially linear stress distribution over the cross-section of the component.
geosynthetic reinforced soil integrated bridge system (GRS-IBS)	Geosynthetic Reinforced Soil (GRS) technology consists of closely spaced layers of geosynthetic reinforcement and compacted granular fill material. GRS–IBS includes a reinforced soil foundation, a GRS abutment, and a GRS integrated approach. When integrated with a bridge superstructure, the system blends the embankment with the superstructure to act as a single unit with respect to settlement.

girder-floorbeam bridges	A bridge framing system that is composed of main girders that run parallel to the centerline of the roadway combined with transverse floorbeams that support the deck. Often, the system includes stringer beams that run between floor-beams (parallel to the roadway).
glue laminated wood	A structural framing material that consists of multiple lay-ers of dimensional lumber glued together to form a large timber element.
greenfield	A construction area where a bridge or highway is being built on land that previously did not support a roadway or bridge.
grout	A material (often cementitious or epoxy) that is used to fill voids between elements.
grouted reinforcing splice couplers	A proprietary product used to join precast concrete ele-ments by connecting reinforcing steel bars at the ends of the elements. They consist of a steel casting sleeve that is filled with grout. The reinforcing bars are inserted into the ends of the casting and developed by the interaction of the grout with the sleeve.
haunch	The material between the top of a beam element and the bottom of the bridge deck that gaps the space between the two elements (also referred to as the “web gap” in some states).
high early strength con-crete	A concrete mixture that gains strength rapidly in order to accelerate construction.
integral abutment	A bridge abutment type that is made integral with the bridge superstructure through a combined shear and mo-ment connection. They are often constructed with a single row of piles that allow for thermal movement and girder rotation. Soil forces behind the abutments are resisted through the strut action of the superstructure.
integral abutment connec-tion	The connection between the superstructure and the integral abutment substructure that can resist both shear and mo-ment.
integral pier connection	The connection between the superstructure and the pier substructure elements that can resist both shear and mo-ment.

keeper assemblies	Devices that are placed on top of substructures to prevent lateral movement of the bridge superstructure. They are often used to resist lateral seismic forces. They can be constructed with structural steel or reinforced concrete.
leveling bolts	Bolt assemblies embedded in various prefabricated elements that are used to make grade adjustments in the field during construction.
life-cycle cost analysis	A process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs—such as maintenance, user costs, reconstruction, rehabilitation, restoring, and resurfacing costs—over the life of the project segment.
local zone	The volume of concrete that surrounds and is immediately ahead of the anchorage device and that is subjected to high compressive stresses.
match casting	A process of joining two precast concrete elements with high precision. This is done by casting one element against the adjoining element in the fabrication yard, separating them, and then re-joining them in the field. The field connection is normally made with thin epoxy adhesives combined with post-tensioning.
mechanical splices	Devices used to connect reinforcing through mechanical means. Examples of these systems include grouted sleeves, wedge assemblies, and threaded bar ends.
mechanically stabilized earth (MSE) retaining walls	A soil-retaining system, employing either strip or grid-type, metallic, or polymeric tensile reinforcements in the soil mass, and a facing element that is either vertical or nearly vertical. In this system, the soil mass is engaged by the strips to become a gravity type retaining wall.
mild reinforcement	Steel bars or grids within concrete elements that are used to resist tension stresses. Mild reinforcement normally consists of deformed steel bars or welded wire fabric.
modular block retaining walls	A soil-retaining system employing interlocking soil-filled timber, reinforced concrete, or steel modules or bins to resist earth pressures by acting as gravity retaining walls.
near site fabrication	A process of constructing prefabricated elements near the bridge construction site in order to minimize problems with shipping of large elements.

network arch bridge	A type of tied arch that includes suspender cables that are run diagonally, forming a crisscrossing pattern.
non-shrink cementitious grout	A structural grout used for filling voids between elements that is formulated with cement, fine aggregates, and admixtures. The admixtures are used to provide expansive properties of the material during curing. This expansion counteracts the natural tendency of cement grouts to shrink during curing.
one-way slab	A reinforced concrete slab system that primarily spans between two parallel support members. In this system, the majority of the reinforcing runs perpendicular to the support members.
open grid decks	A bridge deck system that is composed of an open steel grid spanning between supporting members.
orthotropic bridge deck	A steel bridge deck system comprised of a top deck plate supported by open or closed ribs that are welded to the top plate.
parapet	A structural element that is constructed at the edge of a bridge deck that is used to contain aberrant vehicles.
partial-depth precast concrete deck panels	A bridge deck system that consists of relatively thin precast concrete panels that span between supporting members that are made composite with a thin layer of site-cast reinforced concrete. The precast panel makes up the bottom portion of the structural slab. The site cast concrete makes up the remainder of the structural slab.
pier box	A prefabricated system that includes a precast concrete box that is placed over driven piles or drilled shafts. The box becomes the form to contain site cast reinforced concrete. Often, pier boxes are used in water applications to form a cofferdam for the footing concrete.
pier cap	A structural beam spanning between pier columns.
pier column	The vertical structural element in a bridge pier.
pile bent pier	A bridge pier without a footing that is comprised of driven piles or drilled shafts supporting a pier cap.
pile cap footing	A footing that is supported by driven piles or drilled shafts.

plastic hinge	A method of dissipating lateral seismic forces by allowing portions of reinforced concrete pier columns to bend beyond the yield point. Stability of the structure is maintained by providing adequate confinement reinforcement.
post-tensioning ducts	A form device used to provide a path for post-tensioning tendons or bars in hardened concrete.
post-tensioning (PT)	A method of prestressing in which the strands or bars are tensioned after the concrete has reached a specified strength.
precast concrete	Concrete elements that are cast in a location other than their final position on the bridge.
prefabrication	The process of building bridge elements prior to on-site construction in order to accelerate the construction of the bridge.
prefabricated bridge elements	Portions of a bridge structure that are constructed away from the final bridge site.
prefabricated bridge systems	Portions of a bridge structure that are made up of several elements that are combined to form a larger portion of the bridge such as the superstructure, substructure, or the entire bridge.
prestressed concrete	Concrete elements in which force is introduced into the element during fabrication to produce internal stresses that are normally opposite of the anticipated stresses in the completed structure. Prestressing can be accomplished with pre-tensioning or post-tensioning.
pre-tensioning	A method of prestressing in which strands are tensioned before the concrete is placed, and released after the concrete has hardened to a specified strength.
quality assurance	The process of inspection and control during fabrication to ensure that the specified quality is achieved.
reflective cracking	A crack that can form in site-cast concrete that is placed over a joint between two elements below the pour.
reinforced closure pours	A method of connecting two prefabricated elements by casting a segment of reinforced concrete between two elements. The connection is often made using lap splices or mechanical reinforcing connectors.

reinforced concrete	Concrete elements with reinforcing steel cast into the concrete to form a structural element. The steel is normally used to resist tension stresses in the element.
reinforcing steel	Steel placed in concrete elements (can be either mild reinforcement or prestressing steel).
return on investment (ROI)	Measurement of the efficiency of spending from the viewpoint of the net benefit to society. ROI analysis is essentially identical to benefit/cost analysis, incorporating benefit concepts that do not directly result in a revenue stream.
right of way	The land used for the route of a railroad or public road.
road user costs	Costs incurred by users of a highway network when they are delayed due to construction activities.
saturated surface dry (SSD) condition	A condition that is normally specified for concrete surfaces to be grouted. SSD describes the condition of the concrete surface in which the pores are filled with water; however, no excess water is on the surface. This condition minimizes the absorption of water from the grout into the surrounding concrete.
segregation	A condition where the distribution of course or fine aggregates in the concrete or grout mix become non-uniform.
self-propelled modular transporter (SPMT)	A high capacity transport trailer that can lift and move prefabricated elements with a high degree of precision and maneuverability.
shear key	A shaped joint between two prefabricated elements that can resist shear through the geometric configuration of the joint.
shear studs	Headed steel rods that are welded to elements to provide composite action between two bridge elements. Typically used between beams and the deck slab.
sheeting	A structural system used to retain earth and water and allow for excavation during the construction of a bridge substructure.
shims pack	Flat plates placed between two prefabricated elements used to provide a specified separation. Shims are also used to make vertical grade adjustments. Shims are typically made of steel or polymer sheets.

shrinkage (grout)	A property of cementitious concretes and grouts that occurs during curing where the material reduces in size.
skew angle	In most state agencies, this is defined as the angle measured between the centerline of the bridge elements (abutments, piers, joints, etc.) and a line perpendicular to the roadway alignment (i.e. a bridge with zero skew is square bridge). This definition is used in this manual. Several states define the skew angle as the complimentary angle (i.e. a bridge with 90-degree skew is square).
spandrel wall	A wall that is constructed on the sides of earth-filled arch structures that are used to retain the fill soils.
spiral reinforcement	Transverse reinforcement used in reinforced concrete columns to resist shear. Spirals are also used for confinement of the concrete core as a plastic hinge forms.
steel stay-in-place forms	Corrugated steel sheeting that is used to support the wet concrete in a bridge deck during construction and left in place in the permanent structure.
strength direction	A direction that is normally perpendicular to the supporting members and is parallel to the direction of beam action in reinforced concrete slabs that are designed for one-way slab action.
stress laminated timber deck bridges	A timber bridge deck that is comprised of multiple layers of dimension lumber placed on edge and connected with transverse prestressing. Shear transfer between the laminations is accomplished through friction.
stringers	There are two common uses for this term. (a) Longitudinal steel beams on short span multi-beam bridges. (b) Secondary framing members on floor beam type bridges that span from floor beam to floor beam.
stub abutments	A short cantilever type abutment that is constructed near the top of the approach embankment.
substructure	The portion of the bridge that is below the beam and/or deck elements. It typically includes piers, abutments, and walls.

superstructure	The portion of the bridge that is above substructure. It typically includes bearings, beams, girders, trusses, and the bridge deck.
surface preparation (grout)	The process of preparing a concrete surface for grouting by cleaning or intentionally roughening the surface. This is done to improve the adhesion of the grout to the concrete. It typically includes sand blasting, water blasting, or hand tool cleaning.
sweep	The lateral curvature of a prefabricated element caused by fabrication form irregularities and/or internal stresses.
test pours and test mock-ups	A method of quality control whereas a contractor will build a model of a portion of the bridge structure that includes a void that requires grout placement. These are used to demonstrate proper grout placement in complex voids.
tied arch	An arch structure where the thrust forces at the supports are resisted by a continuous bottom chord that runs from end to end.
timber deck panels	Prefabricated timber panels that are made with glue laminated lumber.
tolerance	Specified allowable dimensional variations in prefabricated elements. The variations are a result of irregularities in formwork and minor deviations in measurements during fabrication.
transverse ties	Reinforcement used in reinforced concrete columns to resist shear. Ties, if properly detailed, can also be used for confinement of the concrete core as a plastic hinge forms.
tremie concrete pour	Concrete that is placed underwater and within a cofferdam to resist the vertical pore pressure of the water below a footing during construction.
ultra high performance concrete	Specially formulated concrete that can attain very high strength through the use of specialized mix ingredients including high strength steel fibers. The fibers increase the compressive strength as well as the tensile strength.
variable web gap	See “Haunch.”
water content	The specified amount of water in a concrete or grout mix.

wearing surface	The top portion of the bridge deck that is directly below the vehicle tires. Often, wearing surfaces are designed to be sacrificial and replaceable.
wet curing	Curing is the process of retaining sufficient moisture (water) in freshly placed grout/concrete to complete the hydration reaction, which occurs when water is introduced to portland cement. Wet curing leaves the freshly placed grout/concrete in an environment of 100 percent humidity.
working time	The amount of time that a concrete or grout mix remains in a liquid or plastic state so it can be placed and consolidated.
yield strength	The stress at which an elastic material begins to deform in a plastic manner. Prior to yield, the material will deform elastically and will return to its original shape when the applied stress is removed. If loaded beyond yield and then unloaded, the material will not return to its original shape.