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PROJECT DELIVERY
DIVISION OF ENGINEERING SERVICES

PREFACE

The purpose of this manual is to provide planners and engineers with a basic understanding of the different ABC methods available, help guide project-specific selection of ABC methods, and encourage the use of ABC methods. This manual is a guideline document. All provisions contained herein are subject to review and adjustment by the Structure Design Project Engineer (PE) with approval by the owner. In many provisions, the terms “must” and “shall,” are used. These provisions are intended to be used in the development of contract specifications. Other provisions use the terms “should,” “may,” and “recommended.” The term “should” indicates a strong preference for a given criterion. The term “may” indicates a criterion that is usable but other suitably documented, verified and authorized criterion may also be applied. The term “recommended” is used to give guidance based on past experiences.

Structure Technical Policies (STPs) and Bridge Design Memos (BDMs) are referenced throughout this manual to supplement design specifications by addressing areas not covered; expanding requirements based on successful past practices; and implementing more recent innovations. These documents include and supersede policies and guidance from previous Memos to Designers (MTDs) and Bridge Design Aids (BDAs). Since STPs and BDMs are under development during the writing of this manual, they may not be available, in which case, the reader should refer to the corresponding MTD or BDA and coordinate with the appropriate technical specialist, if necessary. Lists of STPs and BDMs with corresponding MTDs and BDAs are maintained by the Office of State Bridge Engineer Support.

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Table of Contents

Preface

Acknowledgements

Table of Contents

Definitions and Abbreviations

Chapter 1	Introduction
Chapter 2	Workflow
Chapter 3	Planning
Chapter 4	Design
Chapter 5	Construction
Chapter 6	Resources
Appendix A	Prefabricated Bridge Element Checklists
Appendix B	Lateral Slide Checklists
Appendix C	Self-Propelled Modular Transporter (SPMT) Move Checklists
Appendix D	Caltrans Implementation of Ultra-High Performance Concrete (UHPC)
Appendix E	Ultra-High Performance Concrete (UHPC) Checklists

DEFINITIONS AND ABBREVIATIONS

DEFINITIONS

The following definitions include terminology used in this manual and in relevant literature on Accelerated Bridge Construction. Refer to the *AASHTO LRFD Accelerated Bridge Construction Manual* (*AASHTO GSABC*) Section 1.3 for further definitions.

Accelerated Bridge Construction (ABC)—Bridge construction methods that use the most efficient combination of innovative planning, design, materials, and construction techniques to significantly reduce construction related impacts by reducing the number of onsite construction days and/or minimizing traffic disruption.

Assembly Plan—A workplan that is a combination of plans, specifications, and calculations developed by the contractor that describes the step-by-step process for the assembly of prefabricated bridge elements and prefabricated bridge element systems. The assembly plan details how a bridge or bridge components are to be lifted, rolled, launched, slid, or otherwise transported into place. The assembly plan may include handling and erection plans, move plans, communication plans, geometric control plans, contingency plans, material specifications, details and calculations for temporary supports, and construction scheduling.

Bridge Staging Area (BSA)—A temporary location, often near the bridge's permanent location, where the bridge is constructed before being moved to its permanent position.

Bridge System—A bridge superstructure, or superstructure and substructure, constructed in a BSA using conventional construction methods or assembled prefabricated bridge elements, and moved into place.

Construction Completion Time (CCT)—An estimate of the total onsite construction days required for bridge construction work, not including roadway or offsite activities such as roadwork, mobilization, procurement, or traffic handling preparations.

Construction Impact Time (CIT)—An estimate of the working days or hours that bridge construction will impact a specific item of interest, such as road closures and detours, environmentally sensitive areas, local businesses, and essential services.

Contingency Plan—A plan prepared by the contractor that will be implemented if an event occurs that could cause a significant delay, such as a major equipment malfunction or inclement weather. .

Conventional Bridge Construction—Construction method where prefabrication is typically limited to beams or girders. Conventional Bridge Construction does not significantly reduce onsite construction time or any impacts through the use of innovative planning, design, materials, and construction techniques.

Construction Manager/General Contractor (CMGC)—A project delivery method that allows Caltrans to engage a construction manager to provide input during the design process. Caltrans and the construction manager agree on a price for construction of the project, and the construction manager then becomes the general contractor.

Design-Build (DB)—A project delivery method in which the design and construction of a project is awarded to a single entity. DB involves a single contract between Caltrans and a design-builder covering both the final design and the construction of the project.

Design-Bid-Build (DBB)—A traditional linear project delivery method in which the design is first completed and then put out to bid for a qualified contractor to build the project.

Every-Day Counts (EDC)—A Federal Highway Administration (FHWA) program that identifies and rapidly deploys proven yet underutilized innovations to shorten the project delivery process, enhance roadway safety, reduce traffic congestion, and integrate automation.

Erection Work Plan—A work plan that describes procedures, details, and sequences for unloading, lifting, and erecting prefabricated bridge elements and bridge systems and includes temporary support installation.

Geometric Control Plan—A work plan that describes how the geometric detail of the bridge assembly will be controlled and monitored.

Geosynthetic Reinforced Soil–Integrated Bridge System (GRS-IBS)—An ABC technology that uses alternating layers of compacted granular fill material and fabric sheets of Geotextile reinforcement to provide support for the bridge in place of a traditional abutment. The use of GRS-IBS to support state bridges in California is not allowed at this time.

Interim Loading Condition—A loading condition of a bridge element and bridge system that exists prior to completion of construction.

Maintenance of Traffic (MOT)—The requirements for maintaining traffic during construction.

Prefabricated Bridge Element (PBE)—A single prefabricated structural component of a bridge assembled in place using ABC methods. It is feasible to use PBEs in a bridge system installation.

Prefabricated Bridge Elements and Systems (PBES)—Structural components of a bridge that are built offsite or near the bridge site that include features to reduce the onsite construction time compared to conventional bridge construction methods.

Lift Points—Locations underneath structure to lift and carry the bridge or element.

Pick Points—Locations above the structure to lift and carry the bridge or element.

Reference Points—Control locations established by the contractor at the bridge site for verifying the layout of prefabricated elements during erection.

Self-Propelled Modular Transporter (SPMT)—Remote-controlled, multi-axle platform vehicle capable of transporting several thousand tons of weight.

Stroke—The displacement capacity of any jacking mechanism including the distance an SPMT can raise or lower its platform.

Temporary Supports—Temporary construction used to support structures during retrofit, reconstruction, assembly of prefabricated bridge elements and systems, and removal activities.

Total Project Cost—A qualitative assessment of project direct and indirect costs.

Traffic—Vehicles, pedestrians, or cyclists moving on roads, highways, freeways, or railroad facilities.

Travel Path (TP)—The course that the SPMTs travel to carry the completed structure from the bridge staging area to its permanent location.

User Costs—Costs borne by motorists, the community, the local economy, freight, and the environment during the construction of a project. User Costs are not included in the capital and support costs of a project.

Work Plan—A detailed formulation of a program of action prepared by the contractor.

ABBREVIATIONS

The following are lists of abbreviations used in this manual, excluding those defined previously. Refer to Caltrans Structure Technical Policy 1.2 for further abbreviations.

National Organizations

ARTBA—American Road and Transportation Builders Association

AASHTO—American Association of State Highway and Transportation Officials

ACI—American Concrete Institute

AISC—American Institute of Steel Construction

ASBI—American Segmental Bridge Institute

ASCE—American Society of Civil Engineers

ASTM—American Society for Testing and Materials

FHWA—Federal Highway Administration

PCI—Precast/Prestressed Concrete Institute

NCHRP—National Cooperative Highway Research Program

NSBA—National Steel Bridge Alliance

TRB—Transportation Research Board

Caltrans Organizations

Caltrans—California Department of Transportation

DES—Division of Engineering Services

GS—Geotechnical Services

METS—Materials Engineering and Testing Services

SM&I—Structure Maintenance and Investigation

SC—Structure Construction

SD—Structure Design

SPB—Structure Policy Board

SP&I—Structure Policy and Innovation

Terminologies Used Nationwide

ADTT—Average Daily Truck Traffic

CCO—Contract Change Order

CIDH—Cast-in-Drilled-Hole

CIP—Cast-in-Place

CISS—Cast-in-Steel-Shell

CMGC—Construction Manager/General Contractor

ERS—Earth Retaining System

ESA—Environmentally Sensitive Area

FCM—Fracture Critical Member

FDDP – Full Depth Precast Concrete Deck Panels

FE—Finite Element

GRS-IBS—Geosynthetic Reinforced Earth-Soil Integrated Bridge Systems

ILM—Incremental Launch Method

LFD—Load Factor Design

LRFD—Load and Resistance Factor Design

MSE—Mechanically Stabilized Earth

NHS—National Highway System

PCC—Portland Cement Concrete

PC/PS—Precast/Prestressed *C*oncrete

PT—Post-Tensioned; Post-Tensioning

QA—Quality Assurance

QC—Quality Control

RC—Reinforced Concrete

RFI—Request for Information

UHPC—Ultra-High Performance Concrete

VA—Value Analysis

VECP—Value Engineering Change Proposal

Terminologies Used in Caltrans

APS—Advance Planning Study

AML—Authorized Materials List

BC—Branch Chief

C+T—Cost-Plus-Time

CMP—Corrugated Metal Pipe

CPM—Capacity Protected Members

CSL—Cross-Hole Sonic Logging

ECR—Epoxy-Coated Reinforcement

GGL—Gamma-Gamma Logging

GP—General Plan

IQA—Independent Quality Assurance

PDT—Project Development Team

PE—Structure Design Project Engineer

PID—Project Initiation Document

P&Q—Plans and Quantities

PR—Project Report

PS&E—Plans, Specifications and Estimates

PTFE—Polytetrafluoroethylene

RE—Resident Engineer

RSC—Rapid Strength Concrete

RUC—Road User Cost

SCM—Seismic Critical Member, Supplementary Cementitious Material

SHS—State Highway System

SOE—Structure Office Engineer

SR—Structure Representative

SSD—Surface Saturated Dry

TLE—Transportation Liaison Engineer

Technical Publications

AASHTO-CA BDS—AASHTO LRFD Bridge Design Specifications and California Amendments

AASHTO GSABC—AASHTO Guide Specifications for Accelerated Bridge Construction

BCM—Caltrans Bridge Construction Memos

BDM—Caltrans Bridge Design Memos

BDPPM—Caltrans Bridge Design Process and Procedure Manual

CBSSD—California Bridges and Structures Strategic Direction

FWM—Caltrans Falsework Manual

NSSP—Caltrans Nonstandard Special Provisions

PSDC—Caltrans Project Specific Design Criteria

PSP—Caltrans Project Special Provisions

SDC—Caltrans Seismic Design Criteria

SDSSB—Caltrans Seismic Design Specifications for Steel Bridges

SPD—Caltrans Structure Policy Directive

SP—Caltrans Standard Plans

SS—Caltrans Standard Specifications

SSP—Caltrans Standard Special Provisions

STP—Caltrans Structure Technical Policy

XS Sheets—Caltrans Bridge Standard Detail Sheets

ACCELERATED BRIDGE CONSTRUCTION

Chapter 1

INTRODUCTION

District 3

21st Avenue Undercrossing, Route 99, Sacramento County, CA

CONTENTS

1 INTRODUCTION 1-1
1.1 PURPOSE OF THE MANUAL 1-1
1.1.1 Load and Resistance Factor Design Guide Specifications for ABC 1-1
1.2 DEFINITION OF ABC 1-1
1.3 CALTRANS POSITION ON ABC 1-2
1.4 BENEFITS OF ABC 1-2
1.5 ABC LOGO 1-3
1.6 KEYS TO SUCCESS 1-4
1.7 REFERENCES 1-5

1 INTRODUCTION

1.1 PURPOSE OF THE MANUAL

The Accelerated Bridge Construction (ABC) Manual supports efficient and consistent ABC practice in California by providing guidance for the evaluation, planning, design, construction, and administration of projects using ABC design methods and materials. This manual provides planners and engineers with a basic understanding of the different ABC methods available, helps guide project-specific selection of ABC methods, and encourages the use of ABC methods.

1.1.1 Load and Resistance Factor Design Guide Specifications for ABC

The *American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Guide Specifications for Accelerated Bridge Construction (AASHTO GSABC)* (AASHTO 2018) are referred to frequently in this manual's discussion of ABC. There are topics in the *AASHTO GSABC* that conflict with *AASHTO LRFD Bridge Design Specifications* and with *California Amendments (AASHTO-CA BDS)* (AASHTO 2017; Caltrans 2019a), the *Caltrans Seismic Design Criteria (SDC)* (Caltrans 2019, 2020), and other bridge and structure policies and standards, as defined in *Structure Policy Directive 1-3* (Caltrans 2019b). In particular, seismic resistant details and methodologies do not conform to the *SDC*. Consequently, Caltrans has not adopted the *AASHTO GSABC*.

Although the *AASHTO GSABC* does not represent Caltrans policy, specific sections referenced in this manual may be used for ABC project planning, design, and construction.

1.2 DEFINITION OF ABC

ABC is defined as the most efficient combination of innovative planning, design, materials, and construction that significantly reduces construction related impacts by reducing the number of onsite construction days and/or minimizing traffic disruption.

ABC design is driven by consideration of how the bridge is going to be constructed. ABC uses a variety of tools to accelerate scheduling, minimize risk, and improve efficiencies, including innovative materials and specifications, fabrication and erection of bridge elements, alternative procurement methods, creative staging and traffic control, the use of incentive/disincentive provisions, and cost-plus-time-based bids.

The construction related impacts addressed through ABC are determined by project goals and constraints. Examples of project goals and constraints include single season construction, minimizing disruption to traffic or local businesses, restricting construction activities in sensitive areas, or maintaining access to essential services. Communication and collaboration with stakeholders are emphasized to achieve project goals.

1.3 CALTRANS POSITION ON ABC

ABC aligns with the Caltrans Strategic Plan, the Project Delivery Strategic Direction, and the Division of Engineering Services (DES) Strategic Direction by placing a priority on safety, meeting new challenges through innovation, and achieving outcomes that provide a safe and reliable transportation network that serves all people and respects the environment.

ABC improves the efficiency, safety, and sustainability of the transportation system by providing Caltrans with an alternative to conventional construction methods. This results in faster project delivery and improved lifecycle costs with a significant reduction in impacts to the environment and traveling public (FHWA 2011; UDOT 2019). ABC is therefore considered for all Caltrans projects and should be utilized when it is determined to be the best solution for achieving project goals.

By implementing ABC in California, Caltrans supports the Federal Highway Administrations (FHWA) Every Day Counts (EDC) Initiative to deploy innovations that shorten the project delivery process, enhance roadway safety, and reduce traffic congestion.

1.4 BENEFITS OF ABC

The benefits of ABC include improved work zone safety, reduced traffic delays, minimized environmental impacts, less disruption of the local economy, and expedited transportation projects. The following list describes how these benefits are realized.

1. Improve work zone safety. ABC reduces the risk of conflict between construction activities and the traveling public. This is accomplished by separating traffic from the work zone and/or reducing the amount of time that traffic is exposed to construction activities (ARTBA 2011).
2. Accelerate project delivery. ABC methods can remove the bridge as a critical element of the construction schedule by reducing onsite construction time. This is beneficial for projects where work windows are limited by seasonal, environmental or economic restrictions.
3. Minimize traffic disruption. ABC reduces traffic delays and congestion by minimizing lane closures, duration of onsite construction activities, and the need for complicated traffic handling requirements or detours. Minimizing disruptions benefits local businesses, essential services such as hospitals and schools, and regional economies. Reduced congestion also results in less air and noise pollution.
4. Improve constructability. ABC methods provide solutions for sites that are

challenging for conventional construction. Sites with limited access and/or short work windows because of weather, traffic, and environmental concerns may require rapid construction that is difficult to achieve with conventional construction. Building portions of the bridge offsite at either a prefabrication plant or a Bridge Staging Area (BSA) could allow year-round construction and reduce onsite construction and impact on environmentally sensitive areas and traffic.

5. Enhance quality. Constructing portions of the bridge in a prefabrication plant or BSA result in better quality because the bridge elements are fabricated in a controlled environment. Prefabrication plants provide optimal conditions for producing bridge elements. For example, concrete can cure under ideal temperature and humidity for the optimum amount of time. Quality control is also easier to perform in a prefabrication plant or BSA which are free from constraints like distance from a concrete batch plant, weather, traffic, and access.
6. Lower life-cycle costs. The enhanced quality of the bridge elements that are produced in a prefabrication plant or BSA should result in less maintenance and a longer service life. Using precast concrete reduces restrained shrinkage cracking, which improves durability (FHWA 2011; UDOT 2019).
7. Avoid and minimize environmental impacts. ABC methods can reduce onsite construction time to fit within environmental work windows or lessen the construction footprint by eliminating falsework or conventional construction activities that would affect areas with sensitive environmental and biological resources. ABC is often used to reduce the number of construction seasons thereby reducing the environmental impacts associated with multiple season construction.
8. Reduce project costs. Although ABC methods are often more expensive than conventional methods, they can yield savings in other aspects of the project and should be considered in the decision-making process. Fewer days on the job site means less traffic handling requirements, project administration, and environmental compliance monitoring. Eliminating falsework could allow the bridge profile to be lowered and, therefore, the footprint of the approaches reduced. In projects involving wetlands, significant savings can be realized by reducing or eliminating the need for wetland mitigation. ABC also presents the opportunity for savings in user costs (not accounted for in project cost) that meet project goals and constraints.
9. Encourage innovation. ABC encourages the utilization of innovative design and construction methods to meet challenging project goals that would be difficult or impossible to achieve with conventional construction methods.

1.5 ABC LOGO

ABC projects and ABC alternatives employ innovative planning, design, and construction practices that require analysis, cost and working day estimates, specification development, design details, and other ABC-related considerations specific to this method of construction.

The Caltrans ABC Logo, shown in Figure 1.6-1, alerts all parties involved that the project or alternative is atypical and requires specific attention to support the effective and efficient implementation of ABC. This logo will be placed on all ABC planning study and structure contract plans sheets. The logo also allows ABC projects and alternatives to be tracked to facilitate consistent application and continual improvement of ABC methods.

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Figure 1.5-1 Caltrans ABC Logo

1.6 KEYS TO SUCCESS

The keys to successful ABC delivery include the following:

- Embracing innovation. By nature, ABC projects encourage innovative solutions to meet project goals and objectives, as described in Chapters 4 and 5.
- Considering ABC early. ABC must be considered early in the planning stage to ensure all scheduling, environmental, right-of-way, and cost impacts are factored into the planning, environmental, design, and construction contract documents, as discussed in Chapters 2 and 3.
- Communicating with stakeholders. A pro-active communication plan with stakeholders is essential to increasing awareness, minimizing traffic and economic disruption, building trust, and gaining project buy-in.
- Defining project goals. ABC, by definition, is a tool used to help achieve project goals. Therefore, these goals need to be defined early in the project, as they will serve as a foundation for the ABC design.
- Evaluating capital and support cost. The combined total of capital and support costs of bridge and roadway work should be evaluated when comparing ABC and conventional bridge construction, as discussed in Chapter 3.
- Identifying user cost benefits. For a meaningful comparison of ABC to conventional construction, identify and communicate user cost benefits that are not accounted for in the project budget but are addressed in the project goals and constraints.
- Provide opportunities to include other ABC technologies. Multiple ABC technologies can be used on the same project; for example, a project could utilize prefabricated bridge elements and then be moved into place using lateral slide or SPMTs.

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ACCELERATED
BRIDGE
CONSTRUCTION

Chapter 2

WORKFLOW

District 1

Hardscrabble Creek Bridge, Route 199,
Del Norte County, CA

CONTENTS

2 PROJECT WORKFLOW 2-1
2.1 GENERAL ROLES AND RESPONSIBILITIES 2-1
2.2 PLANNING STUDIES (K-PHASE AND 0-PHASE) 2-3
2.2.1 Technical or Feasibility Study 2-3
2.2.2 Structure Cost Estimate 2-3
2.2.3 Advance Planning Study 2-3
2.3 STRUCTURE PS&E (1-PHASE) 2-3
2.3.1 Field Review Meetings 2-4
2.3.2 Type Selection 2-4
2.3.3 General Plan Distribution 2-4
2.3.4 Unchecked Details 2-4
2.3.5 Checked Details and Independent Quality Assurance Review 2-4
2.3.6 Draft Structure PS&E 2-4
2.3.7 Advertise and Award 2-4
2.4 CONSTRUCTION (3-PHASE) 2-5
2.4.1 Construction Hand-off 2-5
2.4.2 Design Support During Construction 2-5
2.4.3 Project Closeout 2-5
2.5 ABC PROJECT DEVELOPMENT FLOWCHART 2-6
2.6 REFERENCES 2-6

2 PROJECT WORKFLOW

The Accelerated Bridge Construction (ABC) Project Workflow describes the Division of Engineering Services (DES) procedure for developing and managing ABC projects from project initiation to closeout as well as DES staff roles and responsibilities.

2.1 GENERAL ROLES AND RESPONSIBILITIES

ABC Branch/ABC Specialist: Bridge Design Branch 2 is the designated ABC Branch. The ABC Branch supports the ABC project development process in the evaluation, identification, assignment, type selection, review, tracking, and documentation of ABC Projects. The ABC Branch works on ABC projects. It develops and maintains the Department's ABC guidance. The ABC Branch serves as Structure Design's ABC Specialists and provides advice to Caltrans staff on ABC matters. A member from the ABC Branch may serve as a team member or technical reviewer on Value Analysis studies of ABC projects. The ABC Specialist attends type selection meetings of ABC projects.

The ABC Branch serves as the Functional Reviewer, as described in *Bridge Design Process and Procedure Manual* (Caltrans 2019) Chapter 3.5, on ABC projects at Unchecked Details, Checked Details (IQA review), and Draft Structure Plans Specifications and Estimates (PS&E). The ABC Branch is also responsible for tracking ABC projects from project initiation through construction. At the end of construction, it prepares the lessons learned report on the project's ABC aspects and posts the report on the ABC website.

Branch Chief (BC): The BC ensures that staff consults the ABC Branch when ABC methods are considered for a project. During development of the Structure PS&E, the BC ensures the ABC specialist is invited to the Type Selection Meeting and reviews the Advance Planning Study (APS), the Type Selection Report, Unchecked Details, Checked Details (Independent Quality Assurance (IQA) review), and Draft Structure PS&E.

Detailer: The Detailer places the ABC logo on the plans according to *Structure Design Alert, Subject Area: Accelerated Bridge Construction (ABC)* (Setberg 2017).

District Project Engineer: Provides information on project constraints, including work windows, sensitive areas, traffic management, desired roadway geometry, and funding.

Estimating Engineer: The Estimating Engineer collaborates with the PE, the Structure Construction ABC Specialist, and the ABC Branch to develop cost estimates for unique items of work and to develop working day estimates that provide the duration of construction related impacts identified as items of interest in attaining project goals.

Geotechnical Services ABC Specialist: The Geotechnical Services ABC specialist assists Structure Design and Geotechnical Services with foundation evaluation and foundation type selection when ABC is considered for a project.

Material Representative: Materials Engineering and Testing Services (METS) Material Representative provides material recommendations and assists with the material evaluation and selection during the design phase and assists with fabrication inspection challenges during production.

Office Chief: The Office Chief directs staff working on ABC projects to follow the Department's procedures for developing and managing ABC projects. The Office Chief directs ABC projects to the ABC Branch for input, review, and tracking.

Specifications Engineer: The Specification Engineer collaborates with the PE, subject matter experts, and industry representatives to prepare and develop specifications for construction of bridges and other transportation-related structures, including unique materials, work plan requirements, and QA/QC processes.

Structure Construction ABC Specialist: The Structure Construction ABC Specialist, located in Structure Construction Headquarters, assists Structure Design and Structure Construction in constructability evaluation of the design and the development of working day estimates for ABC projects. Engineers conducting the constructability evaluation should have experience and technical knowledge commensurate with the ABC methods of the project.

Structure Design Project Engineer (PE): The PE consults with the ABC Branch to ensure that their ABC designs and details are consistent with the Department's ABC guidelines and policies. This includes coordinating with the ABC Branch during the development of ABC alternatives for an Advance Planning Study, as described in Advance Planning Study (APS) Development Requirements. The PE invites the ABC specialist to the Type Selection Meeting and includes the ABC specialist in the APS, Unchecked Details, Checked Details (IQA review), and Draft Structure PS&E reviews. During the construction phase, the PE supports ABC, in accordance with Chapter 6 of the *Bridge Design Process and Procedures Manual* (*BDPPM*) (Caltrans 2019) and is available during critical phases of construction.

Structure Design Task Management Unit: The Structure Design Task Management Unit includes the ABC Branch when resourcing for ABC projects.

Technical Liaison Engineer (TLE): The TLE provides the initial evaluation of ABC to address project objectives in the Project Initiation Phase (K-phase) and informs the ABC Branch of projects that may have ABC in their scope of work. The TLE may consult the ABC Branch for assistance with ABC related questions and development of ABC options for project consideration.

2.2 PLANNING STUDIES (K-PHASE AND 0-PHASE)

2.2.1 Technical or Feasibility Study

When investigating ABC techniques as part of a Technical or Feasibility Study the TLE may consult with the ABC Branch for assistance in developing feasible ABC solutions. It can be beneficial to have workshops with construction industry representatives to get feedback on the feasibility and cost effectiveness of ABC concepts. Industry associations such as the Association of General Contractors (AGC) or the Precast Prestressed Concrete Institute (PCI) can help facilitate these meetings, as discussed in Section 4.17.1.

2.2.2 Structure Cost Estimate

When the Project Development Team (PDT) identifies any specific construction impacts that can be reduced with ABC techniques, the TLE/BC/PE may consult the with ABC Branch for assistance in developing feasible ABC solutions. The TLE/BC/PE will consult the ABC Branch for assistance in developing feasible ABC solutions and Structure Cost Estimates for assistance with estimating the cost in support of Project Initiation Document (PID) and Project Study Report-Project Development Study (PSR-PDS) development.

2.2.3 Advance Planning Study

The TLE/BC/PE, in collaboration with the PDT, will determine if ABC methods should be recommended by completing the ABC Decision Making Guidance Development Requirements, which can be found on the Structure Design Project Resources webpage. If the use of ABC methods is recommended by the PDT, the construction impacts that will be reduced using ABC methods are identified and goals for the amount of impact reduction are established. The TLE/BC/PE may then coordinate with the ABC Branch to determine the most appropriate ABC methods for achieving the project goals. The ABC Branch may be asked to help develop ABC alternatives for the Advance Planning Study. The TLE/BC/PE may also ask the ABC Branch to attend meetings, such as PDT meetings, to explain the benefits, costs, and requirements of the proposed ABC alternatives. The Detailer will place the ABC logo on the APS plan sheet. The completed ABC Decision Making Guidance will be included in the APS/GP Estimate request.

2.3 STRUCTURE PS&E (1-PHASE)

The ABC Branch will serve as the ABC specialist and support Bridge Design Branches on the development of PS&E for ABC projects.

2.3.1 Field Review Meetings

The PE is encouraged to have the ABC Branch and Structure Construction participate in field review meetings when ABC methods are under consideration.

2.3.2 Type Selection

The BC/PE will re-evaluate, in coordination with the PDT, ABC alternative(s) considered in the APS stage. When ABC methods are proposed for final design, the ABC specialist will be included in the Type Selection meeting.

2.3.3 General Plan Distribution

The PE will ensure that the ABC logo is placed on the general plan sheet. The PE will include the ABC Branch in the GP distribution. The ABC Branch will review ABC components on the general plan.

2.3.4 Unchecked Details

The PE will include the ABC Branch in the Unchecked Details distribution. The ABC Branch will review ABC components in the Unchecked Details plan set.

2.3.5 Checked Details and Independent Quality Assurance Review

The ABC Branch performs the IQA review on ABC projects. The Office Chief will assign the IQA review to the ABC Branch. Projects done by the ABC Branch may be assigned to a non-ABC Branch member of the IQA review team.

2.3.6 Draft Structure PS&E

The PE will include the ABC Branch in the Draft Structure PS&E review meeting. The ABC Branch will review ABC components of the Draft Structure PS&E package.

2.3.7 Advertise and Award

The PE and the ABC specialists will attend pre-bid meetings, as discussed in Section 4.17.2.

2.4 CONSTRUCTION (3-PHASE)

The ABC Branch serves as the ABC specialist and supports the PE during the construction of an ABC project.

2.4.1 Construction Hand-off

After award, the Structure Representative (SR) has a meeting with the PE and the Resident Engineer (RE), to discuss unique aspects of the project, which are described in the RE Pending File.

2.4.2 Design Support During Construction

The ABC Branch will serve as the ABC specialist and support the Structure Design Branch with request for information (RFI), value engineering change proposal (VECP), change order, shop drawing and work plan review and authorization of items that involve ABC methods and components.

2.4.3 Project Closeout

The PE will include the ABC Specialist in the project closeout meeting at the end of construction. The PE will provide a copy of the project closeout report to the ABC Specialist. The ABC Specialist will work with the PE and Structure Construction Representative to create a lessons-learned report covering the ABC aspects of the project. The ABC Specialist will post the lessons learned report on the Division of Engineering Services' ABC website. The ABC Specialist will make recommendations for updates to the ABC Manual based on lessons learned.

2.5 ABC PROJECT DEVELOPMENT FLOWCHART

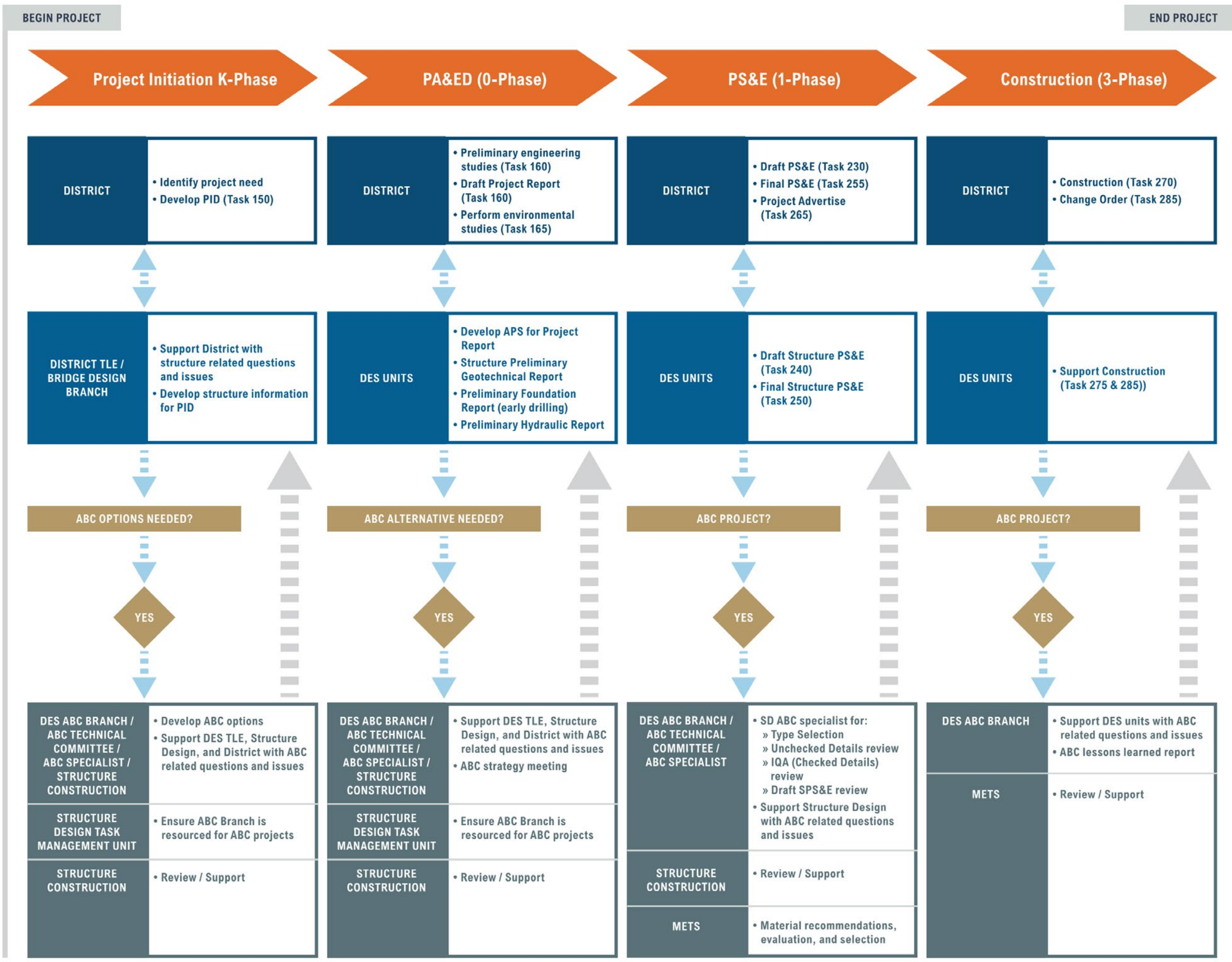


Figure 2.5-1 ABC Project Development Flow Chart

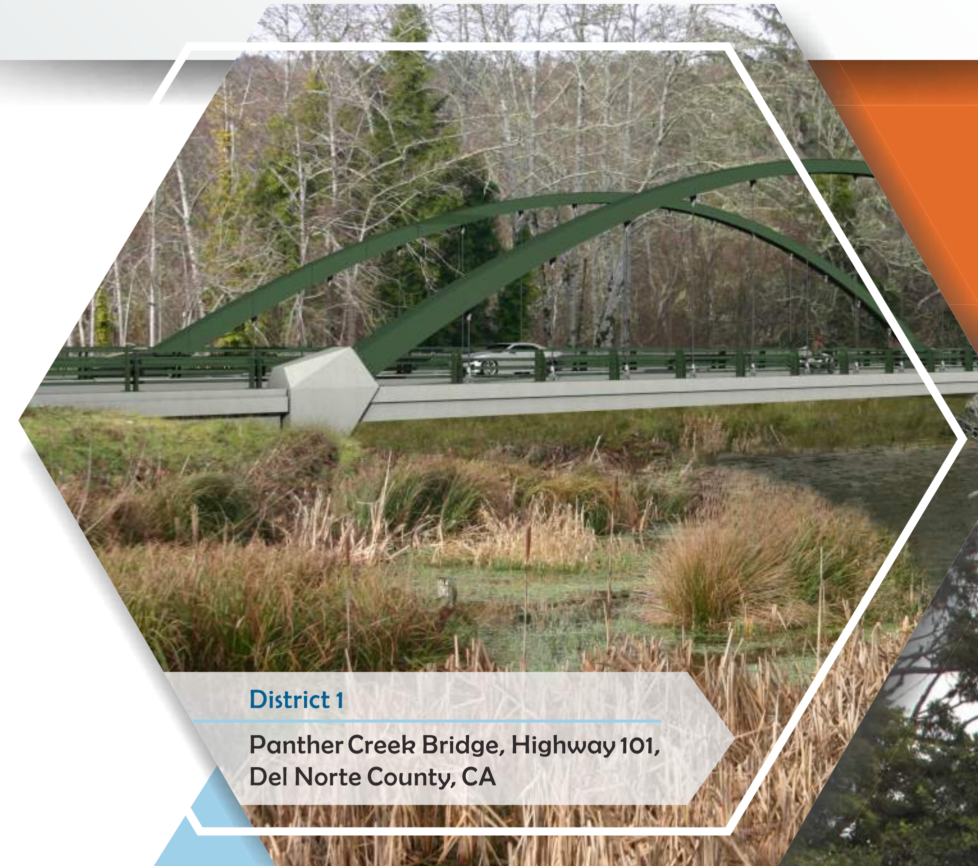
2.6 REFERENCES

1. Setberg. (2017). *Structure Design Alert, Subject Area: Accelerated Bridge Construction (ABC)*. California Department of Transportation, Sacramento, CA
2. Caltrans. (2019). *Bridge Design Process and Procedures Manual*. State of California, Department of Transportation, Sacramento, CA.

ACCELERATED
BRIDGE
CONSTRUCTION

Chapter 3

PLANNING



District 1

Panther Creek Bridge, Highway 101, Del Norte County, CA

District 4

Lagunitas Creek Bridge, Highway 1, Marin County, CA

CONTENTS

3 PLANNING 3-1
3.1 ABC DECISION MAKING 3-1
3.1.1 Selecting ABC Over Conventional Bridge Construction 3-1
3.1.2 Project Goals 3-1
3.1.3 Total Project Cost 3-2
3.1.4 Caltrans ABC Decision Making Guidance 3-3
3.1.5 Required Advance Planning Study Working Day Estimates 3-10
3.2 ABC METHOD SELECTION 3-11
3.2.1 Description of Methods/Types of ABC 3-11
3.2.2 Offline Construction 3-11
3.2.2.1 Lateral Slide 3-12
3.2.2.2 Self-Propelled Modular Transporter (SPMT) Move 3-14
3.2.2.3 Crane Based Move 3-15
3.2.3 Online Construction Guidelines 3-16
3.2.3.1 Prefabricated Bridge Elements (PBEs) 3-17
3.2.3.2 Longitudinal Launch 3-18
3.3 TRAFFIC MANAGEMENT 3-19
3.3.1 Full Closure of Existing Facilities 3-19
3.3.1.1 Determining the Closure Schedule 3-20
3.3.1.1.1 Construction Sequence 3-20
3.3.1.1.2 Incentive/Disincentive 3-20
3.3.2 Temporary Bridge 3-21
3.3.3 Temporary Culverts for Shoofly Detours 3-21
3.4 ABC ADVANCE PLANNING STUDY 3-21
3.4.1 Design Considerations 3-21
3.4.1.1 Project Goals, Constraints, and Opportunities 3-21
3.4.1.2 Project Site 3-22
3.4.1.2.1 Environmental Requirements 3-22
3.4.1.2.2 Heavy Lift Requirements 3-22
3.4.1.3 Risk to Schedule 3-23

3.4.1.4 Foundation Selection ... 3-24
3.4.1.5 Construction Sequence ... 3-24
3.4.1.6 Tolerances ... 3-25
3.4.1.7 Durability ... 3-25
3.4.1.8 Cost Control ... 3-26
3.4.1.9 Demolition ... 3-26
3.4.1.10 Traffic Management ... 3-26
3.4.2 Resources ... 3-26
3.4.2.1 ABC Specialists ... 3-26
3.4.2.2 ABC Strategy Meeting ... 3-27
3.4.3 Information on the Plans and APS/GP Request ... 3-27
3.4.4 Working Day and Cost Estimates ... 3-28
3.4.5 APS Transmittal Letter ... 3-28
3.5 PROCUREMENT AND CONTRACTING METHODS ... 3-28
3.5.1 Project Delivery Methods ... 3-29
3.5.1.1 Design-Bid-Build ... 3-29
3.5.1.2 Construction Manager/General Contractor ... 3-29
3.5.1.3 Design-Build ... 3-30
3.5.2 Procurement Practices ... 3-30
3.5.3 Contract Management Methods ... 3-31
3.6 REFERENCES ... 3-32

3 PLANNING

Accelerated Bridge Construction (ABC) is not just a method of construction but a combination of innovative planning, design, materials, and construction. Developing an ABC solution involves the consideration of multiple items including how the bridge will be constructed, how traffic will be maintained, how risks and impacts will be minimized, and how the bid documents will promote fewer onsite working days. Proactive and frequent communication with project stakeholders during project development is essential in developing an effective ABC solution.

3.1 ABC DECISION MAKING

ABC decision making is based on a comparison of the overall value of conventional and ABC design alternatives. The overall value is a qualitative assessment of the project costs and the user costs referred to as Total Project Cost. The Total Project Cost considers the capital project cost, schedule, and construction related impacts of ABC versus conventional bridge construction methods.

3.1.1 Selecting ABC Over Conventional Bridge Construction

ABC is suited for a project when it most effectively addresses the project goals and constraints, and the benefits outweigh the costs. It is the responsibility of the Structure Design Project Engineer (PE) to consider ABC during project development and communicate the benefits and costs to the District. When an Advance Planning Study (APS) is developed, the PE will recommend whether an ABC alternative should be developed along with the conventional alternative(s) and provide documentation supporting this recommendation. Documentation includes benefits, costs, requirements, and impacts associated with ABC as compared to conventional bridge construction methods. Section 3.1.4 explains the ABC selection process and documentation for supporting an ABC recommendation. Ultimately, the District will determine if the benefits justify the cost of the ABC approach.

3.1.2 Project Goals

The ABC selection process is driven by the project goals and constraints. These goals and constraints are developed by the District Project Engineer (District PE) in cooperation with the Project Development Team (PDT) and described in the Project Initiation Document (PID), the Project Report (PR), and the environmental documents. Examples of project goals and constraints include, but are not limited to single season construction, staying out of the stream bed, minimizing impacts to local businesses, or maintaining access to essential services.

The benefits and costs of meeting project goals using ABC methods are communicated with the District PE and the PDT throughout the planning process. If ABC is recommended, these benefits and costs will be discussed in the Advance Planning Study Transmittal Letter and presented during the Type Selection Meeting.

3.1.3 Total Project Cost

Total Project Cost is a qualitative assessment of direct and indirect costs of a project. Direct costs include bridge and roadway construction capital and support costs. Indirect costs, also referred to as user costs, are costs associated with construction related impacts that are not included in the capitol and support costs. Below are examples of direct and indirect project costs.

Direct Costs (Construction Related Capital and Support Costs)

- Bridge and roadway construction
- Maintenance of traffic
- Storm water management
- Contract administration
- Construction and source inspection
- Right of way (temporary and permanent)
- Environmental permitting, compliance, and monitoring
- Environmental mitigation

Indirect Costs (Construction Related User Costs)

- Work zone accidents (worker and public)
- Traffic delays
- Access to essential services
- Impact to local business
- Impact on movement of goods and services
- Environmental impacts (noise level, air quality, wildlife)
- Durability/maintenance costs (life cycle)
- Public approval leading to improved public support of infrastructure funding

Evaluating the Total Project Cost, with a focus on construction schedule and minimizing construction related impacts, will show if ABC is worthwhile for the project. Developing the

Total Project Cost to compare ABC and conventional alternatives is a collaborative effort by the PDT. The PE is responsible for identifying and communicating bridge related direct and indirect cost savings to the PDT. The PE is also responsible for supporting the PDT in identifying roadway direct and indirect cost savings by providing relevant bridge construction methods and schedule information. The PDT is responsible for the overall evaluation of the Total Project Cost. Project goals that are achieved through an ABC approach as well as any savings in roadway and lifecycle costs should be identified and shared with the District and other stakeholders via transmittal documents, PDT meetings, and the Type Selection meeting.

Value Analysis (VA) studies, when undertaken early, can be ideal for comparing ABC methods with conventional bridge construction alternatives because Total Project Costs are considered.

3.1.4 Caltrans ABC Decision Making Guidance

ABC is to be considered for every new bridge design and bridge replacement project and may be considered for bridge widenings and rehabilitation projects. This is done through the ABC Decision Making Guidance. The ABC Decision Making Guidance helps to determine when and where ABC may be more effective at meeting the goals and objectives of the project than conventional construction. The ABC Decision Making Guidance is comprised of the ABC Design Impact Questionnaire (Figure 3.1.4-1), the Description of Terms in ABC Design Impact Questionnaire (Table 3.1.4-1), and the ABC Decision Making Flow Chart (Figure 3.1.4-2). These documents can be downloaded from the Caltrans ABC Decision Making Guidance webpage.

The ABC Design Impact Questionnaire is a qualitative assessment of how ABC methods may reduce or minimize construction impacts on the overall project. The questionnaire allows for the consideration of a project’s direct and indirect costs not usually included in an engineering estimate, such as the construction related impacts on the travelling public, economy, environment, and safety. Each question in the ABC Design Impact Questionnaire is further described in Table 3.1.4-1. The questionnaire is to be completed by the PE in cooperation with the Technical Liaison Engineer (TLE), the District PE, and the PDT. The District PE is often the best and most effective way to gather input from the PDT. When all the questions are scored for relevance and priority, individual question scores are calculated and then summed to get the project’s ABC rating. The ABC rating is then used to enter the ABC Decision Flow Chart. Through a series of questions that are scored based on relevance and priority, the flow chart will help guide the user to determine whether an ABC alternative should be developed for comparison with conventional construction alternatives. The ultimate decision to advance an ABC alternative further into the project development process will be made by the District.

ABC DESIGN IMPACT QUESTIONNAIRE

Project:

Date:
Completed by:

Category	Decision Making Question	(R) Relevance Range 0 = NA 1 (Low) to 5 (High)	(P) Priority Rating 1 = Low 2 = Med 3 = High	(RxP) Score
Construction Time	Are there weather limitations for conventional construction?			
	Is there restricted construction time due to environmental schedules?			
	Is there restricted construction time due to economic impact?			
	Has the District expressed the desire to complete the bridge construction in one season?			
	Is the bridge construction on a critical path of the total project?			
Environmental	Does ABC avoid, minimize, or mitigate a critical environmental impact or sensitive environmental issue?			
User Costs and Delays	Does the bridge carry or is it over a route with high ADT and/or ADTT?			
	Would ABC significantly improve the traffic control/maintenance plan?			
	Are only short-term closures allowable?			
	Will conventional bridge construction cause a significant delay/detour time?			
	Will bridge construction have an adverse impact on the local economy?			
Site Conditions	Are there existing railroads that impact the construction window or construction activities?			
	Are there existing utilities that impact the construction window or construction activities?			
	Does the site create problems for conventional construction methods?			
	Is the bridge over a waterway?			
Risk Management	Does ABC improve worker safety?			
	Does ABC improve traveler safety?			
	Does ABC allow management of a particular risk? If yes, identify risk here:			
Other	Will repetition of elements allow for economy of scale?			
		ABC Rating		

Figure 3.1.4-1 ABC Design Impact Questionnaire

There is an acknowledged level of subjectivity in both the ABC Design Impact Questionnaire and the ABC Decision Flow Chart. The tools of the ABC Decision Making Guidance present a variety of considerations to help guide the user in the evaluation of construction impacts and the importance of reducing those impacts as a project goal. This is a qualitative process that requires engineering judgment.

Table 3.1.4-1 Description of Terms in the ABC Design Impact Questionnaire

Decision Making Question	Scoring Guidance Description
Are there weather limitations for conventional construction?	This is a measure of the restrictions that the local weather causes for on-site construction progress. ABC methods may allow a large portion of the construction to be done off-site (such as a controlled fabrication facility) which helps reduce delays caused by inclement weather (rain, snow, etc.). Depending on the location and the season, faster construction progress could be obtained by minimizing the on-site construction time.
Is there restricted construction time due to environmental schedules?	This is a measure of how the construction schedule is modified by environmental season work-window requirements for threatened or endangered species protection. Environmental items to consider are breeding seasons, migratory patterns, etc. If there are significant restrictions on the construction schedule, provide a high score. If there are little to no restrictions, provide a low score.
Is there restricted construction time due to economic impact?	This is a measure of how the construction schedule is impacted by community concerns or requirements. Community items to consider are local business, tourism, access windows, holiday schedules and traffic, special event traffic, etc. If there are significant restrictions on the construction schedule, provide a high score. If there are little to no restrictions, provide a low score.
Has the District expressed the desire to complete the bridge construction in one season?	Multiple season construction can have varying economic impact on the structure and overall cost of construction. Staged construction can often push construction into a second season or increase the risk of a second season. In an effort to control the risk of increased cost and schedule the District may express the desire to develop a design that can confidently be completed in one season.
Is the bridge construction on a critical path of the total project?	This is a measure of how the construction schedule of the structure impacts the construction schedule of the entire project. If the construction of the structure impacts the critical path of the entire project and utilizing ABC methods provides shorter overall project duration, provide a high score. If other project factors are more critical for the overall project schedule and utilizing ABC methods will not affect the overall project duration, provide a low score.

Decision Making Question	Scoring Guidance Description
Does ABC avoid or minimize a critical environmental impact or sensitive environmental issue?	This is a measure of how using ABC methods can avoid or minimize impacts to the environment within the project action area. Primarily ABC avoids and minimizes construction related impacts since accelerated methods allow a shorter on-site construction time and/or smaller environmental footprint (fewer bents, no falsework, less noise, etc.). In some cases, an ABC project will avoid a critical environmental issue. For example: if the waterway under the bridge is habitat for a threatened fish species or wetlands are present immediately adjacent to the roadway, ABC could reduce impacts to those sensitive features, both in the size of the footprint impacted and the duration of the impact. If ABC methods avoid or minimize a significant or critical environmental concern or issue, provide a high score. If there are no environmental concerns that can be avoided or minimized with ABC methods, provide a low score.
Does the bridge carry or is it over a route with high ADT and/or ADTT?	This is a measure of the total amount of traffic crossing the bridge site. Use a construction year average daily traffic (ADT) value equal to the sum of the traffic on the structure and under the structure. For structures with a higher-than-average percentage of average daily truck traffic (ADTT), consider providing a higher score. The number associated with “high” ADTT/ADT varies from district to district. The District PE can consult with their traffic operations engineer to determine the appropriate score for the project. Potential impacts to traffic congestion or traffic safety should be taken into account.
Would ABC significantly improve the traffic control/maintenance plan?	This is a measure of how using ABC methods can improve the plan for controlling traffic through the construction area. Complex Maintenance of Traffic (MOT) schemes involving multiple traffic shifts, one-way closures, and extensive flagging are expensive, cause delays to the traveler, and pose increased safety risks to both workers and the traveling public. If ABC methods significantly improve the MOT scheme provide a high score.
Are only short-term closures allowable?	This is a measure of what other alternatives are available besides ABC. If staged construction is not an alternative at a particular site, the only alternative may be to completely shut down traffic on the bridge for a lateral slide or Self-Propelled Modular Transporter (SPMT) move, and therefore a high score should be provided here. If there is a good alternative available for staged construction that works at the site, a low score should be provided here.
Will conventional bridge construction cause a significant delay/detour time?	This is a measure of the delay time imposed on the traveling public. If conventional construction methods impact the critical path and delay (either by increased traffic congestion or detours) the traveling public, provide a high score here. If conventional construction methods do not impact the critical path and create minimal delays to the traveling public, provide a low score here. The District PE can provide information in determining the score for this item.
Will bridge construction have an adverse impact on the local economy?	This is a measure of the impact to the local businesses around the project location. Consider how the construction staging, road closures, etc. will impact local businesses (public access, employee access, etc.) A high impact to the economy equates to a high score.

Decision Making Question	Scoring Guidance Description
Are there existing railroads that impact the construction window or construction activities?	This is a measure of how railroad traffic adjacent or under the bridge will be affected by the project. Railroads often provide very limited access for construction equipment, falsework, and short work windows. Prefabricated Bridge Element Systems (PBES) are often a preferred alternative by the railroad agency. If a major railroad line runs under the bridge which would disrupt construction progress significantly, provide a high score.
Are there existing utilities that impact the construction window or construction activities?	This is a measure of how utilities (power lines, water authorities, etc.) will create restrictions on construction work windows and activities. If utilities have a significant impact on construction progress that would be eliminated or reduced by ABC, provide a high score.
Does the site create problems for conventional construction methods?	This is a measure of site conditions that make conventional construction problematic. Examples of this include steep terrain, where falsework or shoofly detours are problematic; limitations of right-of-way; and construction easements.
Is the bridge over a waterway?	This is a measure of the impact of a waterway on construction work windows and construction activities. Often a waterway prohibits the use of falsework, or access during wet seasons, or limits the number of bents, etc. These limitations can extend a project into multiple seasons. In addition, waterways are commonly habitat for threatened or endangered species. Navigable waterways with marine or recreational vessel traffic can also restrict falsework use. If ABC can avoid or minimize impacts to waterways, provide a high score.
Does ABC improve worker safety?	This is a measure of relative safety of the construction workers between conventional construction methods and accelerated construction methods. The reduced onsite construction time from using ABC methods reduces the exposure time of workers in a construction zone to traffic, thus increasing safety. If a significant increase in worker safety can be achieved by utilizing ABC methods, provide a high score. If utilizing ABC methods does not provide additional worker safety, provide a low score.
Does ABC improve traveler safety?	This is a measure of relative safety of the traveling public between conventional construction methods and accelerated construction methods. The reduced on-site construction time from using ABC methods reduces the exposure time of the traveling public in a construction zone, thus increasing safety. If a significant increase in safety of the traveling public can be achieved by utilizing ABC methods, provide a high score. If utilizing ABC methods does not provide additional safety to the traveling public, provide a low score.
Does ABC allow management of a particular risk?	This is an opportunity to add any project-specific items or unique issues that have risk associated with them that are not incorporated into another section in this table. Consider how ABC may or may not manage those risks. An example would be a bridge located in a remote site that is 60–90 minutes from the nearest batch plant. Exceeding the concrete discharge limit time could lead to poor concrete quality. Alternately, the requirement of an on-site batch plant could significantly raise the price of the bridge. The use of PBES in this case would assure concrete quality and control structure cost. If ABC methods mitigate a particular risk, provide a high score. Identify the specific risk under consideration on the ABC Design Impact Questionnaire.

Decision Making Question	Scoring Guidance Description
Will repetition of elements allow for economy of scale?	This is a measure of how much repetition is used for prefabricated elements and assembly processes on the project, which can help keep cost down. Repetition can be used on both substructure and superstructure elements.

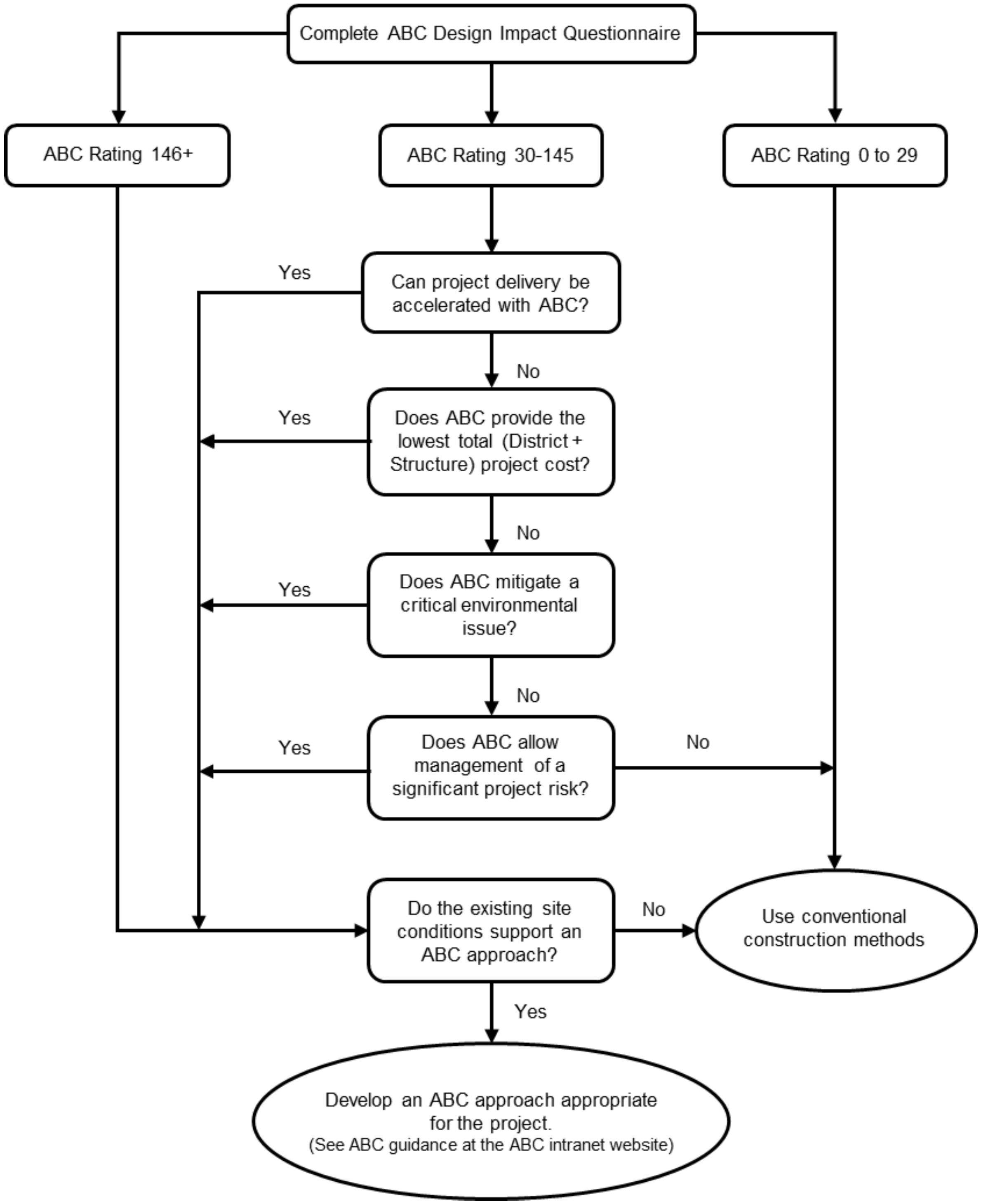


Figure 3.1.4-2 ABC Decision Making Flow Chart

3.1.5 Required Advance Planning Study Working Day Estimates

The bridge construction costs of ABC alternatives are often higher than conventional construction alternatives. This higher cost may be offset by reduced construction impacts directly related to ABC methods and schedule. To properly compare ABC alternatives with conventional construction alternatives, bridge Construction Completion Time (CCT) and specific bridge Construction Impact Times (CIT) are to be developed for both conventional construction and ABC alternatives. The CCT and CIT working day estimates provide important input for assessing construction impacts and Total Project Cost.

CCT is an estimate of the number of total onsite construction days required for the bridge construction work. The CCT does not include off site or roadway activities such as roadwork, mobilization, procurement, or traffic handling preparations.

CIT is an estimate of the number of working days or hours that a bridge construction activity will affect a specific item of interest as it relates to the project goals. Examples of CIT items of interest include road closures, detours, construction activities in environmentally sensitive areas, impacts to local business, and access to essential services. The PDT is responsible for identifying the CIT items of interest and the PE is responsible for including them on the APS/GP Checklist submittal to Structure Office Engineer (SOE) – Structure Cost Estimates.

A typical time relation is depicted in Figure 3.1.5-1.

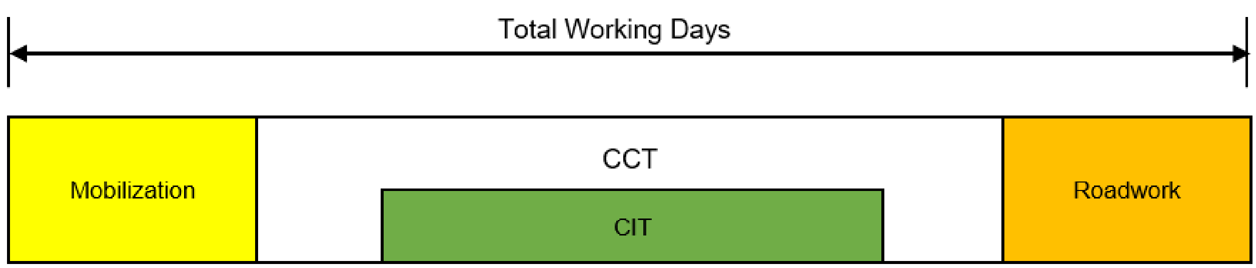


Figure 3.1.5-1 Bridge construction project time schematic

Due to limited resources during the APS stage, working day estimates should be requested for the most viable or preferred ABC alternative when ABC alternatives are developed for comparison to the preferred conventional construction alternative. SOE – Structure Cost Estimates will provide a working day schedule per bridge from which the PE can extract the CCT and CIT. The PE will discuss probable construction methods with Structure Construction and Structure Cost Estimates. Probable construction methods are to be documented and included in the APS/GP Estimate Checklist.

Both the CIT and CCT are approximate measures of bridge construction durations and are intended to prompt the District to evaluate the merits of ABC alternatives at an early project development phase. When ABC is anticipated, CCT and CIT estimates for the ABC and conventional construction preferred alternatives are included with the APS Transmittal Letter to the District.

3.2 ABC METHOD SELECTION

As stated in Section 1.2, ABC is driven by the goals and constraints of the project, and there is no one-size-fits-all approach. The purpose of this section is to describe the ABC methods available and how to select the most appropriate method considering the goals, constraints, and opportunities, as illustrated in Figure 3.2-1.

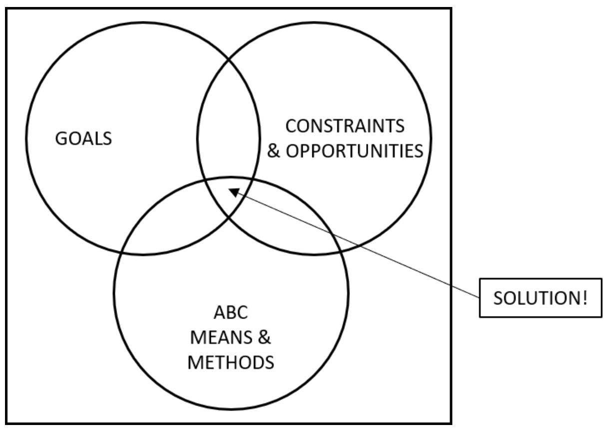


Figure 3.2-1 Venn-diagram Illustrating how ABC Methods are Selected (Mellon 2017)

3.2.1 Description of Methods/Types of ABC

There are many types of ABC methods available, but determining the appropriate method for a specific project depends on the goals, the site constraints, and the opportunities of the project. Constraints include MOT requirements, environmental requirements, limited right-of-way, site access, seasonal weather patterns, and project funding. Opportunities could include collaborative funding, signalized traffic control, temporary stream diversion, available right-of-way, available routes for prefabricated element delivery, and bridge staging areas.

ABC methods are divided into two main categories: (1) Offline Construction (Section 3.2.2) and (2) Online Construction (Section 3.2.3).

3.2.2 Offline Construction

With Offline Construction, a bridge system is constructed outside of its final location using conventional construction methods or is assembled using prefabricated bridge elements. A bridge system could represent a span, a superstructure, a substructure, or a superstructure and substructure. Once construction is essentially complete, the bridge system is moved to its permanent location. Offline construction is divided into three subcategories — lateral slide, SPMT moves, and crane-based moves. Offline construction should be used when MOT requirements are too stringent for online construction or when it is more cost effective.

According to the *Accelerated Bridge Construction Manual – Experience in Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems* ((FHWA 2011), Offline construction has the following benefits:

- Longer cure and less potential for restrained shrinkage cracking in concrete components
- Efficient use of construction equipment
- Controlled environmental conditions at prefabrication facilities.
- Lower life-cycle costs
- Improved safety
- Enhanced public support because traffic continues using the existing bridge while the new bridge is being constructed offline.

The following is a brief description of offline ABC methods for purposes of selection. More detailed descriptions can be found in Chapter 4.

3.2.2.1 Lateral Slide

The lateral slide method involves building a structure next to the travelled way without disruption to traffic and then moving it into place over a single night or weekend closure. This method is typically for bridge replacement projects where the new bridge's permanent location is the same as the one it is replacing. The new superstructure is first constructed next to the existing bridge. Once the new bridge is complete and the substructure for the new bridge is ready, the existing bridge is removed and the new bridge is moved transversely into place.

To minimize traffic disruption during removal of the existing bridge and building of the new substructure, or preparation of the existing substructure, it is common to detour traffic onto the new bridge on a temporary alignment while that work is being performed. This removes that portion of the work off the critical path so that the only impact on traffic is when the road is closed to move the bridge from the temporary alignment to its permanent location.

The lateral slide method can also be used to remove an existing bridge off of the alignment. After the move, the existing bridge can be dismantled off to the side where the work does not impact traffic. Section 4.10 presents specific lateral slide design requirements and slide equipment information.

Selection Criteria

Lateral slides are particularly effective when:

- The road crossed has low traffic volumes or low off-peak hour demands
- Minimizing traffic disruption is critical

Site Requirements

To construct and move a new bridge using a lateral slide, the project site must include an area adjacent to the bridge with adequate space to build the bridge. High skews and large superelevations complicate the design and the slide. Vertical clearance under the bridge in the temporary construction location may also be required. If necessary, vertical clearance can be maintained during construction by building the bridge high and lowering the bridge before the move.

Clear zones measuring 50-feet minimum around three sides of the bridge system footprint and at least 10 feet between the bridge system and the existing bridge are recommended for construction equipment and staging, as illustrated in Figure 3.2.2.1-1. These zones include overhead utilities, which could limit crane location. Lateral slide projects have been successfully executed with less available space and should be evaluated on a case-by-case basis.

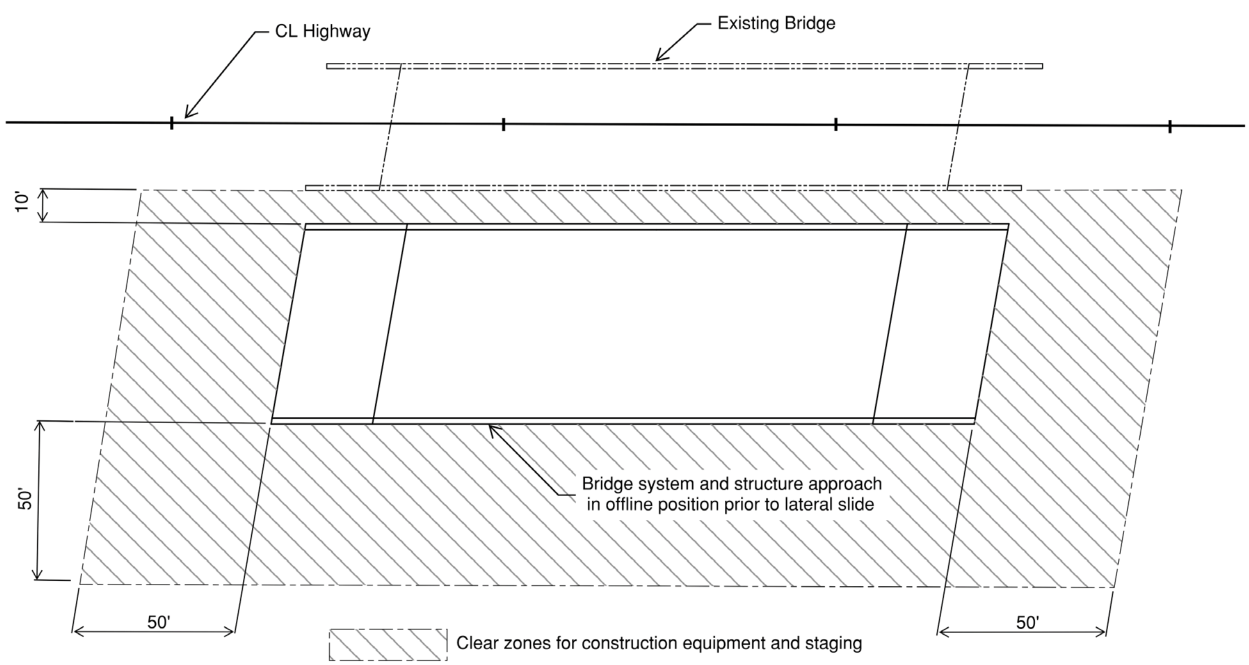


Figure 3.2.2.1-1 Clear Zones for Construction of Lateral Slide Bridge Systems

Cost Considerations

The initial cost of a lateral slide project is primarily a function of the temporary supports, the bridge move, and possibly the additional temporary right of way, as discussed in the *Slide-in Bridge Construction Implementation Guide* (FHWA 2013). Lateral slide systems that require lowering the bridge before the move increase costs. For more detailed information on the cost of lateral slides, refer to the *Slide-in Bridge Construction Cost Estimation Tool Guidelines* (FHWA 2015).

3.2.2.2 Self-Propelled Modular Transporter (SPMT) Move

SPMTs are high-capacity self-propelled modular trailers that have a high degree of precision and maneuverability that can be operated remotely without the aid of a tractor for propulsion. SPMT systems are capable of pivoting 360 degrees as needed to lift, carry, and set very large and heavy loads, including single and multi-span bridges, trusses, and arches. Depending on the complexity, SPMT moves can be executed in a matter of hours or over a weekend.

SPMT moves are best suited where the ADT crossing over and under the bridge is high. In most SPMT move projects, the bridge is constructed offsite so construction does not impact traffic. SPMTs are used to move the new bridge into place after the superstructure and substructure are complete. SPMTs can also be used to remove an existing bridge so that it can be dismantled offsite away from traffic.

Section 4.11 presents specific SPMT move design requirements and SPMT information.

Selection Criteria

SPMTs are advantageous for bridge replacements when:

- The bridge or cross street has high traffic volumes
- Minimizing traffic disruption on the bridge or cross street is needed
- The bridge is over a railroad or navigable waterways that allow minimal closure windows, and barge mounted SPMTs can be used to erect spans.
- Overhead or adjacent work area constraints, such as power lines, prevent the use of conventional in-place construction with cranes
- Air quality or noise level constraints limit the type or timing of construction activities
- Threatened and endangered species on the site limit the timeline for construction activities
- Weather constraints, such as cold weather, limit the length of time for onsite construction activities

Site Requirements

To construct a new bridge and move the bridge using SPMTs, the project site must include a staging area with adequate space to build the bridge upon a temporary substructure. Soil conditions must be sufficient to support all loads during construction and during transport of the new bridge. The travel path from the bridge staging area (BSA) to the final bridge location must provide adequate clearance, grade, and ground bearing capacity to allow the SPMT to transport the new bridge. The final bridge location must be accessible by the SPMT.

A clear zone measuring a minimum of 50 feet around the perimeter of the bridge system should be available for construction equipment and staging in the BSA. SPMT move projects have been successfully executed with less available space but going below the recommended minimum clear zone should be evaluated on a case-by-case basis.

The grading and geometry along the travel path is also critical. SPMT systems can accommodate grade changes with a well-planned system, as discussed in the *AASHTO LRFD Guide Specifications for Accelerated Bridge Construction* (AASHTO GSABC) (AASHTO 2018), Section C1.5.1.2.1. Use of SPMTs is challenging and requires significant planning and engineering if the travel path or route from the BSA to the site has:

- Grades exceeding four percent
- One or more grade breaks or superelevation transitions
- A road with a split profile
- A large area of uncompacted ground
- Buried structures or sensitive utilities
- Existing bridges, overhead structures, or utilities

Cost Considerations

The costs of a SPMT move are dictated by the base rate for mobilizing and reserving the equipment, the engineering effort by the heavy lifter, and the number of moves. Requirements such as evaluation, preparation, and restoration of the BSA and travel path also add to the cost of a project. Since mobilization is a significant portion of the cost, using SPMTs at multiple locations and purposes makes this method more cost effective.

3.2.2.3 Crane Based Move

Crane based moves are effective when the site permits easy access for cranes and the bridge system weights are reasonable. Crane based moves involve constructing a bridge system in a BSA and moving them into place with crane(s). Crane based moves can include multiple sections that are connected after erection.

Selection Criteria

Crane based moves are particularly effective for ABC projects when:

- The project area does not permit the use of a lateral slide or have adequate access to use SPMTs;
- Locally available cranes have the capacity to move and place the bridge or bridge sections; and
- The bridge system size and weight are relatively small and easily handled or moved with a crane.

Site Requirements

To place a new bridge with a crane requires a project site with an area adjacent to the bridge to set up a crane or cranes. A location for the prefabricated bridge sections or complete span where the crane can pick up the sections and accommodate any required swing radius are critical. Additional site requirement considerations include:

- The crane travel path should be level
- Overhead utilities, if present, could require relocation or temporary shutdown
- Airspace conflicts with nearby airports must comply with Federal Aviation Administration requirements

Cost Considerations

The initial cost of a crane-based move is primarily a function of the weight of the bridge sections. Heavy sections and/or poor crane locations requiring a large reach require very large cranes. The use of large cranes that are not locally available can significantly increase the cost.

3.2.3 Online Construction Guidelines

Online Construction, as defined herein, consists of: (1) a bridge system assembled in its final location using prefabricated bridge elements or (2) a bridge system constructed on the alignment using conventional construction or assembled using prefabricated elements and longitudinally launched into position. Online construction is used when offline construction is impractical due to geometric constraints or when online construction is a more economical method for achieving project goals.

The following is a brief description of online ABC methods for purposes of selection. More detailed descriptions are provided in Chapter 4.

3.2.3.1 Prefabricated Bridge Elements (PBEs)

PBEs are the most used ABC method in California. With this method, bridge elements are manufactured at a prefabrication yard and then transported to the project site where they are assembled to make a complete bridge. This method performs most of the construction activities offsite, thereby eliminating the need for falsework and significantly reducing the amount of cast-in-place concrete needed at the job site.

PBE structures can be assembled onsite over a single construction season or in a matter of days. How quickly PBE structures are assembled depends on the size of the structure, number of elements to be connected, connection detailing, the number of construction stages, and when foundations are constructed.

Successful projects where PBEs have been used were the result of detailed planning and design that focused on constructability, ease of fabrication, repeatable elements, reasonable tolerances, speed of assembly, simplicity of design, and minimizing risk to schedule. Section 4.9 presents specific prefabricated bridge element design and construction requirements.

Projects using a single PBE such as girders that are not used in combination with other ABC methods are not considered ABC projects.

PBEs allow the construction of bridge elements in controlled environments, thus improving quality. Constructing the bridge with PBEs also:

- Reduces restrained shrinkage cracking of concrete components
- Controls cure conditions
- Provides better control over materials and construction tolerances
- Lowers life cycle costs
- Promotes public support from reduced duration of traffic disruption

Selection Criteria

PBEs are effective for an ABC project when:

- The bridge is over a railroad, waterway, or other feature that could preclude falsework
- Air quality or noise level constraints limit the type or timing of construction activities
- Threatened, endangered, or otherwise sensitive species on the site and/or work area limit the timeline for construction activities
- Work windows limit the length of time for construction activities
- A remote site makes delivery of cast-in-place (CIP) concrete problematic

- Discharge of CIP concrete into a sensitive waterway is a concern
- Bridge geometry is not overly complicated; i.e., excessive skew, reversing superelevation, tight radius, or a combination thereof

Site Requirements

To construct a new bridge using prefabricated elements, the project site must include a staging area with adequate space to set up a crane to lift the prefabricated elements into place and a route that will support transportation of elements from the fabrication yard to the job site. Temporary storage of multiple elements may also be required at the site.

Cost Considerations

Transportation and assembly costs of PBEs can be significant, and limiting element size and weight can control these costs. This consideration should be balanced with the benefit of having fewer elements and connections for durability and ease of construction, as discussed in Section 4.9.4.1. Fabrication costs are controlled by the use of repeatable simple element designs and the avoidance of complicated geometry.

3.2.3.2 Longitudinal Launch

In this method of construction, the bridge superstructure is assembled on one side of the obstacle to be crossed and then pushed or pulled longitudinally (or “launched”) to the other side into its final position. The launching is typically performed in a series of increments so that additional sections can be added to the rear of the superstructure unit prior to subsequent launches. This method is often referred to as the Incremental Launching Method (ILM).

Longitudinal launches are not constructed as quickly as offline methods but are effective at spanning challenging obstacles while minimizing construction related impacts.

Section 4.12 presents specific longitudinal launch design requirements and launching equipment information.

Selection Criteria

Longitudinal launches can be considered for bridge projects when:

- The bridge is closed to traffic during construction
- The bridge is over a major road or rail line, deep valley, or deep-water crossing
- Overhead or adjacent work area constraints, such as power lines, prevent the use of conventional in place construction with cranes
- Environmental requirements limit access or require minimal disturbance

- Limited access due to local bridge site geography such as steep slopes or poor soil conditions

Site Requirements

To construct and launch a new bridge, the project site must include an area behind the bridge with adequate space and grade to build the bridge. High skews and large superelevations complicate both the design and the launch.

The construction area required is a function of the specific launch technique. The bridge can be launched as a single unit, where the entire bridge superstructure is constructed and launched, or the superstructure can be constructed in sections and launched incrementally in stages. The ILM is used when there is not enough room to build the entire superstructure all at once.

Cost Considerations

Project cost specific to the longitudinal launch method is primarily a function of specialized analysis and design, construction equipment required for the launch, and the additional bridge material to accommodate design launch loads. The longitudinal launch method comes with significant cost but in some cases the bridge launch may be the most reasonable way to construct a bridge over a challenging obstacle.

3.3 TRAFFIC MANAGEMENT

Effective traffic management can significantly enhance ABC solutions. Traffic management is often a critical part of the project that affects the types of ABC techniques that can be used. Traffic management is the District's responsibility. Collaboration and frequent communication among the PE, the District PE, Construction, and the District Traffic Division is important for the success of the ABC project.

A primary objective of ABC is to minimize the time required for closure of existing facilities, which include lane, roadway, rail, bike, and pedestrian facilities. The duration of the closure can be managed with ABC methods. For example, precast columns can both shorten the overall construction schedule and reduce the amount of time the adjacent lanes are impacted by construction of the columns. Environmental and community concerns or requirements are factored into the traffic management plans. These factors could include local business access windows, holiday schedules and traffic, and special events.

3.3.1 Full Closure of Existing Facilities

Full closure of existing facilities is one of the most effective ABC methods. It has traditionally been considered too disruptive to employ except in special situations but has become more common, as it offers many benefits including:

- Shorter construction time: under a full existing facility closure, the bridge can be removed and replaced in a single stage rather than multiple stages.
- Cost savings: fewer stages, reduced construction duration, and a more efficient work area result in reduced costs associated with mobilization, MOT, environmental mitigation, and traffic delay.
- Improved quality and durability: full access to the bridge site allows for more efficient construction and the elimination of vibration from traffic provides better conditions for curing concrete. (FHWA 2011; UDOT 2019).
- Enhanced safety: safety is significantly improved when construction is not performed near live traffic (ARTBA 2011).
- Improved public sentiment: public sentiment is more favorable for short, full road closures over partial closures that are spread over months, and possibly years of construction (FHWA 2011; UDOT 2017).

3.3.1.1 Determining the Closure Schedule

A primary objective of ABC is to minimize the time that the facility must be closed, whether a partial or full closure. It is therefore imperative to examine each step in both the construction sequence and schedule to identify when the closure is least disruptive to traffic and those areas where construction time can be condensed and risks reduced. Encouraging the contractor to work quickly with an incentive payment for opening early has also been effective.

3.3.1.1.1 Construction Sequence

Effective ABC planning includes developing a step-by-step construction sequence that minimizes the amount of work done during the full road closure. Tasks that pose a significant risk to the schedule, such as utility relocation, foundation installation, and environmental work windows, require extra consideration. Whenever possible, high-risk tasks should not be performed during a full road closure. The construction sequence should be organized in three separate sections: (1) pre-closure, (2) during closure, and (3) post-closure. Planning these construction sequence sections is not complete without coordination with the District, Structure Construction and other essential organizations.

3.3.1.1.2 Incentive/Disincentive

Experience has shown that it is not enough to provide an effective ABC design and a well thought out construction sequence that reduces the duration of a road closure or detour. Incentives and disincentives can also be used to provide an incentive payment if the road closure or detour is opened early and liquidated damages if the work is not complete, and the road is not opened on time. For more information on incentives and disincentives, see Section 3.5.3.

3.3.2 Temporary Bridge

At some sites, a temporary bridge can be used to maintain traffic and allow for a full bridge closure. Typical dimensions, installation and removal times, standard plans, costs, plan and specification requirements, right-of-way requirements, and District coordination items are discussed in more detail in Section 4.15.

3.3.3 Temporary Culverts for Shoofly Detours

Temporary culverts can be used as a temporary detour, which would allow for a full bridge closure during ABC. As with temporary bridges, areas necessary to construct and remove culverts and approach fills should be identified and included in the planning documents.

3.4 ABC ADVANCE PLANNING STUDY

The details of developing an Advance Planning Study (APS) are discussed in the *Bridge Design Process and Procedure Manual* (Caltrans 2019) Chapter 4.2, Caltrans *Bridge Design Memo* 1.5, and the Caltrans APS Development Requirements. ABC considerations in developing an APS are discussed in the following sections.

3.4.1 Design Considerations

While most ABC design considerations are covered in detail in Chapter 4, they are briefly mentioned here to help guide the direction of the preliminary design and planning, and to spot fatal flaws early in the process. As previously stated, designing for ABC is designing for the construction methods that address the goals, constraints, and opportunities of the project. Simplicity of design and management of risk to schedule are key considerations throughout the development of an APS and subsequent design.

At the beginning of the ABC development process consult with the ABC Branch.

3.4.1.1 Project Goals, Constraints, and Opportunities

The success of an ABC design is determined by how well it aligns with project goals and constraints. Because each project has unique restrictions and opportunities, it is essential to identify the project goals and constraints along with available opportunities early, during the planning phase.

Goals and constraints are identified through direct communication with partners and stakeholders, PDT meetings, completion of the ABC Design Impact Questionnaire, and submittals such as the APS request from the District and the Project Risk Register.

Items specific to ABC that require coordination with the District PE include full facility closures, temporary bridges, right of way, construction windows, staging areas, detours, timely utility relocation, permits, the availability of incentive/disincentive funds, and impacts of public concern.

3.4.1.2 Project Site

As discussed in Sections 3.2, the efficacy of ABC is dependent on the conditions of the site. Site considerations include access, availability of staging areas, available travel paths, crane setup locations, the presence of railroad and utility and their locations, and construction windows.

Structures Construction, the District PE, and other members of the PDT should be involved in the evaluation of the site for ABC.

3.4.1.2.1 Environmental Requirements

Section 9 of the *Project Development Procedures Manual* (Caltrans 2020) states that “it is Caltrans’ policy to evaluate alternatives that avoid, minimize, or mitigate adverse environmental impacts.” ABC can bring environmental benefits to a project both through the method of construction and fewer onsite working days. Hence, environmental considerations can be a significant factor in selecting ABC and the methods used. Considering ABC in the APS affords an opportunity to work with the District Environmental Planning Division through the PDT to determine the environmental benefits of an ABC approach and to optimize the design to reduce construction-related impacts. Input on pile types and location, construction within a single season versus multiple seasons, and stream impact avoidance are examples of issues that require coordination with the Environmental Division.

3.4.1.2.2 Heavy Lift Requirements

Offline ABC projects that utilize SPMT or crane-based moves require an evaluation of potential BSAs and travel paths. The following is a brief discussion of the items to be investigated:

Bridge Staging Area (BSA): The BSA requires space to build the entire structure, move equipment in and out of the structure staging area, and maintain required traffic around the structure staging area, as discussed in Section 3.2.2. Assumptions used to determine required space should be documented in the APS Plans and Transmittal Letter.

Travel Path: For SPMT moves, the travel path geometry should be investigated including grades and turn radii along the travel path, as well as travel path cross slope and longitudinal grades. Access from the BSA to the final location along the travel path should be verified. Obstacles such as utilities (buried or overhead) or existing structures along or under the travel path should be identified and accounted for in the moving plan. Capacities of all bridges and structures along the travel path should be investigated for the heavy lift loads, as discussed in Section 4.7.

Structure Type: Evaluate preliminary structure types to determine approximate dimensions and weights.

Geotechnical Conditions. Coordination with Geotechnical Services is necessary to ensure that the planned investigation and the resulting Structures Preliminary Geotechnical Report (SPGR) address all areas impacted by the ABC alternatives. This includes areas of influence beneath the loaded move equipment, jacking towers, carrier beam towers, various other support structures, and the permanent foundation. Areas of improvement for ground bearing capacity or slope stability should be identified. Consider the areas of influence beneath the move equipment at the lift location, along the travel path, and at the final location.

Subsurface Utilities: The utility type, size, location, depth, and owner of any buried utility lines within potential BSAs and travel paths should be identified. Mitigation for utilities consisting of relocation or in-place protection should be investigated.

Maintenance of Traffic (MOT): Potential traffic impacts of the structure moving equipment on the travel path should be identified. Consider the impact to the project of any local restrictions such as site protection, noise restrictions, structures or roadways driven over, etc.

3.4.1.3 Risk to Schedule

Risk to schedule can be managed through simplicity of design, clear detailing, proactive mitigation of risk items, work plans and communication with stakeholders. A simple design is easier and faster to construct. Prefabricated elements should be designed to avoid complex geometry and connections, account for tolerances, and sized to ensure economical transport and erection. Overly complicated designs have the inherent risk of fit up issues in the field that can result in unwanted delays to the construction schedule.

Utility relocations, railroad coordination, environmental windows, temperature sensitive curing, and foundation type can also pose a significant risk to the schedule. Management of these risks requires proactive communication with stakeholders early in the project development.

Construction activities with risks that cannot be effectively reduced or eliminated should be moved off the critical path in the construction schedule when possible. Risks to the construction schedule and options for mitigating them should be included in the APS Transmittal Letter.

3.4.1.4 Foundation Selection

Select the foundation types that:

- are fast to construct;
- have a low risk of creating a delay in the construction schedule; and
- have a low environmental impact.

Certain pile types present more risk to schedule. This can be due to placement accuracy for fit up with prefabricated substructure elements or installation delays due to anomaly repair or change in site conditions. When the structure demands and site geology allow, piles with lower risk to schedule should be selected.

Foundation installation should occur outside of the full road closure period or other critical construction windows. This can be accomplished by shifting traffic to create space for foundation installation or moving the location of the new foundation to avoid restrictive locations. The use of straddle bents and abutments may allow the foundation construction to be performed while traffic is on the existing bridge. Other creative solutions involve installation of piles through pavement behind the bridge or through the existing bridge deck prior to demolition.

For more information regarding recommended foundations for ABC, see Section 4.13

3.4.1.5 Construction Sequence

A construction sequence is developed during the planning phase to determine feasibility, prepare working day schedules, and estimate construction costs. Considering the means of bridge installation and removal of existing structures is of particular importance in the development of ABC task durations and costs. The construction sequence includes assumptions on when certain tasks will be executed and how they fit within construction windows and road closures.

The construction sequence includes identifying materials to be used in cast-in-place bridge components and connections. Connection materials such as grout, epoxy, rapid strength concrete, and ultra-high performance concrete should be identified along with any associated procurement information (e.g., proprietary or sole source) and minimum strengths and cure times before the bridge is opened to traffic. Additional information is available in Sections 4.8 and 4.9.5.

A construction sequence that identifies critical path items should be part of the APS ABC alternative.

3.4.1.6 Tolerances

Understanding that it is impossible to fabricate and construct elements to the exact dimensions shown on the plans is important, particularly when designing for ABC. Accounting for tolerances requires collaboration of planning, design, fabrication, and construction efforts.

There are several types of tolerances to take into consideration when sizing elements, detailing connections, and planning assembly:

- Element size and shape including location and length of bar protrusions
- Horizontal erection/setting tolerances
- Vertical erection/setting tolerances
- Foundation placement tolerances
- Bridge move tolerances

Overly tight or poorly considered tolerances can result in maintenance problems, as discussed previously. Differences in decked girder lengths can lead to poor fit and subsequent leakage at the expansion joint. Attention to details that allow for adjustment at the joints and connections is very important to the durability of the bridge.

Tolerances can be accommodated through proper sizing of voids and joints, closure pours, deck overlays, and simplicity in detailing. For more information on tolerances, see Section 4.2.2.

3.4.1.7 Durability

Designers should strive to design bridge elements that have simple details, are durable, and easy to construct. Details on the plans should be consistent with the selected ABC method and provide adequate tolerance for assembly. Complex details can lead to fit-up problems during assembly. Poor fit-up at expansion joints could lead to leaks and poor performance. Simple details, good fit-up, fewer joints, and adequate clearance for mechanical couplers and duct-splice connections are characteristics of durable designs.

The durability of a bridge depends on the durability of the connections. Adequate reinforcing, quality material, and proper preparation of the substrate are all necessary for a durable connection. Connection materials should be chosen based on durability properties required for the application including strength, bond, shrinkage, porosity, and flow. Identifying connection materials during planning allows for associated procurement, cure times, mock-ups, and cost information to be included in the APS. These materials should be selected from the Caltrans Authorized Materials Lists, as applicable. For information on CIP connection material, see Section 4.9.5.3.

3.4.1.8 Cost Control

ABC construction costs are controlled by focusing on constructability, simplicity of design, clear detailing, and reduction of risk. Contractors price risk into the bid, the higher the perceived risk, the higher the bid price. It is therefore important to consider how risk affects the overall construction cost. Cost considerations specific to each ABC method are discussed in Sections 3.2.

3.4.1.9 Demolition

Demolition and removal of the existing structure, including temporary shoring requirements, is an important component of ABC construction and should be addressed in the planning phase. Whenever possible, all or a portion of the demolition should be conducted off of the critical path. As-built plan availability; presence of active underground and overhead utilities; and constraints due to safety, environmental concerns, access, and maintenance of traffic can have significant cost and schedule implications. See Section 4.14 for more information.

3.4.1.10 Traffic Management

Effective traffic management can significantly enhance ABC solutions, as discussed in Section 3.3. The ABC method(s) selected for each project will depend on when, how much, and how long traffic can be affected. Therefore, traffic management should be included in the development of the APS. This requires frequent communication with the District PE and the District Traffic Division on the requirements of the selected ABC method along with the benefits and challenges of full roadway closures, lane closures, traffic detours, and the use of temporary bridge structures.

3.4.2 Resources

There are a variety of resources to assist in the development and planning of ABC projects. These resources include ABC specialists, the ABC Strategy Meeting, and the resources identified in Section 6.4.

3.4.2.1 ABC Specialists

Specialists familiar with ABC within DES include representatives from Structures Design, Structures Construction, Geotechnical Services, Earthquake Engineering, and Materials Engineering and Testing Services (METS). In addition, technical specialists on precast/prestressed concrete and structural steel can provide consultation, if necessary. Representatives from the ABC Branch can facilitate communication with these specialists. Since ABC projects are, by nature, construction driven, coordination with Structures Construction is required during APS development.

3.4.2.2 ABC Strategy Meeting

For an APS that requires an ABC alternative, an ABC strategy meeting is recommended. The strategy meeting is held while the APS alternatives are being developed. It is an opportunity for the PE to review the project with ABC Specialists, receive feedback, and discuss ABC options. These specialists can provide details and information from similar projects and help avoid common mistakes.

3.4.3 Information on the Plans and APS/GP Request

A general plan showing elevation, plan, and typical section views are prepared for the APS, as discussed in *Bridge Design Memo* 1.5 and in Section 4.2 of the *Bridge Design Process and Procedure Manual* (Caltrans 2019). To appropriately capture ABC in the project planning documents, the following should be included on the APS ABC general plan:

- Normal clearances for construction operations, see *Bridge Design Memo* 1.7.
- Bridge Staging Area (BSA) and travel routes for lateral slide, SPMT, and crane-based moves.
- Identification of prefabricated elements/systems.
- Areas for assembly and erection of any temporary bridge.
- Assumptions and risks relevant to the ABC alternative.
- ABC logo as discussed in Section 1.5. The ABC logo can be downloaded from the Caltrans intranet website.

Additional information may be needed from the PE for preparation of the APS cost and working day estimates (including CIT/CCT) and constructability reviews. This information could include:

- Size and weights of all elements
- Construction sequence when a special sequence is required
- Temporary supports, shoring, and bracing, if required
- Required cure time/strength for grouted joints and closure pours
- Project specific impacts for CIT estimates

In addition, the following information should be considered during development of the APS, although it is not required on the plans:

- Lift points of elements

- Grouting procedures
- Construction sequence

The feasibility of all major bridge components should be checked with the assumed construction sequence. For example, if the bridge is to be designed as a lateral slide, the abutments and bents should be evaluated to verify that these elements can be designed to resist the moving load applied at the assumed support locations. ABC loads and resistances are discussed in detail in Section 4.3.

3.4.4 Working Day and Cost Estimates

Working day estimates for the preferred ABC and conventional alternatives are required to include both CCT and CIT, as discussed in Section 3.1.5. The preparation of CIT estimates will require details of the assumed construction sequence discussed in Section 3.4.3 and the potential risks to the schedule discussed in Section 3.4.1.3. SOE - Cost Estimating Branch and/or Structure Construction should be consulted on CCT and CIT durations.

The construction cost estimate is based on the ABC methods, assumptions, and risks, and should reflect the cost considerations discussed in Sections 3.2.2 and 3.2.3. Special ABC items, such as mockups should be included in the estimate.

3.4.5 APS Transmittal Letter

The APS Transmittal Letter summarizes the assumptions, risks, costs, and construction durations (both CIT and CCT) for all ABC and conventional bridge construction alternatives. Since this letter allows the District to compare ABC and conventional bridge construction alternatives, it is important to emphasize how each alternative addresses specific goals and constraints of the project.

3.5 PROCUREMENT AND CONTRACTING METHODS

Caltrans has a variety of techniques to support ABC including alternative project delivery systems, procurement practices, and contract management methods. These techniques should be considered by the PE in collaboration with the PDT to accelerate delivery and reduce construction related impacts.

For additional information, please visit the Caltrans Innovative Contracting Techniques webpage or email innovative.delivery@dot.ca.gov.

3.5.1 Project Delivery Methods

Project delivery methods refer to the overall processes by which a project is designed, constructed, and/or maintained. Below is a discussion of (1) Design-Bid-Build (low bid), (2) Construction Manager/General Contractor, and (3) Design-Build project delivery methods.

3.5.1.1 Design-Bid-Build

Design-Bid-Build (DBB), or design then bid then build, is a traditional delivery method for the public sector in which an agency will use in-house staff (or, alternatively, use consultants) to prepare fully completed plans and specifications that are then incorporated into a bid package. Contractors competitively bid the project based on these completed plans and specifications. The agency evaluates the bids received, awards the contract to the lowest responsible and responsive bidder, uses prescriptive or performance specifications for construction, and retains significant responsibility for quality, cost, and time performance.

This is the traditional project delivery system at Caltrans and is available for any project.

3.5.1.2 Construction Manager/General Contractor

The Construction Manager/General Contractor (CMGC) project delivery method allows the agency to select a contractor early in the project development process to act in an advisory role. The CMGC contractor provides constructability reviews, value engineering suggestions, construction estimates, and other construction-related recommendations. When the design is approximately 100 percent complete the CMGC contractor provides a price to construct the project. If the price is acceptable to the agency, the CMGC contractor will become the general contractor and will construct the project. If the price is not acceptable, the project is advertised for a competitive bid similar to the DBB bid process.

CMGC projects allow the agency to maintain full control of the design while getting early involvement of the construction contractor through its preconstruction services contract. Consequently, this delivery method is well suited for ABC, since the design can be tailored to the contractor’s expertise and equipment. Further, preconstruction services often allow the Contractor to award long lead material supply, early work packages, and subcontractor early work packages before the project design is 100% complete thus locking in critical construction material costs at the earliest opportunity and minimizing risk to project schedule. Note that the design of early work packages, including fabrication details, needs to be 100% complete, if applicable

Caltrans has full authority to use CMGC on projects with a construction project cost estimate (roadway and structure work) of over $10 million; using CMGC on smaller projects requires an exception.

3.5.1.3 Design-Build

Design-Build (DB) is a project delivery method involving a single contract between the project owner and a design-build contractor covering both the final design and construction of a project. The design-builder performs design, construction engineering, and construction according to the design parameters, performance criteria, and other requirements established by the agency.

DB projects can by awarded by low-bid method requiring the contract to be awarded to the proposer that submits the lowest-priced responsive proposal or by best value in which the award is based on a combination of price and technical considerations.

The advantage of design-build for ABC is that the project delivery time can be reduced, since the design-build process allows for the design and construction phases to take place concurrently, unlike the design-bid-build process. The disadvantages of design-build for ABC are that the agency does not retain significant responsibility for the quality of the project, and it is difficult to identify project goals in the scope of work that are not quantitative in nature, such as user costs and environmental outcomes.

There are a limited number of slots within a given timeframe available for DB projects. For more information on the availability of DB, contact the Office of Innovative Design and Delivery via email at innovative.delivery@dot.ca.gov.

3.5.2 Procurement Practices

Procurement practices are the procedures agencies use to evaluate and select contractors. Evaluation and selection can be based solely on price, solely on technical qualifications, or on a combination of price, qualifications, time, and other factors. An alternative procurement method uses a method other than the traditional fixed-price, sealed bid procurement process to award a construction contract.

Cost-Plus-Time: Introducing a time factor into the bid can help accelerate construction. cost-plus-time-based (C+T) bidding uses a cost parameter (C) and a time parameter (T) to determine a bid value. The cost component (C) is the traditional bid for the contract items and is the dollar amount for the work to be performed under the contract. The time component (T) is the total number of calendar days required to complete the project, as estimated by the bidder, multiplied by an agency-determined daily road user cost (RUC) to translate time into dollars.

$$C + T(RUC) = \text{Total Bid Value}$$

The total bid value is used only to evaluate bids. The contract amount is based on the bid price (C), not the total bid value. The number of days bid (T) becomes the contract time. Note that the lowest combined bid may not necessarily result in the shortest construction time. C+T bidding relies on the contractor to provide the optimal combination of cost and time.

The objective of C+T is to obtain the optimum tradeoff between time and cost. If schedule is critical, use incentive/disincentive provisions along with C+T.

Consult with the Project Manager and PDT for C+T consideration.

3.5.3 Contract Management Methods

Contract management methods refer to the procedures and contract provisions used to manage construction projects on a daily basis to ensure control of costs, timely completion, and quality of construction.

Incentive/Disincentive Provisions: Incentive and disincentive (I/D) provisions for early completion provide incentive payments to contractors for completing work on or ahead of schedule or impose disincentive deductions for failure to meet the specified completion date. The daily or hourly I/D rate is based on considerations such as traffic safety, traffic maintenance, and user costs.

I/D provisions are well suited to projects requiring traffic restrictions, lane closures, bridge closures, or detours that would otherwise result in high user impacts. I/D provisions are typically used in ABC projects to shorten the required road or lane closure durations.

I/D provisions are considered by the national ABC community to be the most effective way to achieve early construction completion and shorten closure durations. The key to achieve the desired outcome of I/D provisions is a tight, efficient working day schedule that does not provide excess time to complete the work. Therefore, it is particularly important to provide CIT and CCT schedules that are realistic without being overly lenient.

Consult with the Project Manager and PDT for I/D consideration. The authority to approve the use of I/D rests with the District.

Delayed Start: Any project has a variety of tasks that require completion (both by the contractor and agency staff) prior to the start of work on the jobsite. This time requirement is addressed in contract provisions as “Delayed Start” and is typically 55 days. ABC projects may require additional time between contract award and the start of the job due to prequalification of materials, procurement of materials, and the development and review of shop drawings and work plans. The PDT should consider adding days to the delayed start provision that allow for the demands of the project.

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ACCELERATED
BRIDGE
CONSTRUCTION

Chapter 4

DESIGN

District 4

Laurel Street Overcrossing, Interstate 780,
Solano County, CA

Contents

4. DESIGN....................4-1
4.1 CONSTRUCTION CONSIDERATIONS....................4-1
4.2 LAYOUT, TOLERANCES, AND GEOMETRIC CONTROL....................4-1
4.2.1 Layout....................4-1
4.2.2 Tolerances....................4-1
4.2.3 Geometric Control....................4-2
4.3 LOADS AND LOAD FACTORS FOR ABC....................4-3
4.4 INTERIM LOADING CONDITIONS....................4-3
4.5 TEMPORARY SUPPORTS....................4-4
4.6 UTILITIES....................4-4
4.7 LOAD CAPACITY OF EXISTING STRUCTURES....................4-5
4.8 MATERIALS....................4-6
4.8.1 Lightweight Concrete....................4-6
4.8.2 Rapid Strength Concrete....................4-6
4.8.3 Ultra-High Performance Concrete....................4-7
4.8.3.1 Properties of UHPC (Graybeal 2019)....................4-7
4.8.3.2 UHPC Applications....................4-8
4.8.3.3 Considerations....................4-8
4.8.3.4 UHPC Checklists....................4-9
4.8.3.5 Caltrans UHPC Example Projects....................4-9
4.8.3.6 UHPC Resources....................4-10
4.9 PREFABRICATED BRIDGE ELEMENTS....................4-10
4.9.1 Introduction....................4-10
4.9.2 Roles and Responsibilities for PBE Design....................4-11
4.9.3 Site Considerations....................4-13
4.9.3.1 Cranes....................4-13
4.9.3.2 Transport....................4-13
4.9.3.3 Erection....................4-13
4.9.3.4 Storage....................4-14
4.9.4 Prefabricated Bridge Element Design....................4-14

4.9.4.1 Element Weight and Size Guidelines 4-14
4.9.4.2 Tolerances 4-15
4.9.4.3 Construction Sequence....4-16
4.9.4.3.1 Interim Loading....4-16
4.9.4.3.2 Deck Pour Sequence....4-17
4.9.4.4 Precast Concrete Bridge Element Design 4-17
4.9.4.4.1 Footings 4-17
4.9.4.4.2 Columns 4-19
4.9.4.4.3 Bent Caps 4-20
4.9.4.4.4 Abutments 4-21
4.9.4.4.4.1 Integral Abutments 4-22
4.9.4.4.4.2 Seat Abutments 4-23
4.9.4.4.5 Wingwalls 4-24
4.9.4.4.6 Full Depth and Stay-In-Place Precast Prestressed Concrete Deck Panels 4-25
4.9.4.4.7 Girder Selection....4-27
4.9.4.4.7.1 Decked girders....4-27
4.9.4.4.7.2 Non-decked Girders 4-28
4.9.4.4.8 Approach Slabs 4-28
4.9.4.4.9 Precast Concrete Barrier Rail 4-28
4.9.4.4.10 Predesigned PBE Single Span Bridges 4-29
4.9.4.5 Steel Elements....4-29
4.9.5 Precast Element Connections 4-29
4.9.5.1 Superstructures 4-30
4.9.5.1.1 Full Depth Deck Panel Connections 4-30
4.9.5.1.1.1 Connections Between FDDPs....4-30
4.9.5.1.1.2 Girder to FDDP Connections....4-31
4.9.5.1.2 Connections Between Adjacent Decked Beams 4-32
4.9.5.1.3 Girder to Bent Cap Connections....4-33
4.9.5.1.4 Link Slabs....4-33
4.9.5.2 Substructures....4-35
4.9.5.2.1 Adjacent Cap Elements 4-35
4.9.5.2.2 Column to Precast Bent Cap 4-36

4.9.5.2.2.1 Grouted Duct Connections 4-36
4.9.5.2.2.2 Pocket Connections 4-37
4.9.5.2.2.3 Socket Connections 4-38
4.9.5.2.3 Precast Column to Footing Connection 4-38
4.9.5.2.3.1 Fixed Column Base Connection 4-38
4.9.5.2.3.2 Pinned Column Base Connection...4-39
4.9.5.2.4 Precast Column to Shaft Connections 4-39
4.9.5.2.5 Abutments 4-40
4.9.5.2.5.1 Adjacent Abutment Wall Element Connections 4-40
4.9.5.2.5.2 Abutment Wall Elements to Wall Cap Connections 4-41
4.9.5.2.5.3 Abutment Wall Elements to Footing Connections....................4-42
4.9.5.2.5.4 Abutment Wall Elements to Pile Connections..........................4-42
4.9.5.3 Closure Joint Materials 4-42
4.9.6 Achieving a Smooth Driving Surface on Precast Elements......................4-43
4.9.7 Mock-ups..4-43
4.9.8 Preassembly 4-44
4.9.9 Plans 4-45
4.9.10 Specifications 4-45
4.9.10.1 Submittals 4-45
4.9.10.1.1 Shop Drawings 4-45
4.9.10.1.2 PBE Work plans 4-46
4.9.10.1.3 Assembly Plan..4-46
4.9.11 Prefabricated Bridge Element Checklists...4-46
4.9.12 Examples 4-47
4.10 LATERAL SLIDE SYSTEMS 4-49
4.10.1 Introduction 4-49
4.10.2 Roles and Responsibilities for Lateral Slide Systems 4-49
4.10.3 Site Considerations 4-50
4.10.3.1 Traffic Handling 4-50
4.10.3.2 Bridge Geometry 4-51
4.10.3.3 Utilities 4-52
4.10.4 Sliding Systems...4-53
4.10.4.1 Polytetrafluoroethylene Pads...4-53

4.10.4.2 Rollers 4-53
4.10.4.3 Push/Pull Systems 4-54
4.10.5 Forces 4-54
4.10.5.1 Jacking Forces and Jacking Locations 4-54
4.10.5.2 Friction Forces 4-54
4.10.5.3 Resolution of Sliding Forces 4-55
4.10.6 Loading Conditions 4-55
4.10.6.1 Temporary Location 4-55
4.10.6.2 During the Slide 4-55
4.10.6.3 Permanent Location 4-56
4.10.7 Allowable Deflection and Twist 4-56
4.10.8 Geotechnical Design for Slide System 4-56
4.10.9 Substructure Design 4-57
4.10.10 Temporary Support 4-57
4.10.11 Construction Sequence 4-57
4.10.11.1 Roadway Activities During Closure 4-57
4.10.11.2 Abutment Backwall and Shear Keys 4-57
4.10.11.3 Demolition 4-58
4.10.12 Contract Plans 4-58
4.10.13 Specifications 4-59
4.10.13.1 Prior Lateral Slide Move Experience 4-59
4.10.13.2 Geometric Control 4-59
4.10.13.3 Communication During Move 4-59
4.10.13.4 Trial Lateral Slide 4-60
4.10.13.5 Contingency Plan 4-60
4.10.13.6 Mandatory Pre-bid Meeting 4-60
4.10.13.7 Submittals 4-61
4.10.13.7.1 Shop Drawings 4-61
4.10.13.7.2 Temporary Supports 4-61
4.10.13.7.3 Work Plans 4-61
4.10.13.7.3.1 Lateral Slide Assembly Plan 4-61
4.10.14 Lateral Slide Checklists 4-62
4.10.15 Examples 4-62

4.10.15.1 Caltrans Projects 4-62
4.10.15.2 Out-of-State Lateral Slide Projects 4-63
4.11 BRIDGE MOVES WITH SELF PROPELLED MODULAR TRANSPORTER 4-65
4.11.1 Introduction 4-65
4.11.2 Roles and Responsibilities for SPMT Systems 4-65
4.11.3 Site Considerations 4-67
4.11.4 SPMT Systems....4-68
4.11.5 Stages of Construction 4-68
4.11.5.1 Bridge Staging Area and Travel Path 4-68
4.11.5.2 Temporary Supports for Construction....4-69
4.11.5.3 SPMT Move 4-69
4.11.5.4 Final Location....4-70
4.11.5.5 Structure Removal....4-70
4.11.6 Contract Plans....4-71
4.11.7 Specifications 4-71
4.11.7.1 Prior SPMT Move Experience 4-71
4.11.7.2 Deflection Monitoring....4-71
4.11.7.3 Communication During Move 4-72
4.11.7.4 Trial Move 4-72
4.11.7.5 Contingency Plan 4-73
4.11.7.6 Mandatory Pre-bid Meeting 4-73
4.11.7.7 Submittals 4-73
4.11.7.7.1 Shop Drawings....4-73
4.11.7.7.2 Temporary Support....4-73
4.11.7.7.3 Work Plans....4-74
4.11.7.7.3.1 SPMT Installation Plan 4-74
4.11.8 SPMT Checklist....4-74
4.11.9 Examples 4-75
4.11.9.1 I-215 Highgrove UP....4-75
4.11.9.2 Out-of-State SPMT Projects....4-76
4.12 LONGITUDINAL/INCREMENTAL LAUNCH METHOD....4-78
4.12.1 Introduction 4-78
4.12.2 Roles and Responsibilities for ILM....4-79

4.12.3 Site Considerations 4-80
4.12.4 Design Considerations 4-81
4.12.5 Contract Plans 4-82
4.12.6 Specifications 4-83
4.12.6.1 Prior Launch Experience 4-83
4.12.6.2 Deflection Monitoring 4-83
4.12.6.3 Communication During Launch 4-84
4.12.6.4 Trial Launch 4-84
4.12.6.5 Contingency Plan 4-85
4.12.6.6 Mandatory Pre-bid Meeting 4-85
4.12.6.7 Submittals 4-85
4.12.7 Example 4-85
4.13 FOUNDATIONS AND STRUCTURE BACKFILL 4-87
4.13.1 Pile Selection 4-87
4.13.1.1 Cast-in-Drilled-Hole Piles 4-88
4.13.1.2 Secant Pile Walls 4-88
4.13.1.3 Driven Steel and Concrete Piles 4-88
4.13.1.4 Micropiles 4-89
4.13.1.5 Ground Anchor and Soil Nail Walls 4-90
4.13.2 Pile Placement Accuracy 4-90
4.13.3 Pile Placement Prior to Demolition 4-91
4.13.4 Using Existing Foundations 4-91
4.13.5 Accelerated Backfill Material 4-92
4.13.6 Geosynthetic Reinforced Soil-Integrated Bridge Systems (GRS-IBS) 4-92
4.14 BRIDGE REMOVAL 4-93
4.14.1 Introduction 4-93
4.14.2 As-built Plans 4-93
4.14.3 Site Conditions 4-93
4.14.4 Pre-demolition Investigation 4-93
4.14.5 Demolition Activities Prior to Closure 4-94
4.15 TEMPORARY BRIDGE 4-94
4.16 ESTIMATES OF COST AND WORKING DAYS 4-94

4.16.1 Estimates 4-95
4.16.2 Working Days 4-95
4.17 INDUSTRY OUTREACH 4-96
4.17.1 Industry Workshops 4-96
4.17.2 Pre-bid Meeting 4-96
4.18 REFERENCES 4-97

4. DESIGN

The purpose of this chapter is to provide guidance on preparing plans, specifications, and estimates of Accelerated Bridge Construction (ABC) projects.

4.1 CONSTRUCTION CONSIDERATIONS

The design of ABC projects is driven by construction considerations, and all components are designed for both permanent and interim loading conditions. Although the contractor is responsible for developing an assembly plan and detailed shop drawings, the Structure Design Project Engineer (PE) is responsible for developing a feasible ABC plan that accounts for each step of the construction sequence. This plan is detailed on a construction phasing and construction notes sheet which defines the move or construction sequence and any special design requirements. Depending on the project, this sheet can be combined with other typical sheets.

4.2 LAYOUT, TOLERANCES, AND GEOMETRIC CONTROL

ABC has unique challenges associated with prefabrication. The plans and specifications must provide sufficient layout information and allow for realistic fabrication, construction tolerances, and connections. Refer to *AASHTO LRFD Guide Specifications for Accelerated Bridge Construction* (*AASHTO GSABC)* (AASHTO 2018) Section 9 for further discussion of layout and tolerances.

4.2.1 Layout

Refer to *AASHTO GSABC* Section 9.3 for a discussion on layout requirements for ABC.

Establishment of lines and grades should be determined by a licensed surveyor. A verification survey conducted by an independent surveyor is recommended for critical locations, working lines, and elevations.

4.2.2 Tolerances

Refer to *AASHTO GSABC* Section 4.4.2 for element and erection tolerance detailing requirements.

The PE is responsible for establishing and specifying fabrication, erection, and assembly tolerances of prefabricated elements and systems., Corrections can be costly during the critical phase of an accelerated schedule. Excessively small tolerances can lead to fit-up issues in the field, and excessively large tolerances can lead to poor performance. The *Guidelines for Prefabricated Bridge Elements and Systems Tolerances* (Culmo et al. 2017a) has detailed recommendations for determining and specifying tolerances for elements, systems, and the completed structure.

The *Standard Specifications* (Caltrans 2018, 2021) Section 90-4.03 refers to the *Tolerance Manual for Precast and Prestressed Concrete Construction, MNL-135-00* (PCI 2000) for:

- Fabrication tolerance: dimension and dimensional relationships of individual prefabricated members. This includes all interior and exterior dimensions; placement of rebar and prestressing; and deformations including camber, sweep, and warping.
- Erection tolerance: location of precast concrete elements within a three-dimensional coordinate system after erection.
- Assembly tolerance: dimensional relationships with other elements of the bridge including joints.

Tolerance of prefabricated bridge elements and systems are specified in ABC designs for the following reasons:

- **Structural**: to ensure that dimensional variations do not significantly change the loading configuration or resistance assumed by the PE.
- **Feasibility**: to ensure that the design and details are attainable using available construction techniques.
- **Visual**: to ensure that the finished product has an acceptable appearance.
- **Economic**: to ensure that tolerances specified in the design allow for an efficient rate of production.
- **Legal**: to establish a standard to which the work can be compared in case of a dispute and prevent encroachment into adjacent property.
- **Contractual**: to assign responsibility and provide a known range of acceptability.

4.2.3 Geometric Control

The means and methods of controlling and monitoring geometry throughout construction is developed by the contractor and described in the geometric control plan. Depending on the method of construction, the geometric control plan may include means and methods for:

- Developing interim and final grades and lines for assembly, move, slide, and erection of ABC including locations and values of permanent benchmarks and reference points for the bridge staging area (BSA) and bridge site
- A geometric control system including measuring equipment, procedures, and locations of geometric control reference points

- Control of displacement, twist, and strain during assembly, move, slide, and erection
- Monitoring displacement, twist and strain, and alignment during all phases of construction
- Meeting specified tolerances
- Maintaining records of observation and operations

4.3 LOADS AND LOAD FACTORS FOR ABC

The PE is responsible for designing all ABC bridge components for loading conditions in the final configuration and the loading conditions throughout all stages of construction, referred to herein as interim loading conditions. Interim loading conditions include construction loads. *AASHTO GSABC* Section 2 details ABC loads and load factors to be applied in accordance with the *AASHTO LRFD Bridge Design Specifications* and with *California Amendments (AASHTO-CA BDS)* (AASHTO 2017; Caltrans 2019a).

4.4 INTERIM LOADING CONDITIONS

An interim loading condition is a loading condition of a bridge element or bridge system that exists prior to completion of construction. This condition could include loads acting on bridge components as they are being transported and assembled or moved into place. These are construction loads, as specified in the *AASHTO-CA BDS*. For ABC, these loads can include:

- **Jacking and friction forces** during lateral slides and longitudinal launches. Jacking forces are required to overcome both dynamic friction and static friction. The coefficient of friction forces are discussed in Section 4.10.5.
- **Lifting forces** during Self-Propelled Modular Transporter **(**SPMT) and crane-based moves. These forces are also referred to as dynamic forces acting in the vertical direction, as discussed in Section 4.11.5.3.
- **Acceleration and deceleration** during SPMT and crane-based moves. These accelerations result in horizontal forces acting on the structure and supporting braces, as discussed in Section 4.11.5.3.
- **Pick points** where the prefabricated bridge element or system is lifted or picked that may not coincide with support in the final location. The contractor is responsible for a plan to fabricate, transport, and erect precast concrete elements without exceeding the allowable stress or moment resistance, if prestressing is or is not applied, respectively. Feasibility is confirmed during design by analyzing these components considering supports at reasonable pick point locations, as discussed in *AASHTO GSABC* Section 2.4.1. For bridge superstructures assembled in a bridge staging area (BSA), lifting the girders at pick points within the span will

subject the deck to tension, and the section should be designed accordingly, as discussed in Section 4.11.5.3.

4.5 TEMPORARY SUPPORTS

Temporary supports are required during assembly and during moves of prefabricated bridge elements and systems. These supports serve a number of different purposes including safety, stability, lateral resistance during moves, and lateral resistance to wind and seismic forces. The specifications require the contractor to design the temporary supports using a licensed engineer. The design criteria of the temporary supports, including loads, where it is required, when it is required to be in place, and when it can be removed, is described in the plans and in the specifications. Guidance on the specification of temporary supports is currently under development by DES.

4.6 UTILITIES

The presence of utilities both above ground and underground can limit the feasibility of using ABC. Utility conflicts must be evaluated across the entire project site including the BSA and the travel path. The best option is to remove or relocate impacted utilities away from the construction site to provide the contractor with an unobstructed work area. These impacts need to be identified and resolved early in an ABC project.

In cases where it is not feasible to remove or relocate utilities, the PE and the District PE will need to investigate other options. The following are common utility issues and possible solutions.

- Overhead wires that will obstruct crane operations can sometimes be deactivated or temporarily moved and supported during erection. Once all the conflicting construction operations are complete, the utility can be installed in its final location. For situations where the overhead utilities cannot be deactivated or temporarily relocated, consider gantry cranes, lateral slide-in systems, longitudinal launching systems, or using SPMTs.
- Crane loads impacting underground utilities can sometimes be mitigated by crane mats or steel plating.
- For utilities that need to be protected in place during construction, some owners might require protective measures, such as allowable load limits, minimum clearances, and protection details that must be included in the construction plan and schedule defined in the contract documents.

4.7 LOAD CAPACITY OF EXISTING STRUCTURES

ABC projects can result in heavy loads being imposed on existing highways and structures. These loads can sometimes far exceed the highway legal load limits defined in the California Vehicle Code – Division 15, or load-carrying capacity of the existing structure or portion of the existing structure as determined by *AASHTO-CA BDS*. The following are a few examples where structure load limits or load-carrying capacity could be an issue on an ABC project.

- Transportation of heavy prefabricated elements from fabrication facility to the construction site.
- SPMT moves from a BSA.
- Cranes positioned on existing bridges to install prefabricated elements.
- Earth moving equipment across an existing structure within the project limits.

It is best to avoid moving heavy loads over existing structures. If this is not possible, the PE is responsible for determining if load limits and load-carrying capacity requirements can be met by the contractor for purposes of establishing feasibility during design using assumed equipment loads. Determining anticipated construction equipment loads requires coordination with the ABC Branch and Structure Construction. During the construction phase, the contractor is required to analyze existing structures using the equipment proposed in the assembly/erection plans. If the existing facility cannot safely accommodate these heavy loads, alternative routes, load reduction, and shoring or strengthening should be investigated.

The evaluation requirements for heavy lifting equipment including cranes and SPMTs on new and existing structures are in *STP* 3.2. In addition, the *Standard Specifications* Section 5-1.37B require the contractor to provide protective measures and repair related damage. If construction equipment exceeds the size or weight limits in California Vehicle Code – Division 15, as well as the load limitations set forth in the *Standard Specifications* and *Bridge Construction Memo* 150-1, the existing bridge must be evaluated for the proposed construction loads to ensure that the load-carrying capacity of the structure or any portion of the structure is not exceeded, as determined by *AASHTO-CA BDS* and *STP* 3.2. The bridge shall be evaluated using the Structures Maintenance & Investigations (SM&I) *Bridge Load Rating Manual* (Caltrans 2018) using the Strength II Limit State. Therefore, if cranes are to be set-up on an existing structure, this structure should be evaluated to verify feasibility using Strength II limit state load combinations, and locations and loads on the existing structure assumed in design should be shown on the project plans.

For SPMT moves, the BSA and the travel path should be evaluated by the PE for feasibility using assumed equipment loads discussed in *AASHTO GSABC* Section 1.5.1.2. If the SPMT move is not feasible, alternative travel paths and/or ABC methods, such as modular decked beams or prefabricated bridge elements, should be evaluated.

4.8 MATERIALS

There are several materials with unique properties that can facilitate transportation and assembly of prefabricated bridge elements and systems (PBES) in ABC, which merit discussion herein. These materials include lightweight concrete, rapid strength concrete (RSC) and Ultra-High Performance Concrete (UHPC).

4.8.1 Lightweight Concrete

Weight is often a limiting factor in the transportation and erection of prefabricated bridge elements in ABC. Lightweight concrete allows an increase in prefabricated element size or a reduction in size of equipment used to transport, assemble, and erect prefabricated elements. The use of lightweight concrete should be investigated for ABC if conventional concrete is infeasible. The use of lightweight concrete requires coordination with the METS Concrete Materials Testing Branch and the METS Representative. Authorization is required at Type Selection.

The contractor designs the lightweight concrete mix within the parameters specified in *Standard Specifications* Section 90-6, which includes detailed provisions for reliably obtaining specified material properties. Trial batches, mock-ups, and testing are required to ensure that these properties can be achieved during construction.

4.8.2 Rapid Strength Concrete

The time required for concrete elements and closures to reach specified compressive strengths are often on the critical path of ABC. Rapid strength concrete (RSC) consists of fast-setting cement and admixtures that achieve compressive strengths in several hours, whereas conventional concrete would take days or weeks to achieve similar strengths. These characteristics make RSC ideal for ABC components such as closure pours, back walls, approach slabs, and bridge decks.

Using RSC for ABC projects requires additional labor and planning. The contractor is responsible for developing the RSC mix, within the parameters specified in *Standard Specifications* Section 90-3. Trial batch prequalification testing and mock-ups are required to demonstrate that the RSC elements can be placed, and the desired strength can be achieved within a specified time, referred to as the age of break duration. Since atmospheric temperature can impact set time and the compressive strength at the age of break, it is desirable to have the mock-up construction take place in similar conditions as the RSC bridge component.

The age of break, the strength at the age of break, and the 28-day compressive strength must be specified for all RSC components, as discussed in Caltrans *Bridge Design Memo* 5.12. In specifying RSC for ABC, the following should be considered:

- RSC will likely be on the critical path during an ABC closure. The contractor will price this risk accordingly.
- RSC achieves relatively high compressive strengths in a short period of time and significantly more heat can be generated than normal concrete. Therefore, a thermal control plan should be considered for element thicknesses exceeding 24 inches in coordination with the METS Concrete Materials Testing Branch.

4.8.3 Ultra-High Performance Concrete

Ultra-High Performance Concrete (UHPC) is a class of cementitious composites that exhibit mechanical and durability properties that make it ideal for ABC. High compressive strength, high flexural strength, strong interface bond, shorter development length, flowability, durability, and dimensional stability combine to make UHPC a favorable material for use in field-cast connections of prefabricated structural elements. UHPC is being used in a wide variety of bridge applications worldwide for both new bridge construction and bridge repair.

FHWA reports that while UHPC has a higher initial cost than other field-cast grout materials, it can "provide a better value when constructability, long-term performance, and required maintenance is considered" (Haber and Graybeal 2019).

4.8.3.1 Properties of UHPC (Graybeal 2019)

The Federal Highway Administration (FHWA) defines UHPC as "a cementitious composite material composed of an optimized gradation of granular constituents, a water-to-cementitious materials ratio less than 0.25, and a high percentage of discontinuous internal fiber reinforcement. In general, the mechanical properties of UHPC include compressive strength greater than 21.7 ksi and sustained post-cracking tensile strength greater than 0.72 ksi. UHPC has a discontinuous pore structure that reduces liquid ingress, significantly enhancing durability compared to conventional concrete."

UHPC is made of finely ground dry constituents combined with superplasticizer, a small amount of water and at least two percent by volume of steel fibers. The dry components include Portland cement, silica fume, and fine aggregates. The fibers, a critical component of UHPC, are made of high strength steel that provides crack-bridging capabilities. The fiber type, geometry, amount, dispersion, and orientation contribute to the UHPC properties. The material flows easily and is self-consolidating.

UHPC provides superior performance for field-cast joints over other cementitious materials through better internal distribution of stresses, better confinement of embedded rebar, and reduced rebar development and splice lengths. This leads to smaller joints, less material, and simplified detailing for improved fit-up of precast elements.

UHPC's bonding, freeze-thaw behavior and low permeability result in a highly durable material that does not experience the degradation commonly associated with cracking and the intrusion of corrosive materials. The interface bond of UHPC and precast concrete surpasses the substrate tensile strength. In other words, the bond is stronger than the material to which it is bonded (Graybeal 2017).

4.8.3.2 UHPC Applications

Since 2005, UHPC has been deployed on over 200 structures in the United States and Canada. Information on North American deployments including an interactive map is available at the FHWA website: US Department of Transportation Federal Highway Administration – North American Deployments of UHPC in Highway Bridge Construction.

UHPC is used for field-cast connections, link slabs, bridge deck overlays, and structural bridge elements (Graybeal et al. 2018). UHPC connections can be simpler to construct with better long-term performance than conventional methods (Graybeal 2012).

For Caltrans specific guidance on UHPC connections see Section 4.9.5 (Precast Element Connections). For a list of Caltrans UHPC example projects see Section 4.8.3.5

4.8.3.3 Considerations

To achieve the characteristics of UHPC discussed previously, the following items must be considered:

- **Curing**: The UHPC is to remain undisturbed until it reaches a compressive strength of 14 ksi. Construction activities resulting in relative movement of the field-cast UHPC connections before it is set can weaken the connection. This issue becomes of particular importance when scheduling work near the UHPC connection after placement or on projects with staged construction.
- **Formwork**: The formwork must be constructed of non-absorbent material that prevents leakage of the UHPC material and resists the hydrostatic head created by the UHPC in an unhardened state.
- **Loading:** The compressive strength of 14 ksi is the strength at which the UHPC is mature enough to be fully loaded and at which the rebar development length equations are applicable.
- **Mixing**: The fluidity of UHPC is temperature sensitive. Methods for controlling UHPC temperature during mixing are an important component of quality control.
- **Mock-up**: Mock-ups of UHPC connections of precast elements are an essential component of a successful UHPC project. Typically, two mock-ups are performed for each connection detail.
- **Placement**: Tight spaces can restrict UHPC flow. To support effective UHPC flow, refer to *AASHTO GSABC* Section 3.6.5 and studies undertaken at the University of

Nevada, Reno (Tazarv and Saidi 2014) regarding minimum clear spacing in connection detailing.

- **Procurement:** UHPC is currently a proprietary sole-source product that requires specialized equipment and highly trained personnel, with an associated high unit cost. Development of an Authorized Materials List for UHPC is anticipated.
- **Rate of Strength Gain**: The rate of compressive strength gain of UHPC is highly dependent on cure temperature and mix design. Previous Caltrans projects have demonstrated that a compressive strength of 14 ksi occurs within three to five days depending on ambient temperature. If accelerators and in-situ heat are added to the UHPC, a compressive strength of 14 ksi can be reached within 18 hours.
- **Substrate preparation**: Proper preparation of the precast substrate is essential for interface bonding between the UHPC and the precast element. The precast substrate must have an exposed aggregate finish that is clean and has been pre-wetted prior to UHPC placement (Graybeal 2017).
- **Work Plans**: Work plans are an important component in quality UHPC installation. Work plans are developed by the contractor to communicate the means and methods to be executed for the successful implementation of UHPC in a project from procurement to finishing. It is the responsibility of the PE to work with a UHPC Specialist (ABC Branch) and Specifications Engineer to develop work plan requirements that will go into the contract. The PE and UHPC Specialist support Structure Construction in work plan submittal reviews and recommendation for authorization during construction.

For a comprehensive discussion of considerations for the successful implementation of UHPC, please refer to Appendix D “Caltrans Implementation of UHPC.”

4.8.3.4 UHPC Checklists

Refer to Appendix E for design and inspection procedure checklists for successful UHPC implementation.

4.8.3.5 Caltrans UHPC Example Projects

The following Caltrans UHPC example projects can be found on the Caltrans Project Bucket Search webpage.

Cap to Column Connection: Laurel Street OC (04-4G4504, 04-SOL-780, PM 7.1, Br. No. 23-0255, completed 2018) Route 46/99 Separation (06-0K4604 06-KER-46/99, Br No 50-0524E, PM 57.8 completed 2018)

Adjacent PC Slab & PC Box Girder Connection: EBMUD Outfall Bridge (04-014114, 04-ALA-80-1.4/1.7, Br. No. 33-0742Y – CCO work on SFOBB project, parking lot access bridge off of West Burma Road, completed 2020), Dominie Creek Bridge (01-0F3101, 01-DN-101-39.8, Br. No. 01-0087)

Adjacent PC Slab & PC Box Girder Connection early strength UHPC mix with accelerated cure, 21st Avenue UC Replacement (03-0H3420, 03-SAC-99-PM 22.59, Br. No. 24-0154), Echo Summit Sidehill Viaduct Replacement (03-3F5304, 03-ED-50-PM 67.3, BR. No. 25-0154)

4.8.3.6 UHPC Resources

The FHWA UHPC Publication List provides a range of publications pertaining to the performance and use of UHPC.

4.9 PREFABRICATED BRIDGE ELEMENTS

This section provides prefabricated bridge elements (PBE) and PBES guidance and identifies resources for the development of design plans and specifications for successful ABC implementation. For more specific information, refer to Section 3 of the *AASHTO GSABC* for design of PBEs except for the provisions for grouted couplers, for Geosynthetic Reinforced Soil-Integrated Bridge Systems (GRS-IBS), and for seismic design, which are not in conformance with *AASHTO-CA BDS* and the Caltrans *Seismic Design Criteria* (*SDC*) (Caltrans 2019, 2020). Also refer to the *Guidelines for Prefabricated Bridge Elements and Systems Tolerances* (Culmo, et al. 2017a).

4.9.1 Introduction

A prefabricated bridge element (PBE) is a single structural component of a bridge built using prefabricated bridge elements and systems (PBES) methods. Examples of PBEs include:

- Precast concrete girders
- Steel girders
- Full depth precast concrete deck panels
- Stay-In-Place Precast Prestressed Deck Panels
- Precast concrete bent caps
- Precast concrete columns
- Precast concrete footings
- Precast concrete abutments
- Precast concrete wingwalls

The advantages of using PBEs are discussed in Section 3.2.3.1. Since PBEs must be transported from the prefabrication facility and erected at the bridge site, hauling and lifting limits must be considered in the design. These limits will control the location of construction joints.

Another important design consideration is the connections between PBEs and between PBEs and cast-in-place components because they are typically on the critical path of the construction schedule. These connections can include:

- Grouted keyways and joints using non shrink grout or UHPC.
- Closure pours using conventional concrete, RSC, or UHPC.
- Post-tensioned connections using high-strength rods or strand
- Welded or bolted structural steel connections.

Refer to Section 6.4 for a list references and resources available to the PE for the development of PBE plans and specifications.

4.9.2 Roles and Responsibilities for PBE Design

Refer to *AASHTO GSABC* Section 1.4 for design responsibilities of PBEs. Note that Caltrans does not allow contractors to fabricate elements onsite or near site as discussed in *AASHTO GSABC* C1.4.1.2. Additionally, note that the PE is responsible for:

- Design of all components and connections for both the final configuration and the interim loading conditions. Although the design of a bridge should be no different in the final configuration, PBEs are designed for loading prior to completion, as discussed in Section 4.9.4.3.1.
- Developing a feasible construction sequence. Although the contractor should have the flexibility to make modifications, a feasible construction sequence must be described in the plans and specifications, as discussed in Section 4.9.4.3. This includes design of all members; locations and details of construction joints; a sequence of operations; requirements for lateral bracing; and required cure times or compressive strengths of closure concrete, UHPC, and grout, as discussed in Section 4.9.5.3.
- Determining locations and sizes of all construction joints and closures. Design and detailing of the PBE connections and closure joints are discussed in Section 4.9.5.
- Establishing temporary support requirements, as discussed in Section 4.5.
- Providing fabrication and erection tolerances, as discussed in Section 4.9.4.2.

- Specifying the criteria that the contractor will use for handling, storage, and erection of PBEs, as discussed in 4.9.3

The contractor is responsible for designing PBEs for shipping, handling, and erection. This allows the contractor maximum flexibility in selecting the location and type of lifting hardware used to handle PBEs. Roles and responsibilities of PBE design is summarized in Table 4.9.2-1.

Table 4.9.2-1 Roles and Responsibilities for PBE

Category	Description of Responsibility	Owner	Contractor
Advance Planning Study / Type Selection	Feasibility of using PBEs in project	✓	--
	Preliminary cost estimate and project constraints	✓	--
New Structure Analysis and Design	Analysis of new structure for all interim and permanent loading conditions	✓	--
	Define all construction joint locations and dimensions	✓	--
	Define all construction joint materials with opening and final compressive strengths	✓	--
	Provide full set of contract documents, including plans and specifications	✓	--
	Feasibility of element transportation and erection	✓	--
Tolerances	Specification of element tolerances, erection tolerances, and joint width tolerances	✓	--
	Survey, implementation, and verification	--	✓
Materials	Specification of materials	✓	--
	Submittal, procurement, and construction	--	✓
	Authorization of materials submittals	✓	--
Temporary Supports	Design criteria	✓	--
	Allowable bearing capacity; proposed foundation	--	✓
	Design and fabrication of all temporary supports	--	✓
Cranes and other equipment	Preliminary crane layout; feasibility of erection	✓	--
	Design of PBE for forces during lifting, hauling, and erection	--	✓
	Setup and operation of all equipment	--	✓
	Contingency plan for equipment failure	--	✓
	Verify existing bridge capacity to support equipment loads	--	✓
PBE Assembly	Preliminary feasibility evaluation	✓	--
	Assembly plan setup, submittal, and execution	--	✓
	Review and authorization of assembly plan	✓	--

Category	Description of Responsibility	Owner	Contractor
Geometric Control	Specifications for geometric control and monitoring throughout construction	✓	--
	Submittal, setup, and execution of geometric control plan	--	✓
	Review and authorization of geometric control plan	✓	--

4.9.3 Site Considerations

To develop a feasible ABC construction sequence using PBEs, the PE must consider the site conditions. These conditions include site accessibility for cranes, availability of staging areas, and the routes available for transport delivery.

4.9.3.1 Cranes

Although the contractor is responsible for developing an erection work plan which establishes the size and location of the crane(s) to be used to erect the PBEs, the PE is responsible for determining that erection of the PBEs is feasible. Since crane size is based on the required lift weight and reach, it is important to keep the PBEs weight and dimensions below the capacity of the crane(s) that can fit into the site.

The site should be investigated for crane setup to erect PBEs and the constraints that could limit their use. The size of the crane could be limited by space requirements, site accessibility and the presence of overhead utilities. Refer to the Second Strategic Highway Research Program (SHRP 2) *ABC Toolkit* (TRB 2013) for guidance on crane setup and innovative methods of erecting PBEs.

4.9.3.2 Transport

Transporting PBE's from a fabrication plant to the site requires planning from the design team. Available routes can limit the size and hauling weight of PBEs. Vertical clearance and bridge load rating must be factored into the maximum size and weight of PBEs. A Request for Precast Element Transportation Form, which can be downloaded from the Division of Engineering Services (DES) Project Engineering Resources website, is submitted by the PE at the beginning of the design to the Precast Prestressed Concrete Technical Specialist, who collaborates with fabricators, through PCI West and the Permits Division, to determine available routes and element transport feasibility.

4.9.3.3 Erection

The contractor is required to submit an erection work plan for precast prestressed concrete girders, per *Standard Specifications* Section 51-4.01C(1). Similar plans should be specified for all PBEs. The Assembly Plan provides details and sequences for lifting, unloading, erecting, and temporary support, as discussed in Section 4.9.10.1.2.1.

The PE is required to verify that PBE erection for the proposed project is feasible and determine that there is sufficient room for cranes and hauling equipment. The presence of overhead and underground utilities, Environmentally Sensitive Areas (ESA), existing bridges, maintenance of traffic requirements, and drainage structures should be evaluated. Refer to the *ABC Toolkit* (TRB 2013) for guidance on innovative approaches to the erection of PBEs.

4.9.3.4 Storage

A major risk in ABC projects is late delivery of PBEs to the site. The risk of delay can be substantially reduced if PBEs are stored on site or in a BSA prior to erection. If that is not feasible, the contractor should identify methods of minimizing this risk during element delivery in the assembly plan.

4.9.4 Prefabricated Bridge Element Design

Refer to Section 3 of the *AASHTO GSABC* for design of PBEs except for the provisions for grouted couplers, for Geosynthetic Reinforced Soil-Integrated Bridge Systems (GRS-IBS), and for seismic design, which are not in conformance with *AASHTO-CA BDS* and the *SDC*.

The PE should utilize standard shapes and sections wherever possible to keep costs reasonable. When standard shapes and sections are not possible, consider shapes and sections that are easy to fabricate, transport, erect, and assemble. The availability of non-standard shapes can be confirmed through PCI West.

4.9.4.1 Element Weight and Size Guidelines

PBEs should be designed so that they can be transported, erected, and assembled using standard equipment to minimize cost and reduce risks of delay. The equipment needed for lifting, hauling, and erecting substructure elements may differ from those needed for precast prestressed girders.

The following are recommended size limits for PBEs. These recommendations should be used as a starting point for initial sizing during preliminary design or planning. The maximum sizes and weights will be dictated by the route and site constraints for each bridge site. For transport restrictions see 4.9.3.2

- Width: 12 feet – includes projecting rebar. Widths of up to 14 feet are allowed with special permits.
- Height: 9.5 feet – includes projecting rebar to allow transport under existing structures on freeways. The height limit may be further reduced on State Highways.

- Length: limited to specified conventional shipping equipment and available routes.
- Weight: 100 kips for substructure elements and 200 kips for girders are desirable limits to facilitate standard hauling and erection equipment. Precast elements exceeding 200 kips have been transported in California. Large elements could require special permits and California Highway Patrol (CHP) escort. Precast element weight can be reduced by adding joints, including voids, and utilizing lightweight concrete.

These limits can be exceeded for some projects where transportation from a fabrication facility is not required. Note that the PE should work with the ABC Branch to optimize the size and weight of PBEs.

4.9.4.2 Tolerances

Refer to Section 4.2.2 of this manual and *AASHTO GSABC* Section 4.4.2 for the development of element and erection tolerances.

Establishing optimal tolerances is essential for preparing a design with PBEs that can be efficiently fabricated and assembled using standard equipment that are cost effective and durable.

For PBE components not addressed in the *Tolerance Manual for Precast and Prestressed Concrete Construction, MNL-135-00* (PCI 2008), the dimensional tolerances must be included in the project special provisions. Recommendations for ABC tolerances can be found in *Guidelines for Prefabricated Bridge Elements and System Tolerances* (Culmo, et. Al. 2017). Fabrication and erection tolerances should be considered when designing and detailing the following:

- **Closure joints**. The width of closure joints is determined based on the required lap splice length of reinforcement bars. Tolerances should be factored into the joint so that if the closure is wider than designed due to fabrication and/or erection errors, the lap length is maintained. For further details see Section 4.9.5.
- **Corrugated Metal Pipe (CMP)**. The inner diameter of CMP used to connect piles and substructure elements should be sized to account for fabrication, erection, and assembly tolerances, as discussed in Section 4.9.5.2.
- **Duct sizes for grouted duct connections**. The size of the ducts specified for grouted rebar splices should account for the deformed diameter of the bar, the minimum amount of space between the bar, and the interior diameter of the duct to ensure grout flow assembled within fabrication and erection tolerance. When sizing corrugated metal duct or pipe, use the minimum inside diameter. For further detail, see Section 4.9.5.2.

- **Impact on cost**. Note that the PE can specify tighter tolerances than those shown in the *Tolerance Manual for Precast and Prestressed Concrete Construction* (PCI 2000) or the *Guidelines for Prefabricated Bridge Elements and System Tolerances* (Culmo, et al 2017), but there is an associated increase in cost.
- **Templates**. Templates should be specified to locate critical items, such as rebars and piles in grouted pocket connections.
- **Working points or lines**. Dimensions and associated tolerances should be measured from a working point or line because center to center measurements can lead to a buildup of errors.

4.9.4.3 Construction Sequence

A feasible construction sequence should be described in the plans if the structure is complex and the means of construction are not self-evident, as discussed in *AASHTO GSABC* Section 1.4.1. This sequence should include a logical sequence of assembly; provisions for closure concrete, UHPC, or grout; required strength or cure time; and requirements for temporary supports and bracing.

Temporary supports or bracing should be called out in the construction sequence. See Section 4.5 regarding temporary supports.

4.9.4.3.1 Interim Loading

The PE is responsible for designing all PBEs for both interim and permanent loading conditions in conformance with the *AASHTO-CA BDS*. Interim loading conditions can be an important if not controlling load case. Examples include prefabricated abutment wall elements backfilled prior to placement of the superstructure or precast girders resisting the fluid weight of the deck prior to achieving composite action.

Precast bent caps require special consideration. Under interim conditions, the bent cap is designed to resist the following loads:

- Self-weight of the cap including the fluid weight of the bent cap diaphragm. Note that for integral connections, this load, along with the weight of the girders and the deck, will act on the non-composite section.
- Girder weight. Check both balanced and unbalanced loading conditions. Placement of girders on one side of the cap can result in significant torsion on the non-composite cap section. The girder bearing seats should be designed for punching shear from the girder reactions.
- Deck weight. Both balanced and unbalanced loading conditions should be evaluated.

4.9.4.3.2 Deck Pour Sequence

It has been common practice in California to pour the bridge deck sequentially from one end to the other. Precast prestressed girder bridges with multiple spans require special consideration to avoid unanticipated negative moments in the girders near the supports. As outlined in the *Standard Specifications* Section 51-1.03D(2), the deck is placed five days after the intermediate diaphragms have been poured or have attained a compressive strength of 3,000 psi. The end diaphragms and the deck over the supports are placed after deck concrete is poured within the spans. Thermal control measures should be investigated if RSC is planned for the end diaphragms.

4.9.4.4 Precast Concrete Bridge Element Design

The following is guidance on the design of PBEs including footings, columns, abutments, bent caps, girders, deck panels, approach slabs, and barriers. Refer to *AASHTO GSABC* Section 3 for further information and note that provisions for grouted couplers, Geosynthetic Reinforced Soil-Integrated Bridge Systems (GRS-IBS), and seismic design are not in conformance with *AASHTO-CA BDS* and the *SDC*.

4.9.4.4.1 Footings

Prefabricated bridge footings can either be spread or pile supported, and they can be used with prefabricated columns or abutment stem wall elements. The size of the footings is limited to the weight and dimensional limits discussed in Section 4.9.4.1. Cast-in-place footing extensions should be used if these limits are exceeded. The precast section of footing can support the column or wall segment to allow subsequent stages of construction to occur during concrete placement and subsequent cure of the cast-in-place portion. The hauling weight can also be reduced using voids, which can be filled with concrete, as discussed in the *Guidelines for ABC Using Precast/Prestressed Concrete Elements Including Guideline Details* (PCI 2014).

Leveling devices are used to control elevations of the footing during placement. These devices typically consist of an embedded plate, nut, bolt, and block out which are designed by the precast fabricator. A minimum of four leveling devices located at the corners of the footings are centered over a steel bearing plate. These devices are adjusted while the footing is still supported by the crane. See Figures 4.9.4.4.1-1 and 4.9.4.4.1-2 for detailed drawings. After the load can be transferred to the soil with grout or piles, the leveling bolts can be removed and the block outs can be grouted.

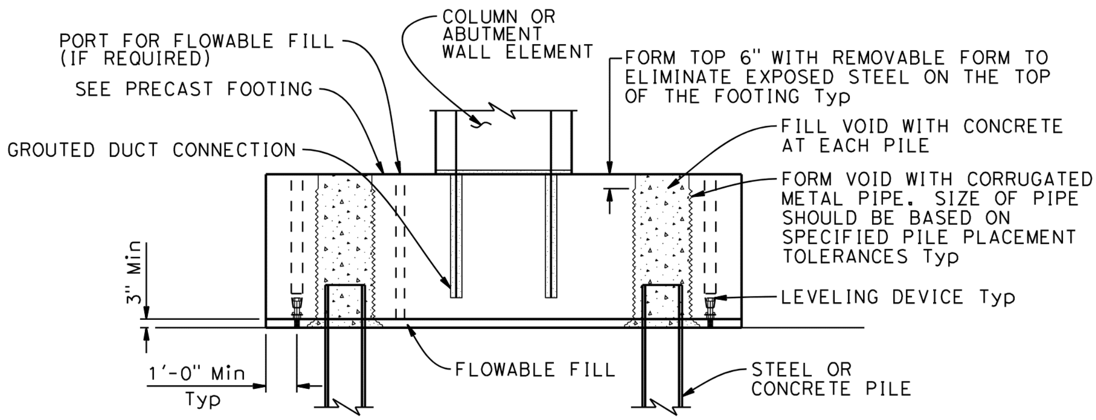

Figure 4.9.4.4.1-1 Precast Footing

The gap between the bottom of the footing and the surrounding soil can be backfilled with flowable fill, as discussed in *AASHTO GSABC* Section 3.8.2. Lean Concrete Backfill, which is a two-sack concrete mix consisting of sand, cement, and water, per *Standard Specifications* Section 19-3.02I, can be used as flowable fill. Note that the bearing pressures on this material are relatively low, typically less than 100 psi. So, significant strength is not required. Lean concrete backfill is not a rapid strength material. Nonshrink grout, per *Standard Specifications* Section 51-4.02C can also be used as a flowable fill material when fast cure times and/or significant strength is required, but it is significantly more expensive. The PE will consult the geotechnical engineer and Substructure Committee about the suitability of using flowable fill or nonshrink grout for grading beneath precast footings.

Flowable fill is placed via ports cast into the footings, which should be shown schematically on the project plans. The gap should be a minimum of three inches to facilitate flowable fill placement and need not be more than six inches. Ports for flowable fill placement should not exceed six feet on center. Refer to *Guidelines for Accelerated Bridge Construction* (PCI 2014) for recommendations for effective placement of flowable fill under precast concrete footings.

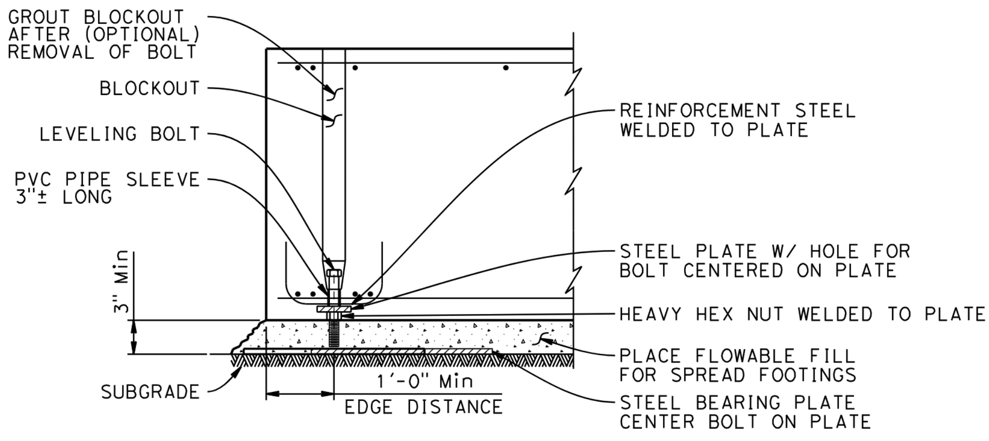

Figure 4.9.4.4.1-2 Leveling Device Detail

Pile supported precast concrete footings require special connections discussed in Section 4.9.5.2. Design of precast footings with many piles may not be feasible, as the connection pockets for the piles affect the location available for reinforcement, which complicates the details.

For spread footings, the flowable fill or nonshrink grout transfers the load to the subgrade material. A leveling pad consisting of a four-inch-thick layer of slurry cement backfill can be used to facilitate placement and leveling of the footings.

4.9.4.4.2 Columns

Precast concrete columns are designed and detailed to accommodate fabrication and delivery, connections to the cap and the foundations, and loading conditions in the permanent structure. Columns with a uniform cross section should be specified. An example of precast concrete columns after erection is shown in Figure 4.9.4.4.2-1.

Precast columns should be sized to the dimensions and weight recommended in Section 4.9.4.1. A void in the center of the column that is filled with concrete after erection reduces hauling and erection weight. The wall thickness should allow for concrete consolidation around the longitudinal bars and permit fabrication and erection without significant bracing and lifting points.

Figure 4.9.4.4.2-1 Laurel Street OC Precast Columns Ready for Bent Cap Assembly

The design of the connection between precast columns and the adjacent footings and bent caps is critical, as discussed in Section 4.9.5.2. For designs that do not conform to the *AASHTO-CA BDS* and the *SDC*, a design exception is required per *Structure Policy Directive* (*SPD*) 1-3 (Caltrans 2019b). Grouted duct and pocket connections can be used if precast bent caps and/or footings are specified. If grouted duct connections are used, the PE should minimize the number of bars within the column by selecting the largest diameter rebar that can be developed within the cap. Reducing the number of rebars will improve constructability by minimizing the risk of fit-up problems during erection. The location of each bar and duct in the receiving bent cap or footing element should be shown based on a common location, such as the intersection of the bent and column centerlines. Column rebar layout could require iteration as the grouted duct locations may need adjustment to accommodate reasonable bent cap reinforcement layout.

4.9.4.4.3 Bent Caps

Refer to *AASHTO GSABC* Section 3.5.1.3 for the design of precast bent caps. The term pier cap is used, which is equivalent to bent cap, and recommendations regarding grouted couplers and seismic design do not necessarily conform with the *AASHTO-CA BDS* and the *SDC*, respectively. For designs that do not conform to the *AASHTO-CA BDS* and the *SDC*, a design exception is required per *SPD* 1-3.

Precast bent caps can be designed to create an integral connection between the column and the superstructure. In this configuration, the cast-in-place bent cap diaphragm and deck are composite with the precast bent cap, as shown in Figure 4.9.4.4.3-1. The precast portion of the bent cap should be designed to resist the weight of the superstructure, the bent cap, and construction loading as a non-composite element.

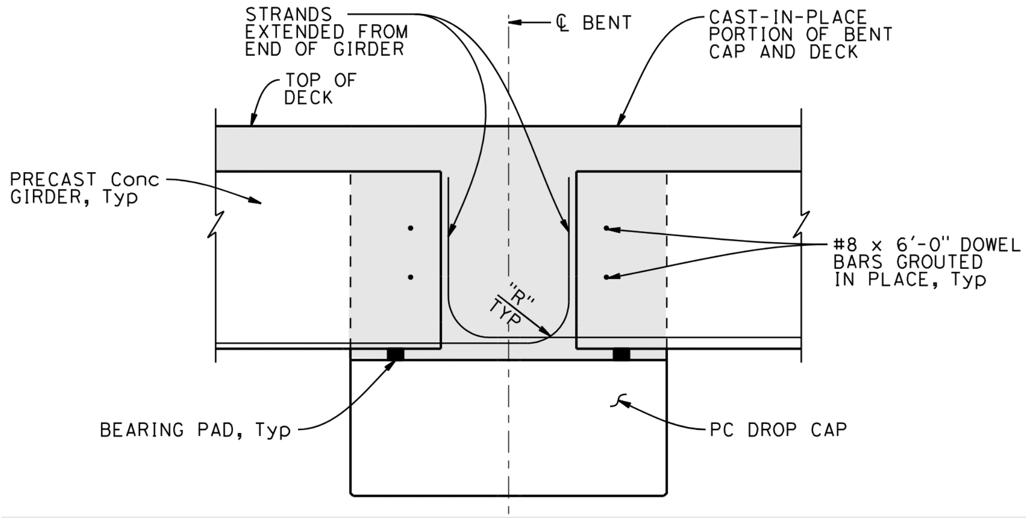

Figure 4.9.4.4.3-1 Precast Bent Cap with Integral Connection Detail

Precast bent caps that are not integrally connected with the superstructure do not resist loads as a composite section with the cast-in-place end diaphragm in the completed structure. Therefore, non-integral precast bent caps are typically heavier than their integral counterparts. The connection between precast non-integral bent cap connections and the superstructure can be pinned with conventional or seismic isolation bearings, as discussed in Section 4.9.5.1.3.

Bent cap elements can be heavy, making them difficult to transport and erect. To reduce the weight, a U-shaped section can be used, where the center is filled after erection. The bent cap can also be fabricated in manageable sections that are spliced in the field to form the overall bent cap. To facilitate connection fit-up, a level soffit is preferred, but the soffit can be designed to match the deck cross-slope.

The cap can be supported on one or more columns. When a bent requires three or more columns, it is recommended to have two separate cap elements connected with a closure pour. Each cap element should be designed to support the dead load of the superstructure so that casting and curing of the closure will not delay construction.

4.9.4.4.4 Abutments

Precast abutment elements can be used for both integral and seat type abutments. These elements include abutment stem walls, wingwall panels, and footings. Wall cap elements can be used to tie multiple abutment stem wall elements together without reinforced concrete closure joints.

Figure 4.9.4.4.4-1 Precast Abutment Wall Element Placement – Fort Goff Creek Bridge

4.9.4.4.4.1 Integral Abutments

Refer to *AASHTO GSABC* Section 3.5.1.5 for design of precast integral abutments. Precast abutment wall elements can be connected to form an integral abutment. Connections of precast abutment wall elements are discussed in Section 4.9.5.2.5. Limitations on the use of integral abutments are discussed in *STP* 11.2.

Precast abutment wall elements can be supported with piles in pocket connections discussed in *AASHTO GSABC* Section 3.6.6. Steel pipe or I-section piles are preferred for integral abutments rather than concrete piles because steel sections can accommodate significant thermal displacements without distress.

Girders can be set on shim blocks to allow for adjustment of girder elevations to accommodate camber variability, as discussed in Section 4.9.5.1.3. The shim blocks also allow the top of the precast abutment wall elements to be level.

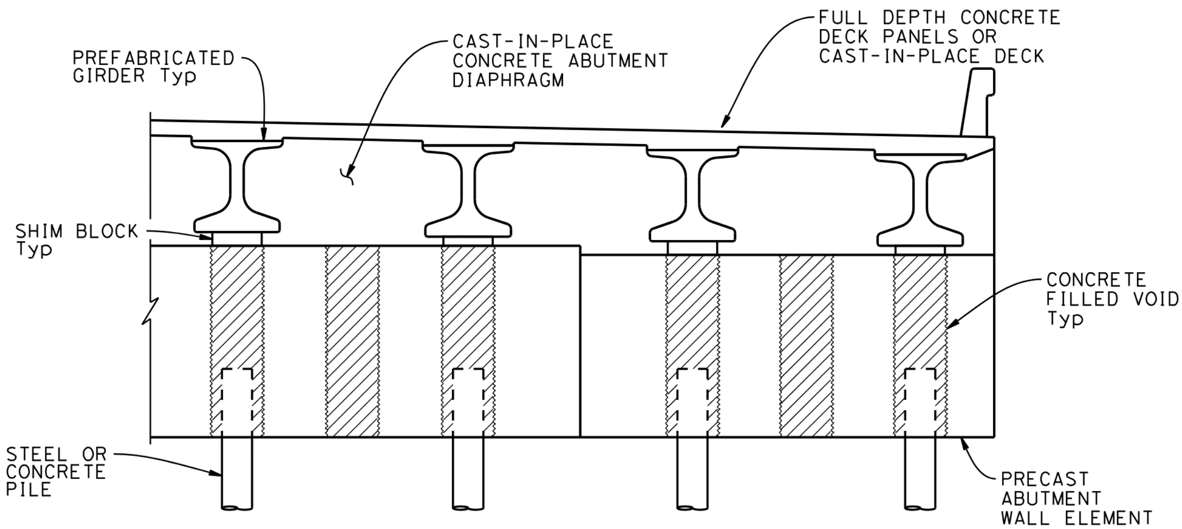

Figure 4.9.4.4.4.1-1 Integral Abutment with Precast Abutment Wall Elements

4.9.4.4.4.2 Seat Abutments

Seat abutments can consist of precast abutment wall elements, wall caps, footings, and wingwall panels. Wall caps are precast concrete elements that top precast abutment wall elements and tie them together without reinforced concrete closure joints. Wall caps should have a minimum depth of two feet, extend the full width of the abutment, and include the girder seats. The backwall and shear keys can be installed after erection. Wall caps allow the abutment wall panels to be relatively simple and repetitive, and cost effective. Since the overturning moment is relatively low, the connection between the wall panels and wall cap can be made with dowel bars embedded in voids formed with galvanized CMPs, as discussed in Section 4.9.5.2.2.2.

Abutment footings can be either precast or cast-in-place and supported directly on subgrade or on piles. The details of precast footings for abutments are similar to those for bents, which can be found in Section 4.9.4.4.1. Cast-in-place footings are recommended for wide footings and footings with a large number of piles due to design and detailing complexity.

Provisions for temporarily bracing abutment wall panels until the footing concrete has cured should be indicated on the drawings, as noted in Section 4.9.3.3.

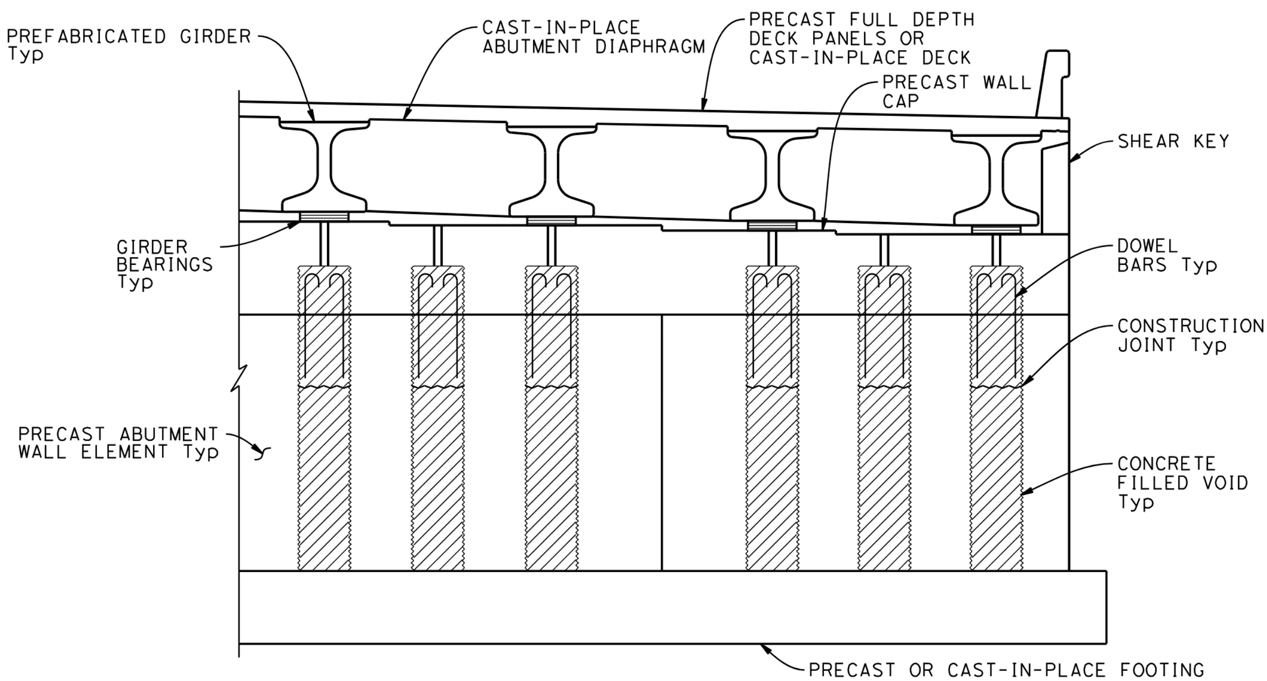

Figure 4.9.4.4.4.2-1 Seat Abutment with Precast Abutment Wall Elements

4.9.4.4.5 Wingwalls

Precast wingwalls can either be cantilevered, as shown in the *Standard Plans* (Caltrans 2018, 2021a), Sheet B0-1, or independent retaining walls. Cantilevered precast wing walls are connected to the abutment diaphragm with reinforced concrete closures. Independent precast retaining walls are similar to seat abutments and include wall panel elements and precast or cast-in-place footings.

Figure 4.9.4.4.5-1 Precast Cantilever Wing Wall – Fort Goff Creek Bridge

4.9.4.4.6 Full Depth and Stay-In-Place Precast Prestressed Concrete Deck Panels

Precast full depth deck panels (FDDPs) are applicable for new and bridge replacement projects. FDDPs can be used with prestressed concrete girders, steel girders, steel girder/floor beam systems, steel truss systems, and long-span cable stayed systems. The key advantage of FDDPs is that they remove deck forming, rebar placement, concrete placement, and curing time from the critical path. Refer to *AASHTO GSABC* Section 3.5.1.6 and the *Full Depth Deck Panel Guidelines* (PCI 2020) for guidance on the design of FDDPs.

The PE is responsible for design of the completed bridge deck per the *AASHTO-CA BDS* and the *AASHTO GSABC*. Key features of the design include:

- Deck reinforcement in panels and closures
- Size and layout of shear reinforcement and connectors to top of girders
- Overhang reinforcement
- Barrier reinforcement and barrier anchoring components
- Layout of deck panels and special details such as skewed end panels
- Expansion joints
- Concrete strengths of both the panels and closures.

Deck panel layouts can consist of full width strips with transverse closure joints. Transverse closure joints require extension and development of reinforcement from the panels into the concrete, RSC, or UHPC closure regions. Alternatively, deck panels can have a longitudinal orientation with closure joints located over the girders. The advantage of this layout is that the joint serves as both a closure and a means of developing shear reinforcement or studs to create a composite connection with the girder. Panels should be dimensioned from a common working line, as shown in Figure 4.9.4.4.6-1, to ensure proper alignment at critical locations, such as the deck edge, and to avoid accumulation of fabrication and placement errors.

FDDPs for continuous spans require splicing of the longitudinal reinforcement at or near the bent caps. The PE should evaluate the zone where splices are not allowed, per *SDC* Section 8.2.2, when laying out deck panels. The seismic resistance of FDDP designs using longitudinal rebar lapped splices over the bent cap embedded in UHPC has been the subject of Caltrans funded research, as discussed in Section 6.2.4.

According to the *Full Depth Deck Panel Guidelines* (PCI 2020), deck panels can be skewed up 25 degrees. Skews exceeding this limit require transverse orientation of deck panel joints with special panel details for the acute corners. FDDPs should be limited to 30 feet without prestress and 45 feet with prestress for practical fabrication and erection (PCI 2020).

An additional 0.5 inches thickness should be added to the top cover to account for differential camber and uneven profile grades. This additional thickness ensures sufficient rebar cover after deck grinding if no overlay is specified.

Stay-In-Place Precast Prestressed Concrete Deck panels can be used in combination with conventional concrete or RSC to expedite construction, as discussed in *STP* 9.1. Stay-In-Place Precast Prestressed Concrete Deck Panel details are available on the Caltrans Bridge Standard Details webpage.

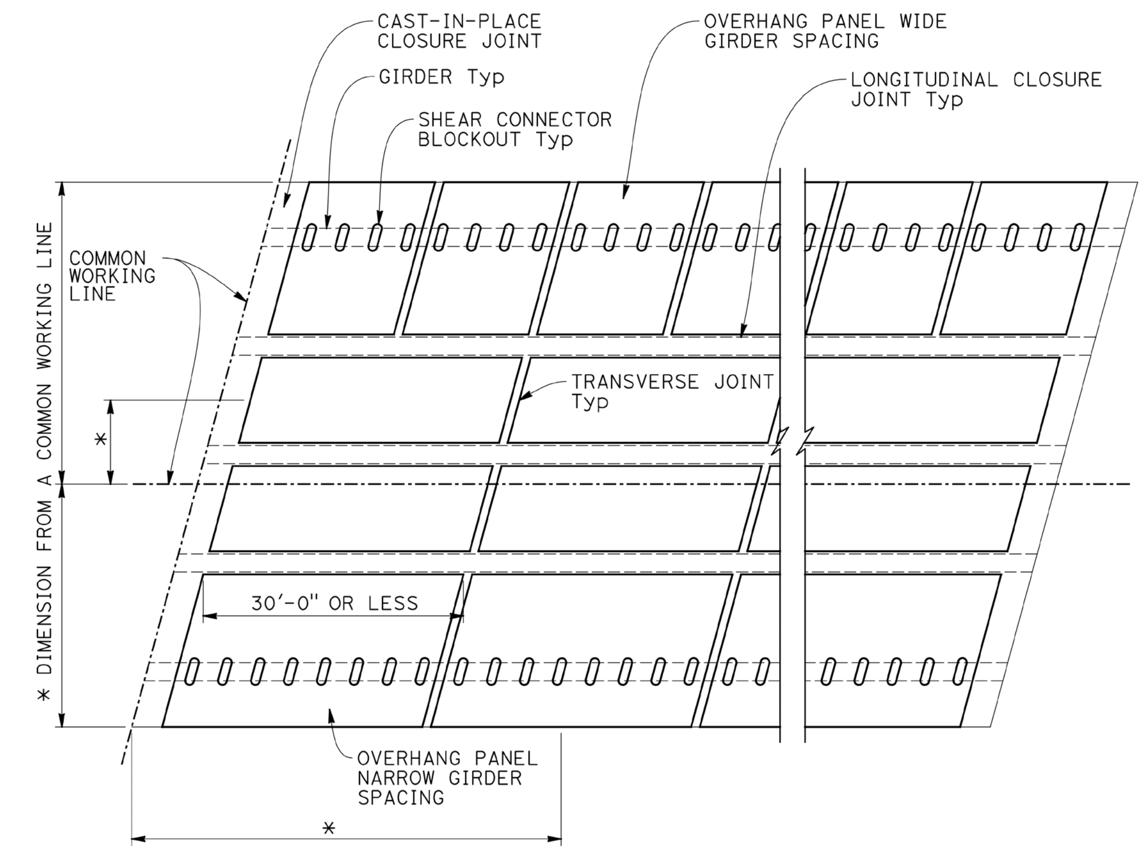

Figure 4.9.4.4.6-1 Longitudinal Full Depth Deck Panel Layout (Skew ≤ 25°)

4.9.4.4.7 Girder Selection

Girders for ABC projects can be classified as decked and non-decked girders. As the name implies, decked girders include the driving surface, which makes them ideal for ABC applications. Decked girders can include an overlay to achieve the desired driving surface profile. Non-decked girders require construction of a deck after the girder has been placed.

4.9.4.4.7.1 Decked girders

Decked girders include precast prestressed box girders, voided slabs, decked bulb-tee girders, double-tee girders, and modular decked beams.

Transverse continuity of adjacent precast prestressed box girders and voided slabs can be achieved with a cast-in-place concrete deck or UHPC closure joints, as discussed in Section 4.9.5.1.2. Polyester concrete overlay can provide a smooth and durable driving surface within hours of placement. UHPC closures should have a compressive strength of 14 ksi before polyester concrete overlays are placed. Precast prestressed box girder sections are relatively heavy and more expensive than other shapes with a practical upper limit of approximately 120 feet. The standard precast prestressed voided slab sections are capable of spans of up to 60 feet.

Modular deck beams consist of two or more steel or precast concrete girders with a concrete deck cast in a bridge staging area. To limit element weight, steel girders are typically used, as discussed in Section 4.9.4.6.

4.9.4.4.7.2 Non-decked Girders

Non-decked girders consist of precast prestressed concrete or structural steel. For construction of the deck, FDDPs and stay-in-place precast prestressed concrete panels, as described in Section 4.9.4.4.6, and RSC, as described in Section 4.8.2 should be considered for all ABC projects.

4.9.4.4.8 Approach Slabs

Refer to *AASHTO GSABC* Section 3.5.1.8 and the *Guidelines for Accelerated Bridge Construction* (PCI 2014) for the design of precast approach slabs.

A key advantage of using precast approach slabs in ABC is that they can be placed and brought into service prior to completing the structural backfill, which is often on the critical path. Precast approach slabs span between the abutment backwall or paving notch and a sleeper slab, which consists of a small concrete footing and a backwall. Structure backfill can be installed during an overnight closure using flowable fill, as discussed in Section 4.13.5.

Alternatively, approach slabs can be constructed using RSC, as discussed in Section 4.8.2.

4.9.4.4.9 Precast Concrete Barrier Rail

Refer to *AASHTO GSABC* Section 3.5.1.9 for design of precast concrete barrier railings. Precast concrete bridge rail must be Manual for Assessing Safety Hardware (MASH) tested and meet all geometric and load requirements specified in *AASHTO-CA BDS* Section 13, the Caltrans *Standard Plans* (Caltrans 2018, 2021a), *Bridge Standard Detail Sheets*, and *Highway Design Manual* (Caltrans 2020). Experimental tests of precast concrete barriers to evaluate the structural connection with the deck were recently completed at Iowa State University (Ecklund and Sritharan 2018) with promising results.

Concrete barriers installed on decked beams prior to their erection can significantly increase the weight and bracing requirements. Consequently, the plans should only show this as an option. Steel barriers with concrete curbs are significantly lighter and can be preinstalled, as discussed in Section 4.9.4.5.

4.9.4.4.10 Predesigned PBE Single Span Bridges

Predesigned PBE single span bridges have been developed for replacement of culverts conveying minor streams that have impediments to fish passage. Although they were developed for improving fish passage, they can be used for general application and not solely for fish passage projects. The use of these designs requires coordination with the ABC Branch.

The predesigned bridge plans consist of precast prestressed voided slab and precast prestressed box girder bridges for spans between 20 and 116 feet and skews of up to 45 degrees.

4.9.4.5 Steel Elements

Steel elements are currently used in California for bridge girders and barriers. Due to their relatively light weight, structural steel girders and barriers are ideal for ABC.

Structural steel girders can be used for ABC projects in combination with precast bent caps, precast full depth deck panels and precast concrete substructures. In California, the girders are supported on bearings or can be cast in the bent cap diaphragm to create an integral connection, per Section 6.5 of the *Seismic Design Specifications for Steel Bridges* (*SDSSB*) (Caltrans 2016).

Modular decked beams consist of two steel I-girders and a concrete deck constructed in a BSA or a fabrication facility. Refer to *AASHTO GSABC* Section 3.5.2.2 for design of modular decked beams. A span of 120 feet is a practical upper limit to allow for reasonable equipment to transport and erect. Note that precast prestressed concrete girders can also be used, but the extra weight typically makes it impractical to do so. Upon erection, the units are tied together with closure joints. These joints can be wider than the width necessary to splice the transverse deck reinforcement to reduce weight.

Steel post and beam style bridge rails or portions of steel post and beam style bridge rails in the *Standard Plans* and the *Bridge Standard Detail Sheets* can be preinstalled prior to erection of decked beams. MASH TL-4 compliant steel post and beam style bridge rails include ST-70SM, ST-75 and the ST-75SW. These bridge rails can also be installed after erection, and installation can be accomplished quickly because posts are bolted to the bridge deck. It is preferable that the bridge rail be preassembled to ensure proper fit prior to erection onsite.

4.9.5 Precast Element Connections

Connections between precast elements are critical and deserve special attention. These items consist of the closure joints, grouted keyways, grouted duct splices, pocket connections, and socket connections.

4.9.5.1 Superstructures

4.9.5.1.1 Full Depth Deck Panel Connections

Refer to AASHTO GSABC Section 3.6.8 and the *Full Depth Deck Panel Guidelines* (PCI 2020) for FDDP connection design and detailing.

4.9.5.1.1.1 Connections Between FDDPs

Refer to *AASHTO GSABC* Section 3.6.8.1.1 for design of cast-in-place concrete closure joints between FDDPs.

Connections between panels can consist of closure joints using conventional concrete, RSC, or UHPC. The flexural strength of the closure joint must meet or exceed the strength of the adjacent panel, and the width of the closure must be wide enough to accommodate the splicing of reinforcement. Methods for determining closure widths and projecting rebar in transverse and longitudinal closures are in *Full Depth Deck Panel Guidelines* (PCI 2020).

To facilitate construction, non-contact lap splices between the bars projecting from adjacent panels are allowed, as discussed in *AASHTO GSABC* Section 3.6.8.1.1. Although the specified spacing must be equal between bars, the actual spacing will vary based on fabrication and erection tolerances.

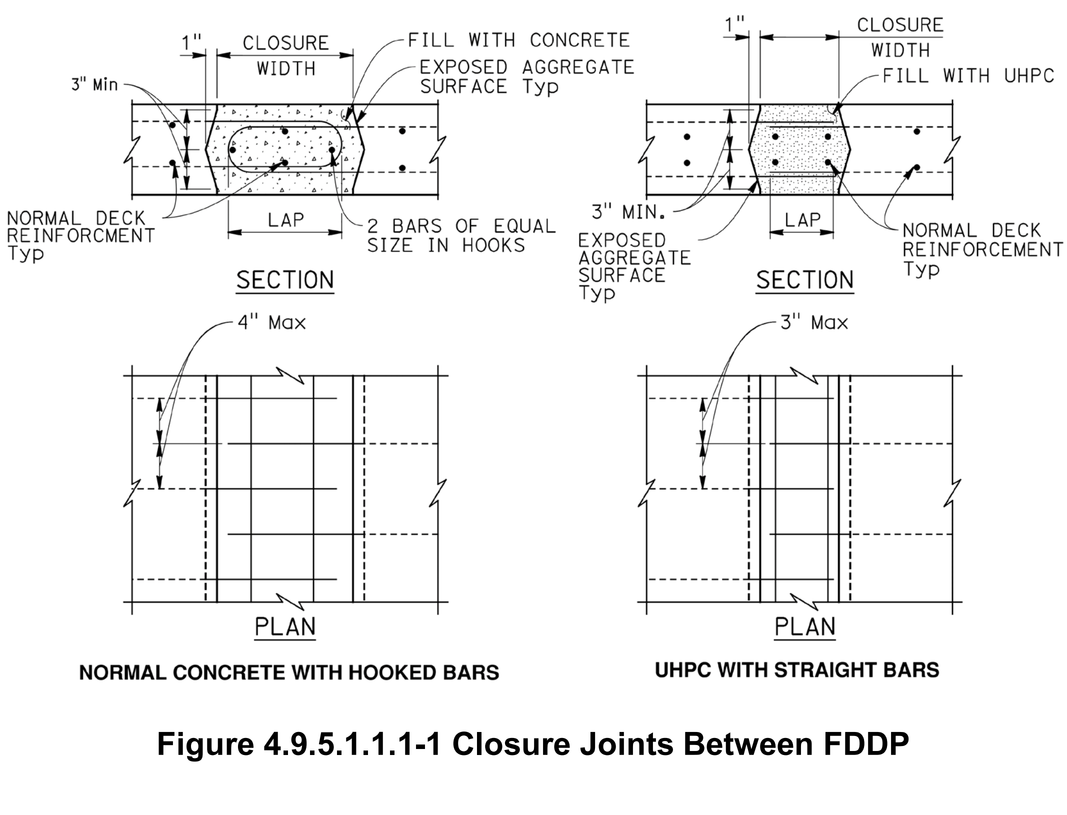

Figure 4.9.5.1.1.1-1 Closure Joints Between FDDP

4.9.5.1.1.2 Girder to FDDP Connections

Refer to *AASHTO GSABC* Section 3.6.8.3 for the design of girder to FDDP connections.

Connections between the deck panels with an orientation transverse to the girders are in grout pockets formed in the panels. Shear connectors can be installed on the girders after the deck panels are placed using welded studs on steel girders. For concrete girders, *AASHTO GSABC* Section 3.6.8.3 recommends using embedment plates in the top flange of precast girders, which allows for the use of welded studs installed after placement of the precast prestressed concrete girder deck panels. Utah Department of Transportation (UDOT) has adopted this method of connection in their Structure Design and Detailing Manual Resources.

Deck panels with a longitudinal orientation allow the shear reinforcement to extend from the girder, and the deck panels are made continuous with the girder in the closure joint over the girder. Concrete or UHPC can be used to form the closure. This detail can only be used for interior girders because the deck panel must extend over the exterior girder to form the overhang, and therefore grout pockets are required.

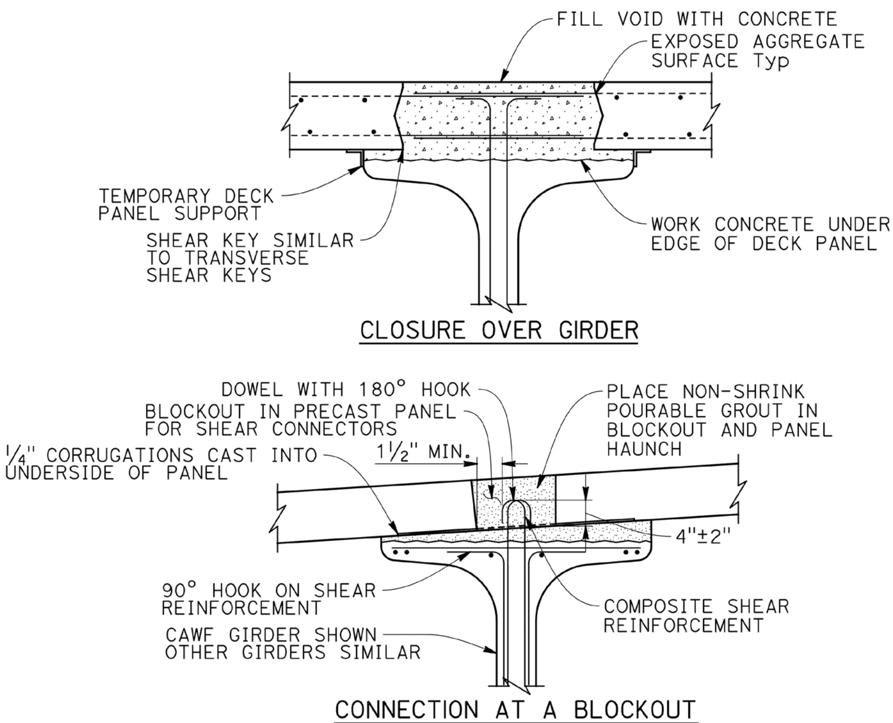

Figure 4.9.5.1.1.2-1 Closure Joints Between FDDP

For grouted connections, the gap between the bottom of the panel and the top of the girder must be filled. Connection details and design guidance are provided in the *Full Depth Deck Panel Guidelines* (PCI 2020).

4.9.5.1.2 Connections Between Adjacent Decked Beams

Connections between adjacent decked girders prevent moisture penetration from the deck and prevent relative deflection between beams. The connection for adjacent precast box girders, voided slabs, and Modular Deck Beams consists of the following:

- **Cast-in-place Concrete Deck**. The concrete deck includes deck reinforcement in both the transverse and longitudinal direction and acts compositely with the girders. This topping has been shown to provide adequate moisture resistance and sufficient stiffness and strength to prevent relative deflection. *AASHTO-CA BDS* Article 5.12.2.3.3.f requires a minimum thickness of 4.5 inches, and this thickness can vary to achieve the desired profile grade.
- **UHPC Connections**. UHPC connections, as shown in Figure 4.9.5.1.2-1, are ideal for connecting adjacent decked beams. Reinforcement projecting into the keyway or pockets provides the necessary strength to prevent relative deflection of the girders, and a cast-in-place composite topping is not required. A polyester concrete overlay provides a smooth driving surface and additional resistance to moisture penetration. If the bridge deck has a superelevation transition, this connection detail may not be feasible, and a cast-in-place concrete deck should be investigated.

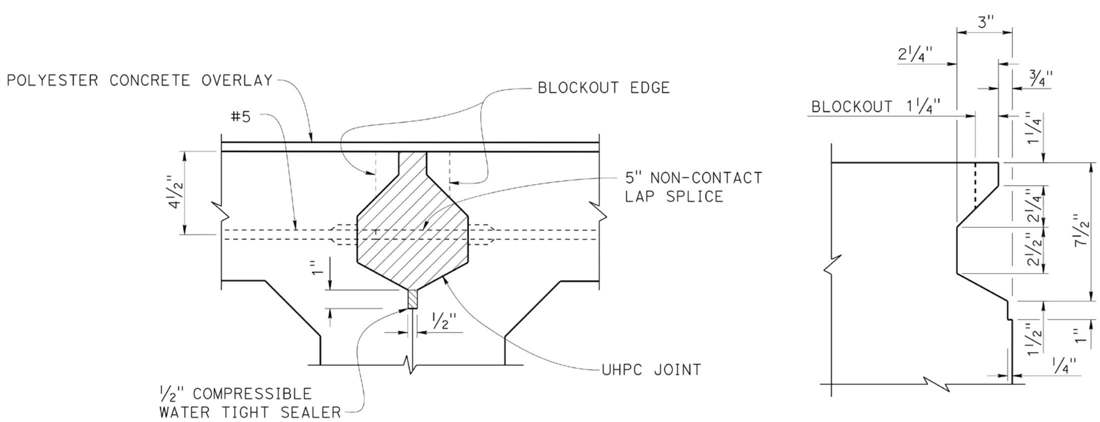

Figure 4.9.5.1.2-1 Longitudinal Keyway Detail with UHPC Connection from the 21st Avenue UC (Replace), Contract No. 03-0H3424

The preparation of the joint prior to placement is important to develop a water-resistant bond between the UHPC and the precast concrete elements, which essential for good performance of bridge decks. To achieve this, an exposed aggregate finish is required, as shown in Figure 4.9.5.1.2-2 and discussed in more detail in Appendix D, Section D.2.

Figure 4.9.5.1.2-2 Longitudinal Keyway with Exposed Aggregate Finish

The closure joints between adjacent modular deck beam units consist of either concrete or UHPC. This is similar to the closure in FDDPs, where the strength of the closure joint must be equivalent to the adjacent section, as discussed in Section 4.9.5.1.1.1. The closure joint can be made wider to reduce the weight of the modular deck beam unit for transport and erection. Connections between modular deck units at the cap beam are discussed in Section 4.9.5.1.3.

4.9.5.1.3 Girder to Bent Cap Connections

The connection between prefabricated superstructure elements and the bent cap are capacity protected and the superstructure can either be integrally or non-integrally connected with the bent cap. The design of precast prestressed concrete girder to bent cap connections is described in *Bridge Design Memo* 20.34 and steel girder to bent cap connections in *SDSSB* Section 6.5.

Steel girders used in ABC could require a spliced connection at the bent cap. Examples include modular decked beams and bridge spans moved with SPMTs. Guidance for the design of this connection is described in *AASHTO GSABC* Section 3.6.10.3. Since this type of connection is not covered in the *SDSSB*, a design exception is required, per Caltrans *SPD* 1-3.

4.9.5.1.4 Link Slabs

Refer to *AASHTO GSABC* Section 3.6.9 and the *Behavior and Design of Link Slabs for Jointless Bridge Decks* (Caner and Zia 1998) for the design of link slabs. Note that link slabs currently require a design exception to *SDC* 7.2.1.2 and 8.2.1.

Link slabs are ideal for ABC applications including continuous decked girder and modular decked beam bridges. This includes both new construction and rehabilitation projects. A link slab using conventional concrete or RSC includes a zone where the deck and girder connections are debonded over five percent of the length of each span adjacent to the bent cap. Since the stiffness of the link slab is negligible as compared to the girders, each span is essentially simply supported.

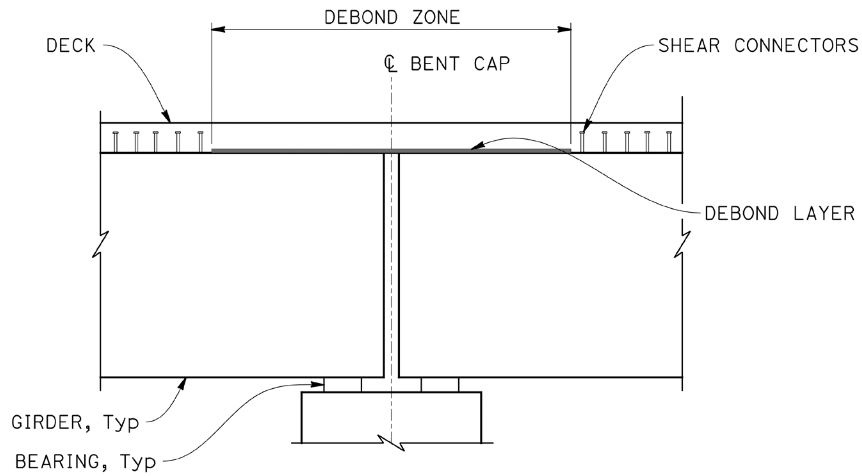

Figure 4.9.5.1.4-1 Link Slab Using Conventional Concrete or RSC

New York State Department of Transportation (NYSDOT 2019) has developed an innovative link slab design using UHPC which is currently part of their Standard Plans, as shown in Figure 4.9.5.1.4-2. This design utilizes a partial depth UHPC slab (approximately 4.0 inches thick) with a relatively short zone where the UHPC is debonded from the lower part of the composite deck (approximately 24 to 36 inches). The fibers in the UHPC mix accommodate the necessary rotations without damage to the link slab or other parts of the bridge. The micro-cracks that develop due to bending of the link slab are sufficiently small that moisture penetration is negligible.

An expansion joint must be provided for any concrete pour over a link slab, including barriers and sidewalk, to allow the slab to flex. Since the performance of link slabs is complex, early coordination with the ABC Branch is essential.

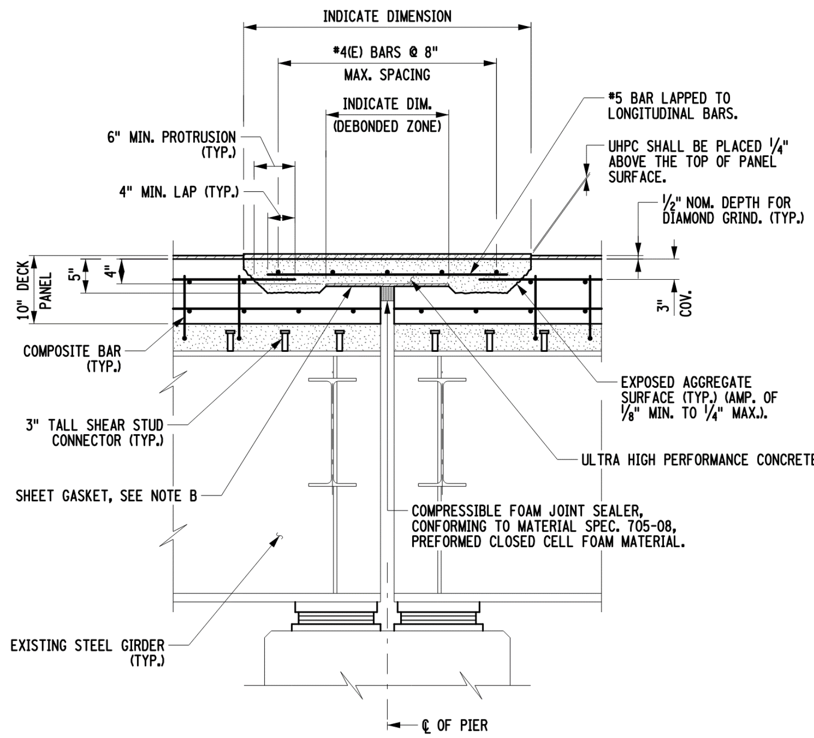

Figure 4.9.5.1.4-2 Link Slab Utilizing UHPC (NYSDOT 2019)

4.9.5.2 Substructures

The design of substructure prefabricated bridge element connections is challenging because they are typically at locations of maximum stress within the members. Furthermore, many of these connect Seismic Critical Members (SCM).

4.9.5.2.1 Adjacent Cap Elements

As discussed in Section 4.9.4.4.3, caps should be spliced if there are three or more columns in the bent due to the challenges of aligning the column bars within the grouted sleeves.

According to *SDC* Section 8.2.1, lap splices are not allowed in bent caps and service splice rebar couplers are required. *SDC* Table 8.2.1-1 allows service splice rebar couplers outside the critical zone of bent caps. So, these couplers will need to be located out of the critical zone(s). For each rebar to be spliced, two couplers connected with a single splice bar should be shown in the closure to account for minor misalignment. The closure joint should be wide enough to accommodate coupler spacing and staggering, per Standard Specification 52-6.03A, and spaced midway between girder seats. As stated in Section 4.9.4.4.3, the cap should be designed to support the girders and the deck to remove the closure from the critical path.

4.9.5.2.2 Column to Precast Bent Cap

The connection between precast columns and precast bent caps can either be fixed or pinned. Fixed connections are preferred for ABC because girders can be erected on the seats without falsework. Columns can be fixed to precast bent caps using grouted duct, pocket, or socket connections. Bent caps with non-integral superstructure connections should be proportioned to meet *SDC* Section 7.3.2.

A pin connection between a precast column and a precast inverted-T cap can be used and should conform to *SDC* Section 7.2.1.2. In this detail, bearings on the tops of the columns support the cap. A pipe shear key at the center of the column provides lateral resistance between the cap and the column. The hole for the pin should be sized to allow for fabrication and erection tolerances, and the annular space created by the oversized hole can be grouted after erection. The contract documents must indicate that the cap needs to be secured against rotation until the girders are connected to the cap.

4.9.5.2.2.1 Grouted Duct Connections

Refer to *AASHTO GSABC* Section 3.6.5 for the design of grouted duct connections.

Precast columns to precast cap connections using grouted duct connections consist of column rebar extending into grouted ducts that are grouted after placement. As shown in Figure 4.9.5.2.2-1, the connection can be designed to meet the design and detailing requirements of *SDC* Section 7.4.

Layout and tolerances are critical for grouted duct connections. Location of column reinforcement and the associated ducts must be identified based on common working layout lines and points. Grouted duct and bent cap reinforcement layout should be investigated during design to ensure feasibility. In addition, the ducts should have sufficient diameter to accommodate tolerances and maintain at least 0.25 inches (or manufacturer’s recommendation) between the bar and the duct to ensure adequate consolidation and bond between the grout and rebar.

A grout bedding layer between the column and the cap with a nominal thickness of approximately three inches should be specified. This bedding layer provides a temporary gap for minor grade adjustment during erection and provides a continuous contact surface between the cap and the column.

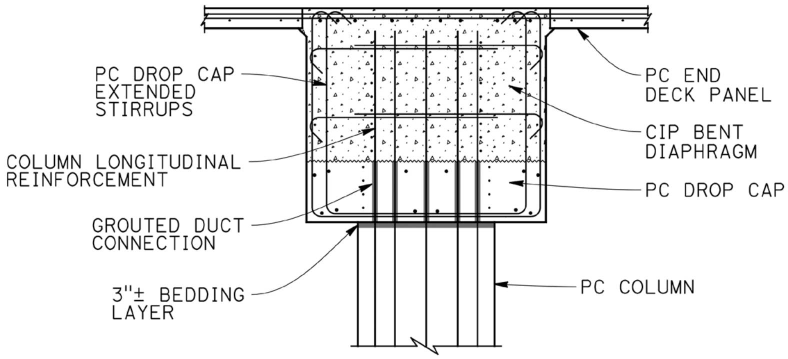

Figure 4.9.5.2.2.1-1 Integral Precast Column to Precast Cap Connection

UHPC can be used for grouted duct connections in accordance with Section 4.8.3. In this application, UHPC allows partial depth precast bent cap elements to achieve fixity with the columns prior to placement of the end diaphragms over the bent caps, and the girders can be erected without temporary supports. Rebar extending eight bar diameters ($8d_b$) from the top of the column should be debonded using duct tape to prevent spalling of the cap and allow strain penetration of the rebar into the cap, as shown in Figure 4.9.5.2.2.1-2. Analytical and experimental investigations have demonstrated good performance using this approach (Benjumea et. Al. 2019; Tazarv and Saiidi 2014; Restrepo et al. 2011).

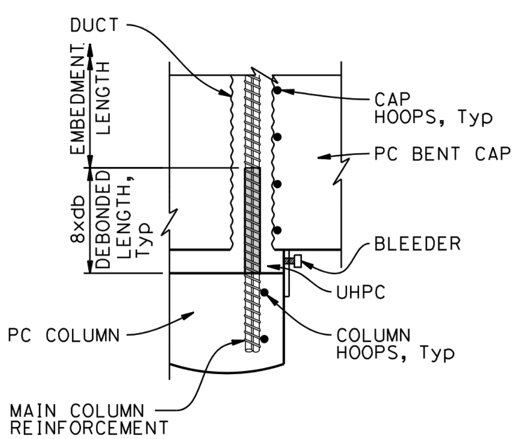

Figure 4.9.5.2.2.1-2 Grouted Duct Connection Detail with Rebar Debonding

4.9.5.2.2.2 Pocket Connections

Refer to *AASHTO GSABC* Section 3.6.6 for the design of pocket connections.

Pocket column to precast bent cap connections can be integral or pinned. This connection utilizes a CMP to form the void to accept reinforcement from the column, which is subsequently filled with concrete. The CMP serves as both a form for the void and as confinement for developing column reinforcement in the cap. Layout and tolerances are not as critical as grouted duct connections but detailing bent cap reinforcement to accommodate the CMP void can be challenging. A bedding layer between the column and the bent cap should be specified to accommodate fabrication and erection tolerances.

Joint shear design methodologies for pocket connections have been developed and validated through experimental studies (Restrepo et al. 2011, Mehrsoroush and Saiidi, 2014). Since the joint shear reinforcement details in *SDC* Section 7.4 are not applicable, a design exception is required, per *SPD* 1-3.

4.9.5.2.2.3 Socket Connections

Refer to *AASHTO GSABC* Section 3.6.7 for design of socket connections.

Socket connections are similar to pocket connections where the receiving element has a formed opening in a precast bent cap. This opening must accommodate the embedded prefabricated column and the grout that fills the annual space. Alternatively, a cast-in-place bent cap can be used if the opening width and depth makes precast impractical. *SDC* Section 7.4 does not apply to socket connections, and a design exception may be required per *SPD* 1-3.

4.9.5.2.3 Precast Column to Footing Connection

Precast columns can either have a fixed or pinned connection to the footing, and the footing can either be precast or cast-in-place.

4.9.5.2.3.1 Fixed Column Base Connection

Precast columns can be designed as having a fixed connection to precast footings using grouted duct, pocket, or socket connections in a similar manner to precast bent caps, as discussed in Section 4.9.5.2.2. Details not in conformance with *SDC* Section 6.2.2 require a design exception, per *SPD* 1-3.

Precast columns can be used with cast-in-place footings. Headed bars should be specified at the base in-lieu of standard hooks to facilitate column fabrication. A temporary support is required since the column will have to be in place during the concrete placement and cure, as shown in Figure 4.9.5.2.3-1. Although the precast fabricator and contractor will design these elements, the support must be described or schematically shown on the plans. If the temporary support device is embedded in the column, the column plastic moment and the corresponding seismic demands could be impacted. Alternatively, socket connections can be used, per *AASHTO GSABC* Section 3.6.7.

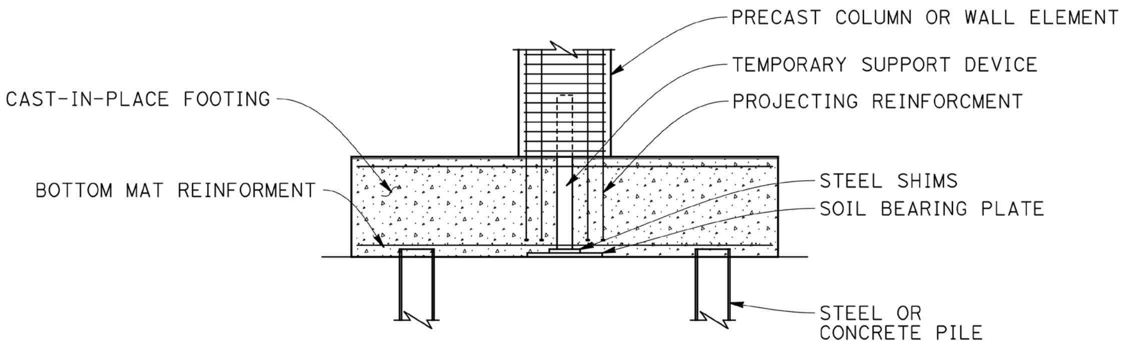

Figure 4.9.5.2.3.1-1 Fixed Precast Column to Cast-in-Place Footing Connection

4.9.5.2.3.2 Pinned Column Base Connection

Precast columns are the receiving end of column-footing pin connections. The footing can either be precast or cast-in-place. Connection details can consist of either reinforcement in a pocket or socket connection or structural steel pipe. Means of temporarily supporting the column and adjusting grade should also be described in the plans.

- **Steel Pipe Pin Connection**. The structural steel pin connection is designed and detailed in the same manner as a cast-in-place column. This detail is preferred over the distributed rebar pin because the connection has been shown to sustain minimal damage during a design seismic event (Mehraein et al. 2016). Since the connection is close to a true pin, temporary supports are required until the bent cap diaphragms have been cast and cured providing fixity to the superstructure.

- **Distributed Rebar Pin Connection**. The pin reinforcement is designed and detailed in the same manner as a cast-in-place column. The void can be formed using CMP and designed as a pocket connection, which eliminates the need for confinement rebar of the pin within the column. The moment resistance of the distributed reinforced connection stabilizes the column after the grout has reached sufficient strength, which could eliminate the need for lateral bracing during subsequent stages of construction. The stability of the column must be investigated during design when establishing requirements for temporary support, as discussed in Section 4.5.

4.9.5.2.4 Precast Column to Shaft Connections

Precast columns can be connected to shafts in a manner similar to cast-in-place footings. These connections can either be fixed or pinned.

- **Fixed connections**. For Type-II shafts, the design of reinforcement above the shaft construction joint can be designed and detailed in accordance with *STP* 10.7 and *SDC* Section 6.2.5. The temporary support device required to support the precast column should be embedded in the lower portion of the shaft, thus removing the member from the plastic hinge zone. Alternatively, a socket connection can be used in accordance with *AASHTO GSABC* Section 3.6.7.3.

- **Pinned connections**. Precast column pin connection to a shaft is the same as the column-to-footing connection described in Section 4.9.5.2.3.

4.9.5.2.5 Abutments

Prefabricated abutment elements can be connected in a number of different ways. The following sections provide guidance in selecting the most efficient and effective means of connecting and assembling prefabricated abutment elements.

4.9.5.2.5.1 Adjacent Abutment Wall Element Connections

Adjacent abutment elements can be connected using grouted keyways, reinforced concrete closure joints, and post-tensioning. The following is a brief description of each of these connections.

Grouted keyways are simple and cost-effective. They consist of a minimum two-inch wide gap, but the width may vary based on segment widths and tolerances. After assembly, the keyway is filled with nonshrink grout. To prevent water intrusion, the joint should be sealed with a 1-foot-wide neoprene strip bonded to the rear face of the wall. Note that the forms for the grouted joint could be subject to significant hydrostatic forces, and the contractor should design the forms accordingly.

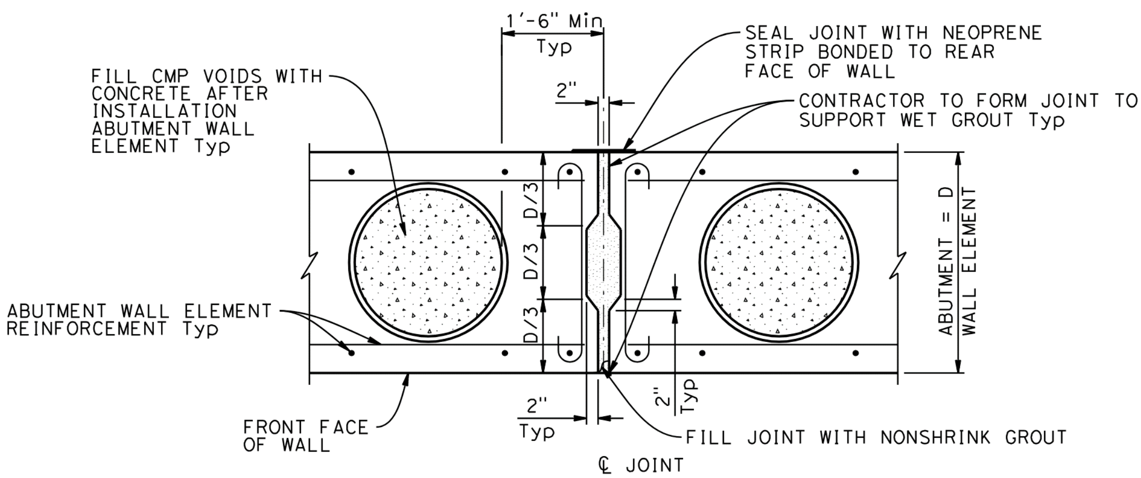

Figure 4.9.5.2.5.1-1 Connection Between Precast Abutment Wall Elements

Refer to *AASHTO GSABC* Section 3.6.2 for design of cast-in-place concrete closure joints using lapped bar reinforcement. Difficulties in placement can arise if lapped spliced bars lie in the same vertical plane, since abutment wall elements are often designed to fit over piles in pocket connections. UHPC can be used to reduce the width of the closure joints. Refer to *AASHTO GSABC* Section 3.6.2.4 for design of UHPC closure joints using lapped bar reinforcement.

Alternatively, the closure bars can be spliced with couplers. If couplers are used, two couplers should be specified for each, and the closure should be at least 3.5 feet wide or the width required for staggering and spacing of the couplers to allow for misalignment.

Abutment wall elements can be connected with post-tensioning, where tendons run horizontally and are filled high-strength rods or strands. The joints between elements can consist of a grouted key. The tendons, consisting of corrugated metal ducts, are spliced between elements and grouted after post-tensioning to provide corrosion protection. Alignment of the ducts is challenging due to fabrication and erection tolerances, and the duct diameter should account for these tolerances. Also, the ducts must be sealed for grouting, which can be challenging.

4.9.5.2.5.2 Abutment Wall Elements to Wall Cap Connections

A cost-effective way of connecting the wall cap to abutment wall elements is to use dowel bars in CMP voids. Since the moments due to earth pressure are relatively low at this location, reinforcement distributed inside of the CMPs can be designed to provide sufficient resistance to applied moment and shear demands. Grout is placed in the gap between the wall cap and abutment elements after CMPs are filled with concrete.

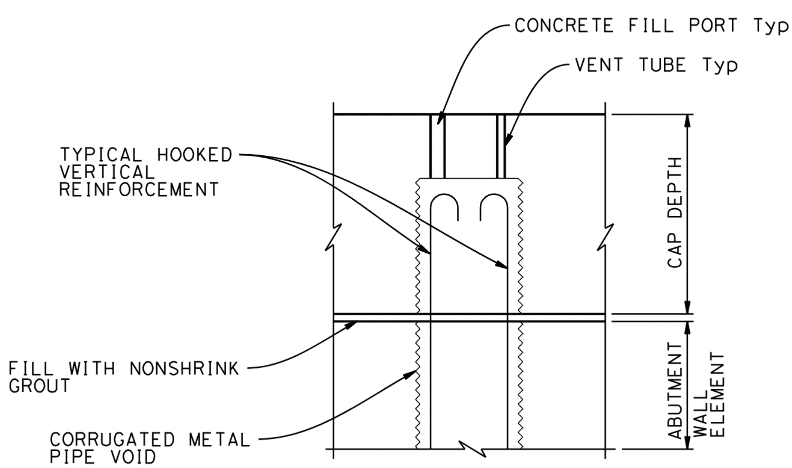

Figure 4.9.5.2.5.2-1 Connection Between Precast Abutment Wall Elements and Wall Cap

4.9.5.2.5.3 Abutment Wall Elements to Footing Connections

Precast abutment wall elements can be connected to precast or cast-in-place footings using a number of methods including:

- Grouted duct connections are where abutment wall segment bars are cast in galvanized CMPs. The wall elements should be seated in a grout bed to ensure uniform bearing. If UHPC is used, the upper eight bar diameters (8db) should be debonded, as discussed in Section 4.9.5.2.2.
- Connections to cast-in-place footings are similar to those described for columns, where the abutment walls are temporarily supported and braced during concrete placement and curing. The plans should schematically show temporary vertical support and requirements for lateral bracing should be specified. The main reinforcement can either be hooked or T-headed.

4.9.5.2.5.4 Abutment Wall Elements to Pile Connections

Precast abutment wall elements can be connected directly to piles. Refer to *AASHTO GSABC* Section 3.6.6.6 for design of abutment-to-pile pocket connections.

Steel piles should be embedded a minimum of 12 inches, and if the piles are not in tension, the U-bars of Standard Plan B2-5 are not required. The inside diameter of the CMP should accommodate driving tolerances plus one inch to ensure that the pile has a minimum amount of cover. Driving tolerances are typically +/- 6 inches, which can be reduced to +/- 3 inches if a driving template or frame is indicated on the plans. Therefore, the inner diameter should be the diameter of the pile measured diagonally plus eight inches with driving templates or frames specified. The capacity of the connection is based on the shear strength of the concrete filling the galvanized CMPs, per *AASHTO GSABC* Section 3.6.6.6.

Abutment walls may require temporary support and bracing until concrete within the CMPs reaches the compressive strength specified on the plans or specifications. A layer of slurry concrete with a three-inch gap between the wall segment and the sub-footing can facilitate erection. This gap can be filled with lean concrete backfill after concrete placement within the galvanized CMPs. Lean concrete backfill, as specified in *Standard Specifications* Section 19-3.02I, is not a rapid strength material. If fast set is required, nonshrink grout should be specified, but it comes with a much higher cost.

4.9.5.3 Closure Joint Materials

Closure joint materials can consist of concrete, nonshrink grout, RSC, and UHPC. Refer to *AASHTO GSABC* Section 10.4.3 for information and requirements on nonshrink grout. Refer to Section 4.8.2 and 4.8.3 for information and requirements on RSC and UHPC, respectively.

4.9.6 Achieving a Smooth Driving Surface on Precast Elements

Precast concrete bridge elements can be part of the bridge deck, which could consist of decked girders, as discussed in Section 4.9.4.4.7, or full depth precast deck panels, as discussed in Section 4.9.4.4.6. After assembly, the driving surface will require treatment to achieve the required finish.

Deck grinding and grooving can be used to smooth local imperfections on the bridge deck. The extent of grinding is determined per *Standard Specifications* Section 51. For full depth deck panels, 0.5-inches of added cover is recommended to account for vertical misalignments at the closure joints if an overlay is not specified, as discussed in Section 4.9.4.4.6.

Polyester concrete can provide a durable driving surface within four hours after placement, which makes it ideal for ABC applications. Refer to *BDM* 16.10 for polyester concrete overlay thickness and application; note that closure joint material must cure prior to polyester concrete placement, as discussed in Section 4.8.

4.9.7 Mock-ups

Mock-ups are recommended for PBE projects for the following reasons:

- Demonstrate that the fabricator can control the dimensions of the elements; the locations of the rebar, ducts, and other hardware; and provide exposed aggregate surfaces on areas that will contact closure joint connection materials.
- Ensure that the contractor can assemble the elements in the field as shown on the drawings.
- Educate and train staff on the assembly of prefabricated elements. Construction staff who will be assembling the actual prefabricated bridge elements should participate in the mock-up construction.
- Verify that the closure joints can be constructed as planned.
- Prequalify the UHPC and RSC mix designs, as discussed in Section 4.8.
- Show that the contractor can pour RSC of similar quantity and shape as the bridge component shown on the plans.
- Verify field installation durations.

The mock-up should be conducted for all critical closure joints and connections. This includes grouted duct connections between precast columns, caps, and footing connections. The mock-up should be full-scale and sawcut after construction to verify that the connection material can consolidate around the reinforcement in the duct. The mock-up shall employ the same means and methods that will be used for the field installation. This includes equipment and staff.

4.9.8 Preassembly

Preassembly of elements is necessary to prevent significant delay during erection of PBEs. Refer to *AASHTO GSABC* Section 8.3.2.6 for dry fit assemblies of precast elements. Adjacent precast prestressed box girders or voided slabs should be preassembled to demonstrate proper alignment of the joints, assembly is within acceptable tolerances, and the protruding rebar in the connection area has sufficient clearance and is free of conflicts. Mark the elements so that they are reassembled in the field as they were preassembled for the dry fit check.

For precast columns and caps with grouted duct connections, assembly may exceed height and weight limits available in the fabricator's facility. Alternatively, a partial height column mock-up of two feet in height may be used in the facility for preassembly. If this alternative is allowed, the special provisions should state this.

Figure 4.9.8-1 Preassembled Precast Concrete Box Girders Prior to Shipping, 21st Ave UC (Replace), Contract No. 03-0H3424.

4.9.9 Plans

Refer to *AASHTO GSABC* Section 4.4 for detailing requirements of PBEs. In addition, the plans should include details of the prefabricated bridge elements, a description of the assumed construction sequence (if not detailed in the specifications), and details of the mock-ups.

Prefabricated bridge element sheets should contain plan and elevation views along with all internal reinforcement details including allowable rebar splice locations. Injection ports should be included for nonshrink grout or UHPC. For precast caps and columns, show the layout for the reinforcement and the CMP's. CMPs should be galvanized and terminate three inches below the surface of the concrete if the surface is to be exposed to a corrosive environment.

The construction sequence should be described on the plans, as discussed in Section 4.9.4.3.

4.9.10 Specifications

A project using PBEs will require project specific Standard Special Provisions. Refer to *AASHTO GSABC* Section 8.5 for guidance on developing contractor submittal requirements for PBEs and note the recommendations in the following sections.

4.9.10.1 Submittals

The specifications outline the requirements for submittals for shop drawings and work plans for the fabrication and assembly of the prefabricated bridge elements.

4.9.10.1.1 Shop Drawings

Shop drawings are required for all precast concrete bridge elements, structural steel elements, and bearings.

Refer to *AASHTO GSABC* Section 8.2.2 and *BDM* 5.3 for precast concrete element shop drawing requirements and *BDM* 5.29 for post-tensioning shop drawing requirements. Shop drawing requirements for precast concrete girders are detailed in *Standard Specifications* Section 51-4.01C(2)(b) and *Standard Special Provisions*. Shop drawings for other elements, such as precast abutment wall elements, wingwalls, columns, footings, and bent caps will require special provisions, as they are not covered in the *Standard Specifications*.

4.9.10.1.2 PBE Work plans

Work plans are prepared by the contractor based on the requirements set forth in the plans and specifications of the project. Work plans that may be required for PBE projects include plans for assembly, mock-ups, pre-assembly, and materials such as RSC and UHPC.

4.9.10.1.3 Assembly Plan

Refer to *AASHTO GSABC* Section 8.5 for PBE Assembly Plan recommendations. The PBE Assembly Plan includes an assembly schedule and detailed work plans for, but not limited to, the following:

- Geometric control
- Temporary support installation and removal
- Unloading, lifting, erecting, and assembling PBEs

Note that the contractor is required to submit an erection work plan for precast prestressed concrete girders, per *Standard Specification* Section 51-4.01C(1). The erection work plan is part of the Assembly Plan.

4.9.11 Prefabricated Bridge Element Checklists

When preparing PBE designs and details, there are several checklists that should be completed as part of the quality control process. These checklists include:

- Prefabricated Bridge Element Checklists, Appendix A
- UHPC Implementation Checklists, Appendix E

The purpose of these checklists is to:

- Verify that the design and details are complete
- Confirm PE and contractor roles
- Demonstrate that a feasible construction method was developed
- Identify where the design requirements are located (e.g., plans, special provisions, *Standard Specifications*)
- Confirm that the contractor’s responsibilities are defined

4.9.12 Examples

Several ABC projects using PBE methods have recently been constructed in California. The plans and specifications are available for review on the Caltrans Project Bucket Search webpage. The following are notable projects and their ABC features:

Fort Goff Bridge Creek Bridge (Contract No. 02-4E6301)

- Single span voided slab bridge
- Precast abutments and wingwalls
- Temporary culvert shoofly
- Prefabricated bridge rail

Laurel Street Overcrossing (Contract No. 04-4G4504)

- Two span wide flange girder bridge
- Precast concrete columns
- Precast concrete drop bent cap
- RSC deck
- UHPC column to bent cap connection

Echo Summit Sidehill Viaduct (Contract No. 03-3F5304)

- Single span adjacent box girder bridge
- UHPC grouted connections between girders
- Polyester concrete overlay
- LCC fill behind abutment
- New abutments constructed prior to demolition of existing
- Full closure 24-hour construction

Similarly, there have been ABC projects that utilize PBE methods built in other states. A project database of ABC projects using PBE and other methods can be found on the ABC UTC Project and Research Databases webpage. Table 4.9.12-1 contains a list of notable ABC projects with PBEs built in other states.

Table 4.9.12-1 Notable Out-of-State PBE Projects

Project	Superstructure	Substructure	Project Delivery / Contracting
SR-30 over Bessemer	Single-span modular deck steel girder bridge with UHPC	Rehabilitated existing abutments with precast caps	Design-Build

Project	Superstructure	Substructure	Project Delivery / Contracting
Ave., Pennsylvania, 2017	closures and latex concrete overlay	and precast approach slabs. Flowable fill used for structure backfill	
Riverdale Rd. over I-84, Utah, 2008	Two-span steel girder bridge with full depth precast concrete deck panels	Precast bent caps, columns, abutments, and MSE walls with lightweight fill	CMGC
Commonwealth Ave. Bridge, Massachusetts, 2018	Longitudinal full-depth precast concrete deck panels replaced existing deck on steel girders.	Replaced concrete piers utilizing existing foundations, rehabilitated abutments	Design-bid-build
Blackhall Rd. over Beech Creek, Georgia, 2020	Three-span modular decked bulb-tee girders with UHPC closures.	Conventional concrete substructure	Design-bid-build, A+B bidding
Boeing North Bridge Washington, 2014	Three-span (134 feet maximum span) continuous steel girder bridge with full depth precast deck panels and UHPC closures	Precast post-tensioned concrete bent caps with precast columns and drilled shafts	Design-bid-build
Bridge 1-438 over Blackbird Creek, Delaware, 2017	Single-span PC concrete box girder bridge with UHPC closure joints and overlay	Precast integral abutments with driven precast concrete piles	Design-bid-build
Sacramento Wash Crossing, Arizona, 2017	Single-span modular deck steel girder bridge with RSC closure joints	Precast concrete abutments and backwalls on drilled shafts with reinforced structural backfill	Design-bid-build, Incentive/disincentive clauses
Rawson Avenue Bridge, Wisconsin, 2013	Two-span precast concrete girder bridge with cast-in-place deck assembled with SPMTs	Precast bent caps and columns with conventional abutments and MSE walls	Design-Build
Marc Basnight over Oregon Inlet, North Carolina, 2018	Eleven precast segmental spans and 71 precast girder approach spans with sand lightweight concrete deck	Precast segmental piers support main spans, concrete filled precast cylindrical piles on precast bent caps support approach spans	Design-bid-build
Hwy 6 over Keg Creek, Iowa, 2012	Three-span modular decked steel girder with UHPC closures and link slabs	Precast bent caps and precast columns, precast semi-integral abutments.	Design-bid-build

4.10 LATERAL SLIDE SYSTEMS

This section provides general guidance on lateral slide bridge move and identifies resources for the development of design plans and specifications for successful ABC implementation. For more specific information, refer to *AASHTO GSABC,* the *FHWA Slide-In Bridge Construction Implementation Guide* (FHWA 2013), the Proposed Guidelines for Dynamic Effects for Bridge Systems (Culmo et al. 2017b), and the *SHRP2 ABC Standard Concepts: The Lateral Slide Addendum Report* (TRB 2015).

4.10.1 Introduction

Lateral Slide Systems are applicable to a variety of bridge types with the main advantage of minimizing traffic impacts. More information on the advantages of Lateral Slide Systems is in Section 3.2.2.1.

4.10.2 Roles and Responsibilities for Lateral Slide Systems

Bridge components designed for lateral slide shall meet requirements of the *AASHTO-CA BDS* and other bridge and structure policies and standards, as defined in *SPD* 1-3. The PE is responsible for the design of the entire bridge, verification that the bridge can be built and moved within the proposed work zone, and specifying the requirements for the contractor to complete the construction. The contractor is responsible for designing the temporary supports and the lateral slide system.

PE responsibilities for lateral slide bridge moves are covered in *AASHTO GSABC* Sections 1.6 and 4.6. The PE is also responsible for placing the following information on the plans or in the specifications:

- Assumed vertical and horizontal jacking forces and jacking points.
- Estimated friction forces that wereused in the design of the bridge system.
- Assumptions about the sliding system and resulting friction forces that could impact the temporary supports. For example, an assumed connection that transfers load between the new bridge and temporary supports.
- Schematic of the assumed temporary supports.
- Fabrication, erection, and joint width tolerances.

An outline of the roles and responsibilities in the design and construction phases of the project is provided in Table 4.10.2-1.

Table 4.10.2-1 Lateral Slide Roles and Responsibilities

Category	Description of Responsibility	Owner	Contractor
Advance Planning Study / Type Selection	Feasibility of using lateral slide moves in project	✓	--
	Preliminary cost estimate and project constraints	✓	--
New Structure Analysis and Design	Analysis of new structure for all boundary conditions during construction	✓	--
	Design of all elements and connections for defined lift points	✓	--
	Define stress, deflection, and twist limits during move	✓	--
	Provide full set of contract documents including plans and specifications	✓	--
	Redesign of elements due to support location deviation	--	✓
Tolerances	Specification of fabrication tolerances, assembly tolerances, and joint width tolerances	✓	--
	Survey, implementation, and verification	--	✓
Materials	Specification of materials	✓	--
	Procurement, submittal, approval, and construction	--	✓
Temporary Supports	Allowable bearing capacity and proposed foundation	--	✓
	Design and fabrication of all temporary supports	--	✓
Bridge Demolition	Verify that there is sufficient staging area for equipment	✓	--
	Verify access and egress for equipment	✓	--
Lateral Slide Move	Preliminary feasibility evaluation of lateral slide assembly the	✓	--
	Lateral slide submittal, setup, and execution	--	✓
	Review and authorization of lateral slide assembly plan	✓	--
Geometric Control	Specification for geometric control and monitoring throughout construction including allowable twist and relative displacement.	✓	--
	Submittal, setup, and execution of geometric control plan	--	✓
	Review and authorization of geometric control plan	✓	--

4.10.3 Site Considerations

4.10.3.1 Traffic Handling

Lateral slide systems allow for construction of a new bridge with limited traffic impacts. A few traffic handling options to accommodate the demolition of the existing bridge are:

- Construct a portion of the new substructure under the existing superstructure and the new superstructure adjacent to the existing bridge while it carries traffic. Close down traffic for several days to demolish the existing bridge, complete the substructure and slide the new superstructure in place.
- Construct the new superstructure adjacent to the existing bridge on temporary supports. Detour traffic on to the new superstructure while the existing bridge is demolished and the new substructure is constructed. Close traffic to slide the new superstructure in place.
- Close traffic and slide the existing superstructure to temporary supports adjacent to the existing bridge location. Detour traffic on to the existing superstructure while demolishing the existing substructure and constructing the new bridge.

4.10.3.2 Bridge Geometry

Attention to bridge geometry is critical to the success of a lateral slide design. Listed below are some geometric constraints that should be considered:

- Bridge skew
- Parallel supports; i.e., abutments and bents
- Alignment curvature
- Bridge profile
- Deck cross slope and superelevation
- Bridge site access and clearance
- Site topography
- Construction tolerances

Complex or unusual bridge geometry does not preclude the use of a lateral slide, but it could increase cost and schedule. For example, for a vertical clearance problem, one solution would be to build the superstructure high and lower it immediately prior to the lateral slide, as shown in Figure 4.10.3.2-1.

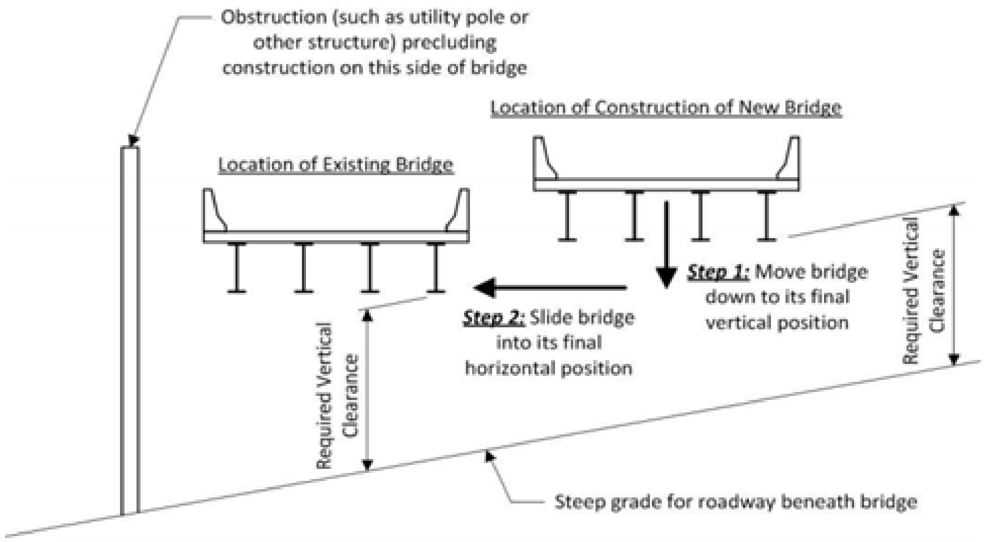

Figure 4.10.3.2-1 Lateral Slide Example with Complex Geometry (FHWA 2013)

Construction tolerances need to be considered in conjunction with bridge geometry. Shear keys, abutment backwalls, and other bridge elements detailed on plans with joints or gaps can become obstructions during the bridge move. Refer to *Guidelines for Prefabricated Bridge Elements and Systems Tolerances* (Culmo et al. 2017a) for a more detailed discussion on the impact of tolerance on lateral slide systems.

The minimum recommended gap between the moving and stationary elements of the bridge is 2.5 inches. Gaps of this size and larger can be provided by selecting an oversized joint seal that accommodates the calculated movement range plus the gap required for sliding the bridge in place. The PE should consult with the Joint Seal Specialist to select the appropriate joint type and movement rating (standard or nonstandard) that will provide enough room during the slide and be quickly installed once the superstructure is in place.

4.10.3.3 Utilities

All overhead and underground utilities shall be identified and shown on the plans. To accelerate the construction schedule, all utility work should typically be completed before construction begins. Unanticipated utility issues that can possibly arise during construction are a major schedule risk.

For bridges designed to carry utilities, significant thought should be put into utility blockout access/tie-in upon completion of the lateral slide.

4.10.4 Sliding Systems

There are many types of sliding systems that can be used for lateral slide moves. The factors that contribute to a contractor's decision include cost, experience with a system, weight of the superstructure, site accessibility, geometry, availability, and tolerances.

The selection of a sliding system should consider directionality, whether or not the move can be reversed, and whether the system is guided continuously along the tracks. The sliding system must have the ability to stop and should have the ability to reverse the lateral slide. The travel speed for the lateral slide system should be limited to 10 inches/minute (Culmo et al. 2017b).

Refer to *ABC Standard Concepts: The Lateral Slide Addendum Report* (TRB 2018) and the *Slide-In Bridge Construction Implementation Guide* (FHWA 2013) for more detailed information on sliding systems and note the recommendations in the following sections.

4.10.4.1 Polytetrafluoroethylene Pads

Pad systems are a simple and low-cost sliding alternative. They allow movement in any direction. Pads can be used with both guided and unguided systems.

- Polytetrafluoroethylene (PTFE) pads have relatively low static and dynamic friction coefficients when stainless steel plates and lubricants are utilized on contact surfaces.
- For an unguided system, the beginning and end of the bridge can be moved at different rates. For this type of move, strict displacement control will need to be in place to reduce the risk of racking and binding.
- Slide tracks can be incorporated if a guided system is required.

4.10.4.2 Rollers

Roller systems are typically used with heavier loads and generate large point loads under the roller. Slide resistance is slightly less predictable than equivalent pads. Starting and stopping the move requires less force (Culmo et al. 2017b). The following should be considered when evaluating a roller system:

- Rollers are usually guided with restrainers or channels.
- Superstructure vertical jacking is required because the system needs to be removed after the move.
- The transition from temporary supports to the new bridge must be smooth. Differential displacements and settlement between temporary supports and the new bridge must be considered during design and construction.

- The move is restricted to movement along the guides in both forward and reverse directions.
- Roller systems are more costly than pads.

4.10.4.3 Push/Pull Systems

The predominate push/pull systems include hydraulic jacks, strand-jacks, and winches. Hydraulic jacks are available in single or double action offering push and pull as required. Winches and strand jacks are pull only.

4.10.5 Forces

The design of a bridge for a lateral slide move is generally the same as for a conventional bridge. The differences are that the bridge must be designed for the forces imposed upon it during the move.

4.10.5.1 Jacking Forces and Jacking Locations

The PE is required to identify the jacking locations on the bridge. This includes both horizonal and vertical jacking points. These jacking locations and associated forces shall be shown on the plans.

The horizontal jacking force shall be increased by a factor of 1.5 for design. This load factor accounts for any unanticipated additional breakaway forces that could increase the assumed friction force. Refer to *Standard Specification* 48-5.02B for jacking design requirements in the vertical direction.

4.10.5.2 Friction Forces

The friction force produced during the lateral slide is the greater of the static or dynamic friction of the assumed sliding system. This force can be estimated using the *Guidelines for Dynamic Effects of Bridge Installations* (Culmo et al. 2017b), which refers to *AASHTO LRFD Bridge Design Specifications* (AASHTO 2017) Table 14.2.2.5-1 for design of the sliding system. Since the magnitude of the friction is dependent on the sliding system, assuming a conservative friction value is prudent. For example, rollers typically exhibit lower friction values compared to other sliding systems. The PE should design for the system that produces the higher friction.

The *Slide-In Bridge Construction Implementation Guide* (FHWA 2015) suggests a coefficient of static friction from 5% - 15%. It further suggests that if the system binds, the coefficient of static friction can be higher, between 10% to 20%. The *SHRP2 ABC Standard Concepts: The Lateral Slide Addendum Report* (TRB 2015) suggests coefficients of static friction from 9% to 12% and dynamic coefficients of friction from 5% to 6%.

Unless the sliding system is known, the designer should assume 15% for design purposes. If a sliding system is assumed, the coefficient should be based on the assumed system.

4.10.5.3 Resolution of Sliding Forces

AASHTO GSABC Section 1.6.1.4 defines two approaches to account for the resolution of friction forces:

- Falsework is attached to the bridge substructure. In this approach, the connection between falsework and the substructure is designed for the total sliding friction force. The resultant forces in the bridge substructure and falsework structure are near zero. For this approach, the PE shall indicate in the contract documents that a connection is required.
- Falsework is not attached to the bridge substructure. In this case, both the falsework and substructure shall be designed for the total sliding friction force.

4.10.6 Loading Conditions

In general, the PE is responsible for designing the bridge for final and interim loading conditions. The contactor is responsible for the design of the temporary supports.

4.10.6.1 Temporary Location

The new bridge superstructure can be built on a temporary support system adjacent to the existing bridge prior to the lateral slide. The support system can be designed by the contractor using the loadings and general notes from the plans and requirements in the specifications. If the new superstructure is used for the traffic detour, the PE may elect to design the temporary abutment to support the new superstructure in its temporary alignment. When designing the superstructure for this construction stage, the PE should consider the following:

- The temporary support locations as defined in the contract documents
- Construction loads and any falsework loads that might control the design
- The vertical jacking reactions
- The allowable settlement

4.10.6.2 During the Slide

The main difference between a bridge designed for conventional construction and one design for a lateral slide move is in the construction stage. During construction, the bridge experiences loads from friction of the sliding system, jacking reactions, and any other move-related loads . When designing the superstructure for this construction stage, the PE should consider the following:

- Friction forces shall be multiplied by 1.5 to accommodate any unanticipated additional breakaway forces.
- How the vertical loads from the Sliding System are applied to the bridge. For example, roller system reactions would be applied as point loads.

4.10.6.3 Permanent Location

Once the bridge is positioned in its final location, the superstructure design will typically be controlled by requirements of the *AASHTO-CA BDS*. There are a couple of scenarios where additional design checks will be required:

- If bearings need to be installed after the move, the superstructure will need to be checked for vertical jacking forces.
- If the sliding system is being removed, the superstructure will need to be checked for vertical jacking forces.

4.10.7 Allowable Deflection and Twist

The PE shall analyze the superstructure to determine both the allowable relative deflection and the allowable twist based on control of cracking of the bridge concrete during the move, as discussed in Section 3.12.1 of the *Guidelines for Prefabricated Bridge Elements and Systems Tolerances* (Culmo et al. 2017a). At a minimum, the beams, girders, deck, and barriers shall be checked. Twist is defined as the upward or downward deflection of one corner relative to the plane defined concurrently by the elevations of the other three corners. Twist must be monitored at a minimum of four points (over centerlines of permanent span support bearings at girders) of the superstructure. Relative deflections must be monitored at a minimum of six points (over centerlines of the girders and at centerline of bridge) on the superstructure.

4.10.8 Geotechnical Design for Slide System

The PE shall request a geotechnical investigation of the area around the proposed temporary support foundation. The plans and specifications shall include information about the allowable foundation type, foundation capacities, and any pertinent subsurface information for the temporary support design and construction recommended by the geotechnical engineer.

4.10.9 Substructure Design

The substructure shall be designed for all loads resulting from the assumed slide system. Vertical loads from the superstructure shall be analyzed as a moving load, but dynamic affects can be neglected.

The design shall consider any transfer of load between the falsework and bridge as discussed in Section 4.10.5.3.

4.10.10 Temporary Support

The design responsibility of the temporary supports falls under the contractor's means and methods. The *Standard Specifications* Section 48-3 and the *Caltrans Falsework Manual* (Caltrans 2020) shall be followed.

4.10.11 Construction Sequence

Early in the project development phase, a detailed construction sequence should be created to identify project constraints, identify work items, verify that project goals can be attained, determine schedules, and establish project feasibility. In the final design, the contract documents shall provide a simplified construction sequence.

4.10.11.1 Roadway Activities During Closure

The detailed construction sequence needs to include all mobility issues that could impact the construction schedule. Coordination with District is required to ensure that the detailed construction sequence incorporates construction site restrictions, roadway closures, detours, and activities such as paving, striping, and guard rail construction.

4.10.11.2 Abutment Backwall and Shear Keys

The construction sequence and associated construction schedule should consider the installation of the abutment backwalls and shear keys. Below are issues that should be considered:

- Tighter assembly and fabrication tolerances are required if the precast abutments include the backwalls. It's important for the performance of the bridge that expansion joint "gaps" are built within tolerance.
- Cast-in-place backwalls also require tight assembly and fabrication tolerances. Moving the backwall away from the superstructure to maintain the expansion joint "gap" could negatively impact the reinforcement concrete cover in the backwall if the backwall is cast after the move.

- Cast-in-place backwalls and shear keys will increase the working days schedule for forming, concrete pours, cure times, form stripping, and finishing.
- The abutment backfill operation in the construction sequence and schedule. See Section 4.13.5 for accelerating backfill.

4.10.11.3 Demolition

Demolition of the existing bridge can have a major impact on the roadway closure schedule and overall construction schedule. Refer to Section 4.14 for a discussion on the demolition of existing bridges and consider the following items that could reduce risk to the schedule:

- If possible, utilities on and around the existing bridge should be relocated prior to the demolition. Protecting utilities in place or temporarily moving utilities can negatively impact the schedule.
- Verify that the demolition subcontractor has a large enough staging area for equipment (cranes, dump trucks, and excavators).
- Verify that the demolition subcontractor has access and egress for their equipment.
- When possible, detour traffic around the work area and remove the demolition from the critical path.
- Confirm environmental restrictions, such as work windows, noise, lighting etc.

4.10.12 Contract Plans

Refer to *AASHTO GSABC* Section 4.6 for items to be included in the plans. In addition, the plans should include:

- Stage construction plan sheet
- Assumed locations of jacking/pulling force including assumed friction values
- Assumed vertical jacking and support locations before, during, and after the slide installation
- Geotechnical information within the temporary support locations
- Allowable concrete bearing pressure for the temp supports under the soffit
- Construction sequence to include general statements which give the contractor flexibility but meet the parameters assumed in design

4.10.13 Specifications

A project using lateral slide will require project specific special provisions. Refer to *AASHTO GSABC* Section 8.6.1 for guidance on developing contractor submittal requirements for lateral slides and note the recommendations in the following sections.

4.10.13.1 Prior Lateral Slide Move Experience

The contractor shall provide prior lateral slide move experience. This prior experience requirement ensures that the contractor is capable of performing the lateral slide move thereby minimizing the risk of inexperience related issues and delays during the move. Inexperienced prime contractor can attain the necessary prior experience through bridge move subcontractors. The contractor's submittal shall demonstrate that the move subcontractor is familiar with temporary support design, lateral slide layout and setup, monitoring during a move, and successful completion of prior projects.

4.10.13.2 Geometric Control

The Contractor shall design and detail a system to continuously monitor deflections and twist of the bridge system during the bridge move. The monitoring system shall account for the following:

- The temporary supports must provide equal load distribution among beams and have adequate foundation capacity to remain below settlement limits before, during, and after construction of the superstructure. Monitoring should be in place to detect settlement.
- Displacement monitoring of deflections of the bridge system throughout the slide is necessary to verify that allowable deflections are not exceeded (for example, to avoid deck cracking).
- Geometric monitoring of the lateral and longitudinal alignments of the bridge system is required throughout the lateral slide. Reference points for geometric control of the bridge and ground shall be provided.
- Any change in the behavior of structure, particularly appearance of any new cracks during the lateral slide.

4.10.13.3 Communication During Move

To illustrate how the team will communicate during the move, the contractor shall provide a communication plan that includes a contact list of approved personnel and the contractor's authorized representative. The communication plan is essential for establishing the protocol for stopping the lateral slide operation if the differential deflection or twist is about to exceed allowable limits or if bridge is out of tolerances during the move. The PE shall be on-call 24/7, and may be required to be present at the site, during the closure and move.

4.10.13.4 Trial Lateral Slide

A trial lateral slide consists of moving the bridge beyond the distance to overcome static friction and demonstrate control of the move, which is typically one to two feet of displacement. This trial move takes place prior to closure of the existing bridge with enough time to allow for repair or modifications before the full bridge move. A trial lateral slide allows the contractor to:

- Become familiar and educate the crew with means and methods
- Confirm all equipment is working
- Determine equipment stroke limits
- Confirm directional control
- Confirm the static and dynamic friction

The trial lateral slide shall demonstrate that the contractor has full control of the bridge movements and is able to correct the deflections and twist of the structure during the move.

The trial lateral slide should occur between 5 to 30 days prior to the final lateral slide to allow for modifications to the system and resubmittal of work plans as required. The crew of the final lateral slide shall be the same as that from the trial lateral slide.

4.10.13.5 Contingency Plan

The contractor shall have contingency plans to address potential problems such as insufficient equipment, equipment breakdowns, inclement weather, extreme temperature, and personnel unavailability, as well as logistical issues related to timing of materials, equipment, public notices, and multiple moves within the same window. The lateral slide company shall anticipate out-of-service conditions and equipment failures and develop contingency plans to ensure that the operator can manually finish the lateral slide. The District will develop a detour route for extended closure in the event problems arise mid-slide that significantly delays completion of the move.

4.10.13.6 Mandatory Pre-bid Meeting

The PDT team should consider holding a mandatory pre-bid meeting and site visit to highlight items that require special expertise and those that impact cost and schedule. This meeting may also be used to highlight the design assumptions so that the contractor can bid the project accordingly and avoid unnecessary delays later to address Request for Information (RFI) and Contract Change Orders (CCO).

4.10.13.7 Submittals

Contractor submittals and their corresponding review timelines are outlined in the special provisions.

4.10.13.7.1 Shop Drawings

If PBEs are used, refer to *AASHTO GSABC* Sections 8.2 and 8.5 for shop drawing requirements and assembly plan requirements respectively.

4.10.13.7.2 Temporary Supports

Refer to *AASHTO GSABC* Section 8.6.1, *Standard Specification* Section 48-3, and the *Falsework Manual* for temporary support system requirements. In addition, the temporary support submittal shall include the following:

- Analysis and design of temporary supports for temporary loads
- Settlement report for temporary supports founded on shallow foundations
- Settlement monitoring plan and means for vertical adjustment

4.10.13.7.3 Work Plans

Work plans are prepared by the contractor based on the requirements set forth in the project plans and specifications. Work plans that may be required for lateral slide projects include plans for assembly, mock-ups, and materials such as RSC and UHPC.

4.10.13.7.3.1 Lateral Slide Assembly Plan

Refer to *AASHTO GSABC* Section 8.6 and the *Slide-In Bridge Construction Guidelines* (FHWA 2013) for lateral slide plan submittal requirements. In addition, the lateral slide plan shall include the following:

- Assembly tolerances;
- Final layout and jacking point locations;
- Lifting and handling details for prefabricated elements;
- Geometric control plan;
- Geotechnical assessment;
- Trial slide plan;
- Communication plan;

- Assembly schedule including a sequence of operations;
- Organization chart and lists of personnel including experience and training;
- Operational checklists;
- Contingency plans; and
- Calibration plots of the hydraulic jacks.

4.10.14 Lateral Slide Checklists

The checklists provided in Appendix B may be used to develop, evaluate, design, deliver contract plans, and provide construction support for lateral slide projects.

4.10.15 Examples

4.10.15.1 Caltrans Projects

Several ABC projects that utilized lateral slide systems have been built in California. Plans, specifications and bid data for some of these projects are available on the Caltrans Project Bucket Search webpage.

Jacoby Creek Bridge (Contract Number: 01-0E0004)

- Single span precast prestressed concrete box girders
- Concrete composite topping slab
- New bridge superstructure built off alignment to carry detoured traffic during existing bridge removal

San Francisco Bay Bridge East and West Tie-ins at the Yerba Buena Tunnel (Contract Number 04-0120T4) Bridge Number 34-0006.

- Multiple-span cast-in-place prestressed concrete box girder
- Superstructure, lateral slide
- Lateral slide total weight of 13,000 kips

Hardscrabble Creek Bridge (Contract Number: 01-293144)

- Single span cast-in-place prestressed concrete box girder bridge
- Span length of 128 feet

- New bridge superstructure built off alignment carried detoured traffic during existing bridge removal

4.10.15.2 Out-of-State Lateral Slide Projects

A project database search for ABC projects using lateral slide installations can be found on the ABC UTC Project and Research Databases webpage.

Table 4.10.15.2-1 contains a list of notable ABC projects built in other states using the lateral slide method.

Table 4.10.15.2-1 Out-of-State Lateral Slide Projects

Project	Superstructure	Substructure	Project Delivery / Contracting
Camp Creek Bridge, Iowa, 2019	Single span bridge with precast/prestressed concrete bulb-tee girders	Prefabricated integral abutments with steel driven piles and UHPC connection with the diaphragms	Design-bid-build
Poplar Street Bridge, Missouri, 2019	Single-span (172 feet) full-width lightweight concrete decked steel beam unit	Abutments were built on cast-in-place spread footing foundations with full-height cast-in-place wingwalls	CMGC
BNSF Bridge Replacement, Washington, 2017	Three span steel truss railroad bridge	Cast-in-place bent caps, abutments, and driven steel piles	Design-bid-build
115-Gar Creek Bridge, Illinois, 2017	Single span bridge on steel wide flange beams and a cast-in-place deck	Precast concrete abutments on driven steel piles	Design-bid-build
H145 Gila River Bridge, Arizona, 2015	Two span precast prestressed concrete girder bridge with approach slabs	Semi-integral cast-in-place concrete abutments and cast-in-place piers on drilled shafts	CMGC, SHRP2 funding
Basnettville Bridge, West Virginia, 2016	Single-span steel wide-flange beams with a cast-in-place concrete deck	Precast integral abutment on steel piles and cast-in-place approach slabs	Design-bid-build, Incentive / disincentive clauses; No Excuse bonus; VECP Redesign
Cottonwood Creek Bridge, Oklahoma, 2014	Three-span precast prestressed concrete girder bridge	Cast-in-place concrete abutments and piers on drilled piles	Design-bid-build
Milton Madison Bridge, Ohio, 2013	Four long-span steel truss (727 ft max) bridge spans	Rehabilitated existing piers	Design-Build, A+B procurement
I-84 Dingle Road Undercrossing, New York, 2014	Single span precast prestressed decked concrete double-tee girders with UHPC closure joints	Integral prefabricated abutments on spread footings with precast concrete approach slabs	Design-bid-build, SHRP 2 Funding
Larpenteur Avenue Bridge, Minnesota, 2014	Two-span precast prestressed concrete bulb-tee girder spans	Cast-in-place concrete abutments, bent caps and columns on spread footings	Design-bid-build

4.11 BRIDGE MOVES WITH SELF PROPELLED MODULAR TRANSPORTER

This section provides self-propelled modular transporter (SPMT) bridge move guidance and identifies resources for the development of design plans and specifications for successful ABC implementation. The focus of this section is on constructability and cost effectiveness through use of SPMT. For more specific information, refer to the *AASHTO GSABC*, the *Guidelines for Dynamic Effects for Bridge Systems* (Culmo et al. 2017b) and the *Manual on the use of Self-Propelled Modular Transporters to Remove and Replace Bridges* (FHWA 2007).

4.11.1 Introduction

SPMTs are high capacity, self-leveling, multi-axle, self-propelled modular trailers that have a high degree of precision and maneuverability and that can be operated remotely without the aid of a tractor for propulsion. SPMT systems can move in any direction and can pivot 360 degrees as needed to lift, carry, and set very large and heavy loads. SPMT units can be linked laterally or longitudinally to achieve the number and configuration of axle lines to move single span bridges, multi-span bridges, trusses, and arches. The advantages of using SPMTs are outlined in Section 3.2.2.2.

4.11.2 Roles and Responsibilities for SPMT Systems

Bridge components designed for SPMT moves shall meet the *AASHTO-CA BDS* and *STPs* during all stages of the move, including construction on the temporary supports, lifting off the supports, transportation along the travel path, and lowering onto the permanent bearings. The PE is responsible for the design of the entire bridge, verification that the bridge can be reasonably moved within the proposed work zone, and for providing the requirements of the contractor to complete the construction.

For PE responsibilities in the design using SPMTs, refer to *AASHTO GSABC* Sections 1.5 and 4.5, and the following:

- Determine the feasibility of a staging area and a travel path to accommodate the assumed layout of the SPMT system.
- Make assumptions on the methods of lifting and moving the bridge using SPMTs.
- Design the bridge to resist the lifting and moving process based on the assumed layout of the SPMTs.
- Specify the monitoring plan and maximum bearing pressure along the travel path.
- State all assumptions on the lifting and moving of the bridge on the design plans. The plans shall also state the variations in the lifting and moving methods which will require an evaluation of the bridge by the contractor.

- Develop the specification of element tolerances, erection tolerances, assembly tolerances, and joint width tolerances.

The PE should consider the possibility of removing the existing structure and transporting it using SPMTs to the BSA where it can be demolished. Considerations for SPMT layout, BSA, travel path (TP), and design check for the existing structure on temporary supports is similar to that for the replacement structure. Refer to *AASHTO GSABC* Section 1.5.2 for the contractor's responsibilities for SPMT system moves.

The roles and responsibilities of the owner and contractor in the design and construction phases of the project is provided in Table 4.11.2-1.

Table 4.11.2-1 SPMT Roles and Responsibilities

Category	Description of Responsibility	Owner	Contractor
Advance Planning Study / Type Selection	Feasibility of using SPMT in project	✓	--
	Preliminary cost estimate and project constraints	✓	--
BSA and TP	Investigate the potential BSA and TP for the bridge move	✓	--
	Structural analysis of bridge along TP	✓	--
	Set allowable bearing stress limits on BSA and TP	✓	--
	Finalize BSA and TP	--	✓
	Mitigation of affected areas at BSA and TP	--	✓
	Protection of structure along TP	--	✓
New Structure Analysis and Design	Analysis of new structure for all boundary conditions during construction, lift, move, and placement	✓	--
	Design of all elements and connections for defined lift points	✓	--
	Define stress, deflection, and twist limits during move	✓	--
	Provide full set of contract documents including plans and specifications	✓	--
	Design of elements due to support location deviation	--	✓
Tolerances	Specification of element tolerances, erection tolerances, and joint width tolerances	✓	--
	Survey, implementation, and verification	--	✓
Materials	Specification of materials	✓	--
	Procurement, submittal, approval, and construction	--	✓
Temporary Supports	Allowable bearing capacity; proposed foundation	--	✓
	Design and fabrication of all temporary supports	--	✓
SPMT and other equipment	Preliminary SPMT layout; feasibility of SPMT move along TP	✓	--

Category	Description of Responsibility	Owner	Contractor
	Design of structure to account for SPMT dynamic forces	✓	--
	Setup and operation of all equipment	--	✓
	Contingency plan for equipment failure	--	✓
SPMT Move	Preliminary feasibility evaluation and approval of work plan proposed by contractor	✓	--
	Lifting and handling work plan submittal, setup, and execution	--	✓
	Review and authorization of the SPMT move work plan	✓	--
Geometric Control	Specification for geometric control and monitoring including deflection and twist throughout construction	✓	--
	Submittal, setup, approval, and execution of geometric control plan	--	✓
	Review and authorization of geometric control plan	✓	--

4.11.3 Site Considerations

The PE is responsible for verifying that the project site can accommodate the SPMT move. The PE shall work with the District PE and Right of Way (ROW) liaison to ensure that the size of the BSA is sufficient for construction of the bridge system, installation of temporary supports, assembly of the SPMT units and falsework, and setup of cranes and equipment. The BSA should be adjacent to the bridge site, but may be located away from the bridge site if there is a feasible TP.

Some site considerations for SPMT system moves include:

- Profile grades
- Geotechnical characteristics (bearing pressure)
- Utilities;
- Real estate
- Obstructions
- Traffic closures

The ground surface at the BSA and along the TP shall be relatively flat and have adequate bearing capacity. Profile and cross slope grades exceeding four percent can be difficult to traverse. SPMTs have a self-leveling mechanism, but uneven grades should be avoided to minimize deflections and twist. The SPMTs account for travel path grade variations via the hydraulic stroke of the units. The hydraulic stroke limit can be between 18 and 24 inches. The variation on roadway grades across the footprint of the entire SPMT layout must be considered and kept within the stroke limit. For more information on the staging area and travel path investigation, refer to *AASHTO GSABC* Section 1.5.1.2.

4.11.4 SPMT Systems

SPMT systems are made up of modular units which can be linked laterally or longitudinally to achieve the number and configuration of axle lines to move the structure on a controller levelled platform. The controller has four basic commands: steer, lift, drive, and brake. The computerized electronic steering capability allows movement in any horizontal direction: straight forward and backward, transversely, diagonally, and at any angle as well as carousel steering. Each pair of wheels can pivot 60 degrees about its support point.

The dimensions and capacities of SPMT systems vary depending on the manufacturer. The preliminary layout of the SPMT platform shall be based on *AASHTO GSABC* Section 1.5.1.2.1. Based on the transported load, the PE estimates the preliminary SPMT layout in terms of width, length, and number of axle lines. For design, round up the number of axle lines by approximately ten percent to account for the potential of a local failure during a move. A layout calculation example is available in *AASHTO GSABC* Section C1.5.1.2.1.

4.11.5 Stages of Construction

The stages of construction include:

1. Preparation of the BSA for the SPMT units, temporary supports, cranes, and equipment;
2. Construction of the replacement structure on temporary supports;
3. SPMT move along the TP; and
4. Placement of the structure in its final position and connection to the substructure.

4.11.5.1 Bridge Staging Area and Travel Path

Considerations in selecting a BSA are discussed in Section 4.11.3. Additional information and requirements on investigating BSA and TP for SPMTs are available in the *AASHTO GSABC* Section 1.5.1.2.3.

The axle line load capacity of SPMT units is typically 30 tons, exerting a ground pressure of 1,500 to 2,000 pounds per square foot. Geotechnical investigation of roadways along the TP may not be required since the wheel loads on the SPMTs are typically less than wheel loads of an HL-93 vehicle. Geotechnical investigation of unpaved roads along the TP shall be conducted. Soil improvements or steel plating may be used when additional ground bearing capacity is required.

The required ground bearing pressures in the BSA and along the TP are based on the weight of the SPMT units, the structure, the falsework, and the vertical dynamic effects. Refer to the *Guidelines for Dynamic Effects for Bridge Systems* (Culmo et al. 2017b) and the *Manual on the use of Self-Propelled Modular Transporters to Remove and Replace Bridges* (FHWA 2007) for methods of determining SPMT loads.

4.11.5.2 Temporary Supports for Construction

Temporary supports include equipment/falsework used to support the structure during construction in the BSA and used to move a bridge with SPMTs. The design responsibility of the temporary supports falls under the contractor's means and methods. The requirements in *Standard Specifications* Section 48-3, the *Caltrans Falsework Manual* shall be followed. The temporary supports shall be designed to provide the required stability of the SPMT units as well as resistance to horizontal loads (wind, dynamic loads, etc.).

The PE shall verify, in coordination with the geotechnical engineer, that adequate bearing can be achieved at the temporary support locations. The PE shall include a recommended foundation type for the temporary supports. If deep foundations are required, the plans shall indicate approximate pile sizes and allowable pile loads. If shallow foundations are appropriate, the allowable bearing pressures shall be stated. Additional information and requirements can be found in the *AASHTO GSABC* Section 1.5.1.2.4.

4.11.5.3 SPMT Move

The bridge system is subject to loads during the move, including vertical dynamic loads which are added to the dead load to account for movement on uneven surfaces. The design of the bridge system for dynamic forces is based on a response spectrum approach that accounts for the natural frequency of the bridge system, the supporting falsework, and the SPMTs. The *AASHTO GSABC* and *Guidelines for the Dynamic Effects for Bridge Systems* (Culmo et al. 2017a) contain recommendations for dynamics considerations in the design and detailing of the bridge system, which utilizes an idealized spectral curve. Note that the *Manual on the use of Self-Propelled Modular Transporters to Remove and Replace Bridges* (FHWA 2007) recommends a vertical dynamic amplification factor of 15%, which is a conservative estimate. The vertical dynamic load factors applied to the bridge for service and strength limit states are available in the *AASHTO GSABC* Section 2.4.2.3.

Locations of the bridge system supports in the BSA and the lift points used to support the bridge system on the SPMT do not necessarily coincide. The lift points are typically placed within the span, which creates a cantilever, and the bridge system is designed for the effects of having the bridge supported in this state. The effects of locating the lift points within the span are illustrated in *AASHTO GSABC* Section 1.5.1.2.4.

The lift points for the SPMT move should be chosen to limit tension in the deck. The maximum length of bridge cantilevers should be limited to approximately 20% of the span length being supported. This minimizes the cantilevered portion of the bridge and prevents excessive tension in the deck.

Auxiliary connections to the bridge during the SPMT move, such as chains, struts, or diaphragm/cross braces, can change the global support boundary conditions and the structural response. The length of the bearing area, the number and type of bearings, and the type of connection to the temporary supports may also affect the structural response. The bridge system is designed based on the support conditions noted in the contract plans and the corresponding capacity. Addition of diaphragms or braces for stability during the SMPT move or changes to the lift points proposed by the contractor shall be supplemented by detailed calculations to demonstrate that the additional support points do not adversely affect the bridge system.

Installation tolerances should be accounted for when evaluating the SPMT move along the TP, including avoidance of obstacles along the TP, and fit up with the new substructure. Fabrication tolerances, erection tolerances, and joint width tolerances are shown on the plans or included in the special provisions.

The bridge is monitored during the SPMT move to ensure that the deflections and twists are kept within acceptable limits, as discussed in *AASHTO GSABC* Section 1.5.2.3.

4.11.5.4 Final Location

The substructure work is usually performed in tandem with the superstructure work and shall account for placement of the bridge from the SPMT and how the grade, rotation, and geometry may be affected by bearing areas, shear keys, and joints. For integral abutments, a closure pour is required between the substructure and the superstructure before opening the bridge to traffic. For non-integral abutments, the superstructure may be placed on the bearings and the bridge opened to traffic before placement of shear keys. Exterior shear keys constructed after bridge placement are preferred. Placement tolerances shall be provided in the bearing design, design of connecting elements, location of shear keys, and reinforcement details at the closures.

The bearings shall be detailed to allow for vertical adjustments. This can be accommodated through use of leveling plates, shim plates, and anchor bolts with leveling nuts. The final bridge configuration shall be verified by the contractor using a detailed survey for both vertical and horizontal geometry.

4.11.5.5 Structure Removal

Transporting the existing structure to the BSA with SPMTs can be a significantly faster and safer method of removing the existing bridge. Performing the bridge demolition in the BSA eliminates the need to protect the underlying roadway and substructure. Portions of the existing bridge to be moved and the lift points shall be analyzed for safe transport on the SPMT. It might be necessary to strengthen areas of the bridge that are overstressed during the lifting and moving operations. Since the SPMT rigging has to be changed for the new structure, this activity must be accounted for when estimating closure duration.

4.11.6 Contract Plans

Refer to *AASHTO GSABC* Section 4.5 for design and detailing items to include in the plans along with the following:

- Weight and center of gravity of the portion of the bridge to be moved
- Preliminary SPMT sizes and layout, and design assumptions that may affect the SPMT layout
- Locations of support for the bridge in the BSA
- Assumed static reactions at each support point during the move, and variation in the reactions that result from the maximum allowable twist
- Assumed TP for the SPMTs
- Geotechnical information for the BSA and TP including results of subsurface investigations (log of test borings)

4.11.7 Specifications

A project using SPMTs will require project specific *special provisions*. The following sections discuss SPMT related special provisions to include in the project contract.

4.11.7.1 Prior SPMT Move Experience

The contractor shall provide prior SPMT move experience. The prior experience requirement ensures the that the contractor is capable of performing the SPMT move thereby minimizing the risk of inexperience related issues and delays during the move. Inexperienced prime contractor can attain the necessary prior experience through bridge move subcontractors. The contractor’s submittal shall demonstrate that the SPMT move subcontractor is familiar with temporary support design, SPMT layout and setup, monitoring during a move, and successful completion of prior projects.

4.11.7.2 Deflection Monitoring

The Contractor shall design and detail a system to continuously monitor deflections and twist of the bridge system during the bridge move. The monitoring system shall account for the following:

- The temporary supports must provide equal load distribution among beams and have adequate foundation capacity to prevent settlement before, during, and after construction of the superstructure. Monitoring shall be in place to detect settlement.
- Monitoring of defections are required for a bridge move to ensure that allowable stresses and defections are not exceeded (for example, to avoid deck cracking).
- Monitoring of geometric distortion during the move is required to ensure that excessive variation in planar supports between adjacent SPMT support points do not result in stresses exceeding the allowable limits. Reference points for geometric control of the bridge and ground shall be provided.
- Any change in the behavior of the structure, particularly appearance of any new cracks during the SPMT move.

The monitoring submittal shall provide description of the measuring equipment and procedures used and their corresponding tolerances and limits.

4.11.7.3 Communication During Move

To illustrate how the team will communicate during the move, the contractor shall provide a communication plan that includes a contact list of approved personnel and the contractor's authorized representative. The communication plan is essential for establishing the protocol for stopping the SPMT move if the differential deflection or twist is about to exceed allowable limits or if bridge is out of tolerances during the move. The PE shall be on-call 24/7, and may be required to be present at the site, during the closure and move.

4.11.7.4 Trial Move

A trial move is where the bridge system is lifted, transported a short distance in the BSA, and returned to the temporary supports prior to the closure. Additional closure time may be necessary for the trial move. A trial move allows the contractor to:

- Become familiar and educate the crew with means and methods
- Confirm all equipment is working
- Determine equipment stroke limits
- Confirm directional control through lift and rotational trial

The trial move shall demonstrate through movement of the bridge on the SPMT unit that the contractor has full control of the movements and is able to correct excessive deflections and twist of the structure during the move.

The trial move must be performed no less than five days prior to the full move to allow for modifications to the system and resubmittal of work plans as required. The crew of the final move shall be the same as that from the trial move.

4.11.7.5 Contingency Plan

The contractor shall have contingency plans to address potential problems such as insufficient equipment, equipment breakdowns, inclement weather, and personnel unavailability, as well as logistical issues related to timing of materials, equipment, public notices, and multiple moves within the same window. Access for emergency vehicles should be considered if the detour is long. A detour route for extended closure in the event of move and placement issues must be developed by the District. The SPMT company shall anticipate out-of-service conditions such as flats and failures and develop contingency plans accordingly to ensure that the operator can manually coordinate the SPMT units as needed to complete the bridge move.

4.11.7.6 Mandatory Pre-bid Meeting

The PDT team should consider holding a mandatory pre-bid meeting and site visit to highlight items that require special expertise and those that impact cost and schedule. This meeting may also be used to highlight the design assumptions so that the contractor can bid the project accordingly and avoid unnecessary delays later to address Request for Information (RFI) and Contract Change Orders (CCO). See Section 4.17.2 for further information on pre-bid meetings.

4.11.7.7 Submittals

Contractor submittals and their corresponding review timelines are in the project specifications. Further information on assembly plan document developed by the contractor can be found in *AASHTO GSABC* Section 8.6 and in the following.

4.11.7.7.1 Shop Drawings

If PBEs are used, refer to *AASHTO GSABC* Sections 8.2 and 8.5 for shop drawing requirements and assembly plan requirements, respectively.

4.11.7.7.2 Temporary Support

Refer to *Standard Specification* Section 48-3, the *Falsework Manual*, *AASHTO GSABC* Section 8.6 and the following for temporary support submittal requirements:

- Analysis and design of falsework for temporary loads, including seismic effects;
- Geotechnical assessment at staging area;

- Temporary supports at staging area;
- Settlement report for temporary supports founded on shallow foundations; and
- Settlement monitoring.

4.11.7.7.3 Work Plans

Work plans that may be required for SPMT projects include plans for assembly, mock-ups, and materials such as RSC and UHPC.

4.11.7.7.3.1 SPMT Installation Plan

Refer to *AASHTO GSABC* Section 8.6 for SPMT Installation Plan requirements. In addition, the SPMT Installation Plan shall include the following:

- Erection tolerances;
- Final SPMT layout and lift point locations;
- Path and direction of motion;
- Lifting and handling of prefabricated elements;
- Geometric control plan;
- Moving equipment and services;
- Contingency planning for incident management;
- Trial move;
- Communication plan; and
- Assembly schedule.

4.11.8 SPMT Checklist

The SPMT checklists included in Appendix C may be used to develop, evaluate, design, deliver contract plans, and provide construction support for SPMT projects. These checklists were developed by UDOT for ABC Heavy Lift Projects to address basic requirements and common concerns. The checklists have been updated for the Caltrans PS&E delivery process.

4.11.9 Examples

4.11.9.1 I-215 Highgrove UP

The Highgrove Underpass on I-215 accommodates two Burlington Northern Santa Fe (BNSF) railroad tracks over the I-215 carrying three lanes of traffic in each direction. The existing four-span bridge was replaced by a two-span steel through truss bridge to accommodate six lanes of traffic each direction on the I-215. The original plan was to use staged construction by installing a shoofly underpass, shift the railroad traffic over to the shoofly underpass and then construct the replaced underpass. During construction, the contractor made a value engineering change proposal to use SPMTs to reduce the number of construction stages and overall construction time by assembling the steel truss bridge superstructure off-site and then moving it to the final configuration. The benefits of this construction method were:

- Eliminated the construction of shoofly bridge spans and subsequent demolition adjacent to live traffic.
- This phasing accommodated Caltrans closures and traffic control schedule as previously planned.
- Reduced exposure to traveling public.
- 80% reduced interface with RR operations and potential for track fouling.
- Reduced cost for railroad flagmen.
- The entire process of building the shoofly, switching the railroad tracks, demolishing the existing bridge, and building the new permanent bridges took approximately eight months. The Contractor estimated approximately 20 months for construction without SPMT, and the material delay would have added another 12 months due to the fourth quarter railroad shutdowns.
- By using SPMT, the overall cost savings to the State of California was approximately $400,000, and the overall time savings was approximately 20 months.

The truss bridge move is shown in Figure 4.11.2. Four KAMAG Transporttechnik SPMTs with 24 total axles (1.61 million pounds gross weight) were used. The project challenges included analysis of stress reversals during jacking with full dead load, skewed geometry during erection, and phasing accommodating live tracks at all times.

(a) Truss span in the BSA (b) SPMT move of a truss span

Figure 4.11.9.1-1 SPMT Move of Highgrove Underpass Truss Bridge on SPMTs

4.11.9.2 Out-of-State SPMT Projects

Example projects including lessons learned and case studies of projects using SPMTs for bridge moves performed in other states can be found in the *Manual on the use of Self-Propelled Modular Transporters to Remove and Replace Bridges* (FHWA 2007). A project database search for ABC projects using SPMTs can be found on the ABC UTC Project and Research Databases webpage.

Some of the highlighted SPMT projects are summarized in Table 14.11.9.2-1.

Table 4.11.9.2-1 Out-of-State SPMT Projects

Project	Superstructure	Substructure	Project Delivery / Contracting
Graves Avenue over I-4, Florida, 2006	Two-span (143 feet maximum span) full-width concrete decked beam unit (Florida bulb-tee beams with composite concrete deck)	Conventional cast-in-place reinforced concrete abutments and piers with pretensioned concrete driven pile foundations	Design-bid-build / C+T bidding, Incentive / disincentive clauses
I-215 / 4500 South Bridge, Utah, 2007	Single-span (172 feet) full-width light-weight concrete decked steel beam unit	Abutments were built on cast-in-place spread footing foundations with full-height cast-in-place wingwalls	CMGC
Sauvie Island Bridge, Oregon, 2007	Three-span (365 feet maximum span) steel arch rib with steel box section floated in place (SPMT on barge)	Cast-in-place concrete substructure founded on drilled shafts	Design-bid-build
I-15 Pioneer	Twin two-span (191 feet	Existing structure was	Design-build;

Project	Superstructure	Substructure	Project Delivery / Contracting
Crossing Bridge, Utah, 2010	maximum span) full-width concrete decked prestressed concrete beam unit	removed and the CIP substructure was placed	Alternative Technical Concept, Incentive / disincentive clauses
Willis Avenue Bridge over Harlem River, New York, 2010	Three-span (350 feet maximum span) truss span with deck (steel through-truss swing span with a half-filled steel-grid deck) floated in place (SPMT on barge)	Piers founded on drilled shafts with a steel casing socketed into bedrock supporting a pier cap consisting of a precast concrete pier box filled with cast-in-place concrete	Design-bid-build, Formalized partnering; Value Engineering
Phillipston Bridge, Massachusetts, 2010	Single-span (60.67 feet) full-width concrete decked steel beam unit	Precast abutment cap w/backwall founded on the existing abutments	Design-Build, Incentive / disincentive clauses; No Excuse bonus; Lump Sum bonus
I-15 / Sam White Lane Bridge, Utah 2011	Two-span (177 feet maximum span) full-width light-weight concrete decked steel plate girder beam unit	CIP concrete with concrete-filled pipe pile foundations	Design-Build
Cedar Street Bridge, Massachusetts, 2011	Two-span (41.5 feet maximum span) steel girders with composite high-performance concrete (HPC) deck	Precast abutment caps, precast pier cap	Design-Build, Incentive / disincentive clauses; No Excuse bonus; Lump Sum bonus
I-20 / LA 3249 (Well Road) Bridge, Louisiana, 2011	Three-span (85 feet maximum span) full-width concrete decked steel beam unit	CIP substructure	Design-bid-build / C+T bidding, Lane rental
Maryland Avenue Bridge, Minnesota, 2012	Two-span (102.75 feet maximum span) full-width concrete decked prestressed concrete beam unit	CIP substructure founded on piling	Design-Build, Best Value

The Florida Department of Transportation (FDOT)'s Graves Avenue bridge over I-4 SPMT project was an FHWA case study, as discussed in the *Manual on the use of Self-Propelled Modular Transporters to Remove and Replace Bridges* (FHWA 2007). Some of the lessons learned from this project are as follows:

- Contractually require the road work to keep pace with the accelerated delivery of the bridge.
- Consider allowing a midspan-supported beam assembly at the staging area for composite dead load design of the prefabricated superstructure to improve cross-

section efficiency. Include it as an option in the contract documents. This may save a line of beams but would require additional temporary shoring.

- Design wider substructure caps and wider clearances to facilitate installation.
- Consider permanently attaching the bearing pads to the bottom of the beams in the plant to avoid setting problems on the substructure.
- The contractor should clearly delineate which construction processes are to be completed by the SPMT company.
- The ground at the staging area and along the TP should not be freshly placed, but instead should be compacted early to allow adequate time for settlement.
- Substructures should be built within construction tolerances to ensure proper fit-up with prefabricated superstructures (for example, backwalls should be plumb).
- Set steel plates close to abutment face to provide adequate ground capacity for SPMTs during span-setting operation.
- Adjustment is needed to accommodate the angle of motion due to the SPMT hinged elbow that moves down during setting operations. To avoid that angle of motion, the contractor should consider using synchronized vertical jacks mounted on the SPMT platform's top cribbing instead of the SPMT hydraulic system to lower the span to set it.
- Spans should be driven into position high enough to clear variable height girder seats arranged to accommodate the roadway crown and then lowered into the final position.
- Consider use of laser guidance to line up superstructure with the abutment backwall.

4.12 LONGITUDINAL/INCREMENTAL LAUNCH METHOD

This section provides general guidance on the longitudinal/incremental launch method and identifies resources for the Advance Planning Study (APS) development and PE/contractor responsibilities. For more specific information on longitudinal launch refer to *Bridge Construction Practices using Incremental Launching* (La Violette et al. 2007). For general information on contingency plans, prior experience, deflection monitoring, work plans, etc. refer to Sections 4.10 and 4.11 of this manual and the *AASHTO GSABC*.

4.12.1 Introduction

The ILM is a highly mechanized erection method in which the bridge superstructure is fabricated in sections at a staging area behind one of the abutments. Each new unit is fabricated directly against the preceding one and then incrementally pushed forward the length of one unit until the full bridge is complete. This principle has been used more commonly for the construction of steel bridges and prestressed concrete bridge superstructures. The alternating stresses which occur when the bridge is slid forwards can be resisted more efficiently by steel structures or, alternatively, by strategic placement of prestressing tendons in concrete structures. The method is more expensive than conventional construction due to the need for specialized equipment and for additional analysis and design effort. In some instances, such as crossing over an inaccessible or environmentally sensitive area, it may be the most effective construction method.

The ILM is specially developed for use with highly modular equipment and an automatic control system. The incremental launching system has adjustment capacity in vertical, longitudinal, and transverse directions, power delivered by hydraulic jacks, and is automatically controlled. The ILM system is composed of an upper sliding part, lower supporting part, and hydraulic equipment that incrementally slides the upper part. A centralized computer control system connected to pressure, displacement, and angle sensors, is used to ensure the simultaneous operation of the entire launching system.

4.12.2 Roles and Responsibilities for ILM

The distribution of PE and Contractor responsibilities for ILM are similar to that for lateral slides and SPMT moves, as outlined in Sections 4.10 and 4.11, respectively, of this manual and in the *AASHTO GSABC*. The bridge analysis and design shall meet all *AASHTO-CA BDS* requirements or the Project Specific Design Criteria during all stages of construction including the final completed stage. The PE is responsible for the design of the entire bridge over the construction stages, verification that the bridge can be reasonably launched within the proposed work zone, and for providing the requirements of the contractor to complete the construction.

An outline of the roles and responsibilities of the Owner and the Contractor in the design and construction phases of the project is provided in Table 4.12.7-1.

Table 4.12.2-1 ILM Roles and Responsibilities

Category	Description of Responsibility	Owner	Contractor
Advance Planning Study / Type Selection	Feasibility of using ILM in project	✓	--
	Preliminary cost estimate and project constraints	✓	--
Staging Area	Investigate the potential staging area behind abutment and cantilever length	✓	--
	Structural analysis of bridge	✓	--
	Set allowable contact stress limits	✓	--
	Finalize staging area and equipment configuration	--	✓
New Structure Analysis and	Analysis of new structure for all boundary conditions during construction, launch, and final configuration	✓	--

Design	Design of all elements and connections as they move along the launching support	✓	--
	Define deflection and lateral displacement limits	✓	--
	Provide full set of contract documents including plans and specifications	✓	--
	Design of elements due to support location deviation	--	✓
Tolerances	Specification of element tolerances and erection tolerances	✓	--
	Survey, implementation, and verification	--	✓
Materials	Specification of materials	✓	--
	Procurement, submittal, approval, and construction	--	✓
Temporary Supports	Design criteria for temporary supports	✓	--
	Design and fabrication of all temporary supports	--	✓
Launching equipment	Preliminary layout; feasibility of launching	✓	--
	Setup and operation of all equipment	--	✓
	Contingency plan for equipment failure	--	✓
Launching operation	Preliminary feasibility evaluation and authorization of work plan proposed by contractor	✓	--
	Launching work plan setup, submittal, and execution	--	✓
Ground Improvements	Identification, design, and implementation of any ground improvements	--	✓
Contingency	Contingency plan in case of equipment malfunction or failure	--	✓
Geometric Control	Specification for geometric control and monitoring including deflection and strain throughout construction.	✓	--
	Submittal, setup, and execution of geometric control plan	--	✓
	Review and authorization of geometric control plan	Add check mark	

4.12.3 Site Considerations

Verification that the project site can accommodate a successful launch behind one of the abutments requires coordination with the District PE and ROW liaison. The available BSA behind the abutment must be sufficient to accommodate the construction of the bridge system, assembly area for the launch equipment, and adequate areas for cranes and other equipment.

Since the structure is fabricated and pushed or pulled forward from behind the abutment, the ILM is suitable for alignments which are tangent in both horizontal and vertical planes. Although more challenging, it is possible to erect a curved bridge using ILM if the curve is constant. To eliminate the relocation and adjustment of lateral bearings, these surfaces must remain aligned with the superstructure during launching operations. A bridge constructed using ILM must be designed with one of the following alignments:

- Tangent in plan and tangent or parabolic in profile
- Circular in plan and horizontal in profile (no launch gradient)
- Circular in plan and inclined with respect to the horizontal plane
- Curvilinear both in plan and in profile

4.12.4 Design Considerations

During erection of a bridge using ILM, the superstructure acts as a continuous beam supported on roller or sliding bearings and is transversely restrained by lateral guides that prevent drifting movement. The force reactions at the substructure, over which the bridge is launched, include three components and shall be considered in the design:

- Vertical loads from the dead load support reaction
- Longitudinal loads generated by the friction and other resistance forces in the bearings as well as the local grade of the launch surface
- Transverse horizontal component generated by the lateral guide system

On some steel girder bridge projects, as the tapered transition ramp (launching nose) encounters the pier roller bearing at the next support during the ILM, a horizontal component of the substructure forces is generated on the superstructure. This component must be combined with the design forces. Any constraint eccentricity (vertical misplacement of launching bearings or transverse misalignment of lateral guides) will cause unintended secondary stresses and may cause launching problems such as excessive wear of bearing devices (La Violette et al. 2007).

Some other non-typical design considerations for bridges constructed by the ILM include:

- **Lateral loads**: Temporary lateral bracing at the supports shall be able to resist lateral loads as required in *STP* 17-3. This will accommodate for the forces generated by wind loads, fabrication, and assembly tolerances for misalignments and out of plane curvature (buckling) for steel girder bridges.
- **Reversible launch and counterweight**. To reduce the chance that a bridge is left in a vulnerable position with a long cantilever for an extended period of time due to a mechanical problem or other site challenges, a reversible launching system is recommended and the longitudinal grade must be considered. Counterweights may also be required for balancing the cantilever and end spans.

- **Temporary supports**. Temporary supports within the span may be required for longer spans but should be avoided, if possible, due to cost implications.
- **Contact stresses**. The design shall consider large, localized contact stresses at the bottom flange or soffit near the launching support. For steel girders, web crippling and web buckling effects shall also be considered. Since the girders are launched incrementally over the supports, the entire length of the girder will be subjected to these contact stresses at some point of construction.
- **Friction**. Use of a low friction roller system is recommended. Support rollers are typically assumed to provide a frictional resistance of five percent when rolling across a surface covered with steel plating that is sufficiently stiff to resist deformations due to the heavily concentrated load (La Violette et al. 2007).
- **Longitudinal grade**. Launching a bridge along a positive grade (uphill) offers safety and erection advantages by preventing the bridge from rolling unencumbered in the event of a mechanical failure. Additional jacking force will be required to overcome the friction in the roller system along with the energy to push the bridge uphill.
- **Erection analysis**. An envelope of flexural moment and shear forces, and deflections must be calculated over the length of the superstructure as it is launched. These calculations are compounded in the case of a bridge constructed with post-tensioned concrete as the additional effects of creep and shrinkage must be included along with thermal gradient concerns (La Violette et al. 2007).
- **Displacement control**. A time dependent staged construction analysis is required for the ILM. Based on the analysis, a displacement control shall be provided to the contractor for monitoring during the launch.
- **Vertical Jacking**. If the bridge is launched from the roadway grade, it will require lowering after the launch which can be a challenge if deep slender girders are used.

4.12.5 Contract Plans

AASHTO GSABC Section 4 and Sections 4.10 and 4.11 of this manual provide guidance on the design and detailing items to be included in the plans of bridge system moves. Non-typical design information to be included in the plans for ILM systems include:

- Weight and center of gravity of the bridge segments
- Size and weight of the launching nose
- Location of temporary support(s)
- Preliminary sizes and layout of the segments

- Changes to the launch system that would require a structural evaluation of the bridge system by the Contractor
- Maximum allowable loads at the supports and variation in the reactions at key stages during the launch
- Maximum allowable deflections
- Assumed staging area including schematic details of the temporary supports for assembly in the staging area
- Location and type of monitoring sensors

4.12.6 Specifications

A project using ILM will require project specific special provisions. Recommended ILM related special provisions are discussed in the following sections.

4.12.6.1 Prior Launch Experience

The contractor shall provide prior ILM experience to demonstrate familiarity and competence in construction of similar bridges. Prior experience is available to inexperienced prime contractors through bridge move subcontractors. The experience shall demonstrate that the subcontractor is familiar with temporary support design, launching nose layout and setup, monitoring during launch, and successful completion of prior ILM project(s).

4.12.6.2 Deflection Monitoring

The use of structural monitoring during the incremental launching stages will supplement visual observations and may provide critical alerts if the erection process is not going as planned and provide validation of the design assumptions and construction process. The contractor shall design and detail a system to digitally monitor the incremental launch of the structure by using tilt and displacement sensors. The measurement system shall be capable of continuous monitoring during the launch. The monitoring process shall:

- Provide reasonable access and assistance to the monitoring staff for coordination among the contractor, the monitoring consultant, and the PE
- Monitor of deflection, tilt, and strain used to verify that allowable stresses and defections are not exceeded and to alert the contractor/ PE/ owner of potential problems
- Provide a pre-launch and post-launch digital survey of the structure
- Monitor the plumbness of the piers during and after launching operations
- Monitor the cross-frame members, girders, and connections of steel bridge superstructures to provide key information about the bridge system stability

- Monitor of the cantilevered portion of the superstructure to provide useful information regarding potential problems
- Monitor the displacement of the piers due to the touchdown forces during the launch and during the passage of the superstructure over the pier

The monitoring submittal shall provide a description of the measuring and recording equipment and procedures used and their corresponding tolerances and limits.

4.12.6.3 Communication During Launch

The Contractor shall provide a communication plan including a contact list of approved personnel and the contractor's authorized representative to illustrate how the team will communicate during the launch. Communication is essential for stopping the launch operation if the differential deflection or twist is about to exceed allowable movement or if bridge is out of tolerances during the launch. The contractor must designate a launch director who will control all launch activities including securing of the superstructure at the end of shift during a multi-shift activity.

The PE should be on-call 24/7 during the trial launch and is recommended to be present at the site during the launch. Communication is essential if the deflection is about to exceed allowable movement or if the bridge is out of tolerances during the launching operation so that appropriate countermeasures can be adopted.

4.12.6.4 Trial Launch

The trial launch, as detailed in the special provisions, is intended for the contractor to:

- Become familiar and educate the crew with means and methods
- Verify breakaway and dynamic friction
- Confirm all equipment is working
- Determine equipment limits
- Confirm directional control
- Confirm that the monitoring system is working

The trial launch shall demonstrate of the bridge that the contractor has full control of the bridge movements and is able to stop and make corrective actions to the launch. A trial launch of one to two feet is typically enough to exceed the static friction forces and demonstrate control of the launch.

4.12.6.5 Contingency Plan

The contractor shall have contingency plans to address potential unplanned incidents such as insufficient equipment, equipment breakdowns, inclement weather, and personnel unavailability, as well as logistical issues related to timing of material delivery, equipment availability, and public notices. A reversible launching system can be used to aid in making corrective actions.

4.12.6.6 Mandatory Pre-bid Meeting

The PE and SOE should recommend holding a mandatory pre-bid meeting and site visit to highlight items that require special expertise and those that impact cost and schedule. This meeting may also be used to highlight the design assumptions so that the contractor can bid the project accordingly and avoid unnecessary delays later to address Request for Information (RFI) and Contract Change Orders (CCO). See Section 4.17.2 for further information on pre-bid meetings.

4.12.6.7 Submittals

Contractor submittals and their corresponding review timelines are outlined in the special provisions. The submittals shall include shop drawings, temporary support details, and work plans. The ILM submittal requirements are similar to those outlined in Section 4.11.7.7 for SPMT moves.

The submittals should also include independent check calculations of the contractor's launch design, if required in the specifications.

4.12.7 Example

Project summaries and case studies of some bridges erected using the ILM are available in *Bridge Construction Practices Using Incremental Launching* (La Violette et al. 2007) and the ABC UTC Project and Research Databases webpage.

An example in California is the Pfeiffer Canyon Bridge Emergency Replacement project on Highway 1 near Big Sur in Monterey County to replace a concrete box girder bridge that had been damaged by landslides. It was replaced with a steel girder bridge utilizing the ILM. The new 310-foot composite welded steel girder bridge spans the canyon with no interior piers which eliminates the bridge's vulnerability to future landslides. Limited access, restricted canyon crossing in the landslide zone, and limited workspace required the use of non-conventional erection methods. A temporary erection tower was used in the canyon for launching the steel girders.

A girder assembly area behind one of the abutments was used to field splice the transported girder pieces to create the 310-foot span length. The girders were then launched from the abutment across the canyon. Field challenges associated with the project included material procurement, access, utilities, and lowering the bridge on to the abutment seats. Photos of the launching operation are shown in Figure 4.12.7-1.

(a) Launch setup at abutment

(b) Temporary launch tower

(c) Jacking frame

(d) Launching

Figure 4.12.7-1 Incremental Launch of Pfeiffer Canyon Replacement Bridge

Notes and lessons learned from the project include:

- The work was contracted and performed at Time and Materials (Force Account).
- Emergency permits were procured from the California Coastal Commission. Work was performed in accordance with this permit. Environmental impacts were avoided and minimized during construction. Unavoidable impacts were mitigated with planting. Utility relocation was performed after the launch was completed.
- The contractor was selected early, allowing them to participate in the decision process. The department and contractor worked together to modify the design to accommodate changes required for the launch method.
- As the girders were launched from the roadway grade, it was necessary to lower them to the abutment seat, approximately 18 feet vertically. A material that

compresses more uniformly, may be considered as an alternative to 12 by 12 timbers.

- Incorporating some of the temporary launch elements into the final structure may yield time saving benefits. For example, the jack-down frames may be cast in the girder end diaphragms which would eliminate activities associated with their removal and planned bar reinforcement installation.
- Conventional steel girder placement using multiple temporary supports and installing a trestle to support a 600-ton crane was considered but eliminated as an option due to the landslide adjacent to the northern abutment.
- Strengthening of the girders and connections was not required to withstand the stress reversals during the launch. This was partly attributed to the design having thicker unstiffened webs and Caltrans' long-standing policy to design splice plates for the capacity of the thinner plate (not based on loads).
- Steel plate girder superstructure was selected to reduce the dead load/live load (DL/LL) ratio for this long-span structure and to reduce the weight of the components that would be erected in the field.
- The coefficient of friction between the rollers and girders was calculated to be five percent of the launch DL
- The five percent friction coefficient was combined with the seven percent longitudinal slope to design the jacking system.

4.13 FOUNDATIONS AND STRUCTURE BACKFILL

Foundations, earth retaining systems (ERS), and structure backfill are often critical path and high-risk items in ABC projects. Operation of an existing bridge or roadway can restrict access to construct the foundations of a replacement bridge until closure and removal of the existing structure. Further, bridge replacement projects often require raising and widening approach roadway embankments which require time consuming placement, compaction, and testing of fill.

Selecting cost-effective foundations, ERS, and backfill options that expedite schedule and minimize risk is a primary objective of ABC designs. Coordination with roadway, geotechnical, environmental, and other disciplines within the Project Development Team (PDT) is necessary to fully assess the opportunities and challenges associated with each foundation and structure backfill options.

4.13.1 Pile Selection

Ideally, pile foundations should be installed prior to roadway closures since they can take a significant amount of time and are typically associated with significant risk. For example, drilled shafts installed outside of the existing bridge footprint can be used to support a bent cap in a bridge replacement project, as discussed in Section 4.13.3.

The following is a brief description of pile types and the associated challenges and opportunities, as they relate to ABC. These include speed of placement, requirements for access, accuracy of placement, and risks to the schedule. Further guidance on the selection and design of pile foundations is in *STP* 10.7.

4.13.1.1 Cast-in-Drilled-Hole Piles

Cast-in-drilled-hole (CIDH) piles, which include drilled shafts, are used for a wide range of applications. They can be used to support footings with smaller diameter piles with diameters of 24 inches, as shown in the *Standard Plans*, and large diameter shafts with diameters of up to 14 feet. CIDH piles cannot be battered. Low overhead equipment can be used to install CIDH piles under existing superstructures.

In the presence of groundwater, pile inspection using gamma-gamma logging and cross-hole sonic logging methods are used to detect anomalies, or defects, within the pile. Depending on the size and extent of the anomalies, mitigation using jet grouting could be recommended. This is a lengthy process and is not preferred for construction during closures.

CIDH piles can be used to support abutment, bent cap, wingwall, and retaining wall elements for ABC projects.

4.13.1.2 Secant Pile Walls

Secant pile walls consist of closely spaced CIDH piles with intersecting soft piles. Soft piles consist of drilled holes filled with lean concrete backfill. CIDH piles with normal strength concrete and reinforcement are placed between the soft piles to complete the wall.

For ABC, the secant pile wall is installed behind the existing abutment during evening closures prior to the bridge closure, demolition, and replacement. The top of the secant pile wall can be designed to support an abutment seat. Using a similar approach, a soldier pile beam wall can be designed to support an abutment seat, where a permanent concrete facing is installed after removal of the existing bridge abutment. A design exception in accordance with SPD 1-3 is required to use secant pile walls to support an abutment.

4.13.1.3 Driven Steel and Concrete Piles

Driven piles can be installed faster than CIDH because the piles are prefabricated, so there is no cure time and gamma-gamma testing. There are *Standard Plans* of both concrete and steel driven piles for Class 90, 140, and 200 applications. They can be driven in wet or dry conditions, and the driving resistance can be used to verify capacity during installation.

Driven piles can be vertical or battered. The latter being efficient for abutments due to the large lateral load requirement.

Although there have been instances of using driven piles in low-clearance applications, the required connections can make it impractical. Driven piles might not be possible for locations where driving noise and/or vibrations are restricted.

Cast in Steel Shell (CISS) piles consist of driven pipe piles filled with concrete. The pipes can be driven open-ended and subsequently drilled out, or with the end closed with a plate for diameters up to 48 inches. CISS piles are ideal for ABC because the piles can be used as columns or pile extensions, as shown in Figure 4.13.1.3-1. Note that static pile load tests, which may add time to the construction schedule, are required for pile diameters greater than 36 inches. Static pile load tests should be coordinated with the Foundation Testing Branch to ensure that they are accounted for in the construction schedule. If the testing cannot be taken out of the critical path, special arrangements must be made to expedite the testing, review, and approval.

Figure 4.13.1.3-1 CISS Piles supporting a precast concrete bent cap and voided slabs, Old Mountain View Bridge in the City of Sunnyvale (Courtesy of KIE-CON, Inc.)

4.13.1.4 Micropiles

Micropiles are small diameter piles (typically less than 12 inches) that are drilled, grouted, and reinforced with a high-strength threaded bar conforming to *Standard Special*

Provisions. The hole is drilled and cased temporarily to tip. This casing is withdrawn during pouring operations and a portion is left permanently in the upper layers. The equipment used to install micropiles is relatively small and can be installed in tight locations with limited overhead clearance, making them ideal for ABC. They can be installed vertically or battered in wet or dry conditions, and the resulting tension and compression capacity can exceed 500 kips.

Caltrans has not widely used micropiles on new projects because they have very little lateral load resistance. Battered micropiles can provide significant lateral resistance. The use of the micropiles in bridge bents or abutments requires an exception, per *SPD* 1-3.

4.13.1.5 Ground Anchor and Soil Nail Walls

Ground anchor and soil nail walls can be used in combination with the CIDH, driven piles, and micropiles to form an abutment. In this configuration, the piles support a wall cap and support the vertical reaction of the abutment and any lateral loads from the abutment backwall. This configuration requires a design exception in accordance with *SPD* 1-3.

The piles are installed behind the existing abutment during evening closures while the existing bridge is still in operation. After removal of the existing bridge and installation and opening of the new structure, the ground anchor or soil nail wall is installed incrementally as the existing abutment is removed. Thus, nearly all earth pressures from the embankment are resisted by ground anchors or soil nails.

This approach is ideally suited for ABC, as it allows construction of the abutment foundations prior to the bridge closure, thus removing it from the critical path.

4.13.2 Pile Placement Accuracy

Pile placement tolerance is needed to design the corrugated metal pipe void used to connect a pile to a precast concrete footing, bent cap, or abutment wall panel. This tolerance should be indicated in the plans.

Driving tolerances are typically +/- 6 inches, which can be reduced to +/- 3 inches if a driving template or frame is specified (PCI 2014). Therefore, the inner diameter of a corrugated metal pipe used for the pocket of a precast footing or a precast abutment wall panel should be the outside diameter of the pile measured diagonally plus 8 inches, with driving templates or frames specified. This results in one inch of clearance between the pile and the inside of the CMP at maximum driving tolerance. A similar result can be expected for CIDH piles both with and without a template or frame.

4.13.3 Pile Placement Prior to Demolition

Constructing piles prior to demolition of an existing structure eliminates the activity and the associated risks to the schedule from the critical path during closure of the existing bridge.

Large diameter drilled shafts located outside of the existing bridge footprint are ideal for supporting bent caps, as the construction of the piles and the risks associated with inspection are placed outside of the critical path. In this configuration, the shafts can form the foundation of a straddle bent for the replacement structure, which can be effective if the existing bridge width is reasonable.

Drilled or driven piles installed behind the abutment during evening closures while the existing bridge is still in operation can be used to remove the abutment foundations from the critical path. Similarly, piles can be installed through the existing bridge deck prior to demolition.

4.13.4 Using Existing Foundations

The use of existing foundations can be an effective way to rapidly construct bridge foundations. However, a design exception, per SPD 1-3, is required. It is unlikely that existing bridge bents and piers will have seismic critical members that meet the SDC, but the bridge piles and footings may have sufficient resistance if the new columns are pinned to the footings. Abutment stems and footings may be reused with the replacement of the seat and backwall. Prefabricated wall caps can be used, as presented in Section 4.9.4.4.4. A seismic retrofit could be required if existing foundations and substructure elements are used.

There are risks with using existing foundations, and any proposed use requires a thorough investigation. This investigation should include detailed analysis and field testing to verify material strengths. Since some substructure elements may not be accessible prior to bid, the investigation could be performed by the contractor as a first order of work. Some of the risk items include:

- Poor as-built documentation
- Unanticipated corrosion of the rebar and/or piles
- Damage occurring during demolition of existing bridge elements
- Presence of weakened concrete due to alkali-silica reaction
- Foundations may not be accessible for inspection during design and construction
- Service life incompatibility between the existing foundation and the new structure
- Existing footings were overpoured beyond the as-built dimensions

4.13.5 Accelerated Backfill Material

Refer to *AASHTO GSABC* Section 3.8 for a description of accelerated backfill materials. Note that the use of backfill behind the abutment that does not comply with *Standard Specification* Section 19-3 requires a design exception, per *SPD* 1-3.

Placing backfill can be a time-consuming process and occupy the critical path during ABC, as bridge replacement projects often require raising and widening the roadway and the bridge approach embankments. There are several methods of accelerating installation of backfill behind abutments and wingwalls and fill embankments. These methods include the following:

- **Granular backfill** or open-graded fill consists of clean crushed angular stone, which can be placed and compacted in far less time than normally graded fill.
- **Flowable fill** is referred to as lean concrete backfill, per *Standard Specifications* Section 19-3.02I.
- **Lightweight materials**, also referred to as controlled density fill, can be used in areas where geotechnical remediation is required. Refer to *AASHTO GSABC* Section 3.8.3 for a discussion on lightweight materials. Lightweight materials include:
    - **Expanded polystyrene (EPS) foam blocks** which can be installed rapidly and minimize settlement period for compressible subgrades. For seismic analysis, the stiffness of longitudinal soil springs at the abutments should be evaluated if lightweight fill is placed near to the abutment backwall.
    - **Lightweight Cellular Concrete (LCC)** which has a foaming agent that distributes gas uniformly through the mix to control the density. It has been widely used in railroad applications, and it can be used in similar applications as flowable fill. LLC was used on the Echo Summit Sidehill Viaduct Replacement project to backfill the new abutment under the existing structure.

4.13.6 Geosynthetic Reinforced Soil-Integrated Bridge Systems (GRS-IBS)

Caltrans does not allow GRS-IBS systems due to uncertainty of the system’s response during a seismic event.

4.14 BRIDGE REMOVAL

4.14.1 Introduction

Bridge removal in ABC requires careful consideration because it carries significant risk to the schedule during the bridge closure. These risks are primarily due to environmental constraints including restrictions on access, water quality, and noise. Further, uncertain site conditions such as the presence of utilities, hazardous materials, erosion protection, and poor as-built drawings or documentation also have significant schedule risks.

These risks need to be identified during design so that they can be minimized. The following is guidance on how to minimize the risks associated with bridge removal.

4.14.2 As-built Plans

The PE should review all as-built plans and related documentation, as there are details that could impact the schedule. These items include the presence of hazardous materials, such as lead-based paint and asbestos containing materials. Also, the presence of stay-in-place deck forms can make removal more difficult.

As-built plans should be part of the contract documents if they are available. Depending on the quality and the extent of the as-built documents, additional site investigation could be required. Items such as cofferdams, shoring piles, and ground anchors used to support the temporary excavation of the existing structure may have been left in place, but not included in the as-built plans. It is not uncommon for the footings to have been overpoured beyond the as-built plan dimensions.

4.14.3 Site Conditions

The site conditions have a significant impact on the speed at which the existing bridge can be removed. The presence of overhead or underground utilities may restrict location and setup of cranes and hauling equipment. Protective mats could be required to prevent damage to existing underground facilities that need to be preserved. Further, the existing bridge may be in or near sensitive environmental resources, where seasonal restrictions may prevent the contractor from accessing the bridge from underneath. The site may need to be protected from falling debris, which requires construction of a protective system.

4.14.4 Pre-demolition Investigation

A pre-demolition investigation should be conducted prior to bid to identify hazardous materials, existing utilities and buried structures., Coring the deck and other bridge components should be considered if as-built information is illegible or unavailable. If the site is not accessible during design, these investigation activities should be included in the contract as a first order of work. This investigation is essential in reducing delay risk during the bridge closure.

4.14.5 Demolition Activities Prior to Closure

Demolition activities should start prior to the bridge closure to reduce risk and expedite the schedule. These pre-demolition activities could require lane closures and placement of temporary protective barrier systems. Pre-demolition activities could include:

- Saw cutting concrete and precutting of the reinforcement
- Drilling lift holes
- Removal of sidewalks and barriers
- Removal of overhangs
- Installation of temporary supports and shoring

4.15 TEMPORARY BRIDGE

Temporary bridges have been used for emergency repair and temporary traffic detour during bridge replacement operations. A commonly used temporary bridge is the Prefabricated Modular Steel Panel Truss Bridge System, which consists of two longitudinal, vertical truss elements, transverse mounted beams attached to the bottom chord, and a deck applied to the top of the beams. The vertical trusses consist of truss panel systems that are bolted together to create a range of span applications. This system can be incrementally launched or assembled by crane. The design criteria for Prefabricated Modular Steel Panel Truss Bridges are detailed in *STP* 17.1.

Another common temporary bridge system consists of steel beams with timber decks. Caltrans is currently developing plans for this bridge system for spans up to 70 feet. Contact the ABC Branch for further details. Also, railroad flatcars have been used in California for temporary bridge spans (SDR, Inc. 2005).

4.16 ESTIMATES OF COST AND WORKING DAYS

The development of cost and working day estimates for ABC requires close coordination between the PE, the Structure Office Engineer (SOE), Structure Cost Estimates, and Structure Construction prior to submitting the package to the District. For discussions on estimating costs and the number of working days for ABC, refer to Chapter 3 and the following sections.

4.16.1 Estimates

ABC cost estimates should reflect costs for all labor and material. Individual items are typically priced based on past bids of similar quantities within the region. There are items unique to ABC that impact costs. These unique items include:

- **Risk** – the contractor includes the risk cost in the price of each item. If the contractor has a short closure window, high liquidated damages, or tight construction tolerances, the bid prices will increase accordingly.
- **Engineering** – the contractor is responsible for engineering, analysis, and design of fabricating, transporting, erecting and/or moving prefabricated bridge elements. Specific engineering submittals include shop drawings, work plans such assembly plans and move in plans, which are typically not part of a non-ABC project.
- **Mobilization of specialized equipment** – high-capacity cranes, SPMTs, low-overhead drilling equipment, and jacks can have significant mobilization costs.
- **Specialty Products** – UHPC, grout, RSC, and lightweight concrete can require proprietary materials, specialized equipment, and expert field personnel for successful delivery. These products can have significant cost implications, even with small quantities.
- **Mock-ups** – construction of the mock-ups of RSC elements, lightweight concrete elements, and UHPC connections is required to demonstrate feasibility. These mock-ups should be full or of similar scale, which results in construction and removal of relatively large pieces.
- **Pre-assembly of PBES** – pre-assembly of PBES prior to shipping to the site could require the use of large cranes at the fabrication facility.
- **Lateral Slides** – refer to the *Slide-In Bridge Construction Cost Estimation Tool Guidelines* (FHWA 2015) for a discussion on the cost of lateral slides.

4.16.2 Working Days

The Working Days Schedules for ABC must be prepared for both the work to complete the bridge and the work during the bridge closure. The development of these schedules requires coordination with SOE and Structure Construction. Information needed includes a detailed construction sequence, and the assumptions that were used during design. The following key items need to be communicated to SOE in the Memo to Specifications Engineer/Estimator form:

- Required compressive strengths and cure times of cast-in-place materials and connections.

- Traffic management assumptions including the durations of full closure, work windows, and detours.
- Right-of-way and access restrictions.
- Special materials and equipment.
- Work schedules (e.g., multiple shifts, seven days per week).

4.17 INDUSTRY OUTREACH

Outreach to the construction community during design is key to the successful execution of ABC projects. This outreach can provide vital feedback on the methods and equipment assumed during design. Industry outreach can also be necessary to communicate information about unique and challenging provisions in the plans and specifications.

4.17.1 Industry Workshops

ABC requires the PE to make assumptions about the contractor's methods, expertise, and available equipment. Engaging the construction community through workshops during design can provide essential feedback on these assumptions and on the proposed schedule. These workshops can be facilitated through the ABC Branch, Structure Construction, and industry organizations, such as the Association of General Contractors, the Precast/Prestressed Concrete Institute, and the National Steel Bridge Alliance.

4.17.2 Pre-bid Meeting

A pre-bid meeting should be held for ABC projects to communicate unique and particularly challenging aspects that impact cost and schedule. Pre-bid meeting attendance should be mandatory for all bidders due to the importance of communicating these aspects of the project to all bidders. Contractor requirements for planning, engineering, submittals, and specialized expertise that are above and beyond what is required for conventional bridge construction is presented. Contractor prequalification and items that require an authorized fabrication facility will also be discussed. Underbidding of an ABC project due to a misunderstanding of the contract requirements could negatively impact project execution. A mandatory site visit should be considered for ABC with complex assembly, move-in methods, or challenging site conditions.

The requirements for a pre-bid meeting are included in the special provisions and the Notice-to-Bidders. Attendance of the PE, the SR, and the ABC Branch representative at the pre-bid meeting is required. Other specialists, such as specialist from Geotechnical Services and METS should attend, if necessary.

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ACCELERATED BRIDGE CONSTRUCTION

Chapter 5

CONSTRUCTION

District 5

Pfeiffer Canyon Bridge, Highway 1, Monterey County, CA

CONTENTS

5 CONSTRUCTION 5-1
5.1 INTRODUCTION 5-1
5.2 CONSTRUCTION HAND-OFF 5-1
5.3 PRE-BID MEETING 5-2
5.4 ABC PRECONSTRUCTION MEETINGS 5-2
5.4.1 Pre-construction 5-2
5.4.2 Prior to Move/Assembly 5-2
5.4.3 Prior to Ultra-High Performance Concrete Field Pour 5-4
5.5 LAYOUT AND TOLERANCES 5-4
5.6 MOCK-UPS 5-4
5.7 CONTRACTOR'S SUBMITTALS 5-5
5.7.1 Shop Drawing Review 5-5
5.7.2 Mock-up Work Plan 5-5
5.7.3 Assembly and Bridge Move Plans 5-6
5.7.3.1 Prefabricated Bridge Elements (PBEs) 5-6
5.7.3.2 Bridge Moves 5-6
5.7.4 Temporary Supports 5-6
5.8 PRECAST CONCRETE ELEMENTS 5-6
5.8.1 Precast Surface Preparation 5-7
5.8.2 Pre-assembly Dry Fit 5-7
5.8.3 Precast Element Inspection Prior to Transport 5-7
5.9 INSPECTION AFTER TRANSPORT 5-8
5.10 DESIGN SUPPORT DURING BRIDGE CLOSURE 5-8
5.11 CLOSEOUT AND LESSONS LEARNED 5-8
5.12 REFERENCES 5-9

5 CONSTRUCTION

5.1 INTRODUCTION

This chapter provides guidance on the construction of Accelerated Bridge Construction (ABC) projects. Many of the materials and processes used in ABC are the same as those used in conventional bridge construction. Therefore, this chapter supplements existing Caltrans bridge construction guidance materials and focuses on aspects that are unique to ABC.

AASHTO LRFD Guide Specifications for Accelerated Bridge Construction (AASHTO GSABC) (AASHTO 2018) Sections 6 through 12 are referenced frequently throughout this chapter. Combined these seven sections are entitled *Part 2: ABC Construction Specifications* and they were written as a supplement to the *AASHTO LRFD Bridge Construction Specifications* (AASHTO 2017), as discussed in *AASHTO GSABC* Section 6. Since Caltrans has not adopted the *AASHTO LRFD Bridge Construction Specifications* (AASHTO 2017; 2018), the reader should consult the *Standard Specifications* (Caltrans 2018), the *Construction Manual* (Caltrans 2021), the Caltrans *Bridge Construction Memos*, and the *Caltrans Independent Assurance Manual* (Caltrans 2019) when any section within *AASHTO GSABC* Part 2 is referenced.

ABC projects typically have unique project requirements detailed in the plans and special provisions. A thorough understanding of these requirements are necessary for success.

5.2 CONSTRUCTION HAND-OFF

The Resident Engineer (RE) Pending File for ABC projects is often more extensive than non-ABC projects. A construction hand-off meeting between the Structure Design Project Engineer (PE), the RE, the Structure Representative (SR), and the METS Representative should be held to discuss the following items in the RE Pending file:

- Unique materials and/or methods
- Construction sequence
- Temporary supports
- Quality control measures
- Layout
- Tolerances
- Additional survey support

- Schedule
- Assumptions made during design
- Concurrent shop drawing/work plan submittals
- Prefabrication facility audits

See *Bridge Design Process and Procedures Manual* (Caltrans 2019) Section 5.14 and *Bridge Construction Memo* C-3.02 for more information regarding the RE Pending File.

ABC projects require more lead time before the contractor starts work at the site. Items that can be accomplished during pre-construction include the preparation and review of shop drawings and work plans.

5.3 PRE-BID MEETING

Refer to Section 4.17.2 for guidance on pre-bid meeting and note their importance to successful ABC project execution.

5.4 ABC PRECONSTRUCTION MEETINGS

5.4.1 Pre-construction

It is important to hold an ABC-focused preconstruction meeting with the contractor for the sole purpose of discussing the ABC aspects of the project. Preconstruction meetings that cover the entire project are too broad to adequately address the scope and complexity of ABC. The ABC preconstruction meeting should address the intent of the design, roles and responsibilities, and items that require long lead times before the work can proceed. These items include prequalification and testing of materials, development of shop drawings and work plans, and construction of the mock-ups. Attendees should include the PE, ABC Branch representative, RE, SR, and METS Representative.

5.4.2 Prior to Move/Assembly

Meetings should be held with the contractor before all significant ABC-related activities are performed. Significant ABC-related activities include:

- Mock-up construction
- Existing bridge/roadway closure
- Assembly and erection of prefabricated bridge elements
- Bridge move using either lateral slide, SPMT, or longitudinal launch methods

Depending on the specific ABC activity, the meeting will discuss one or more of the following:

- Work plans
- Assembly plans
- Bridge removal plans
- Temporary supports and bracing
- Move plans
- Communication plan
- Prefabricated element storage on site
- Order of placement
- Contingency plans
- Material mixing, placement and testing

Depending on the specific activity, the meeting will be attended by some of the following personnel:

- Resident Engineer
- Structure Representative
- Structure Design Project Engineer
- ABC Branch representative
- Contractor, including Contractor's Engineer
- Precast fabricator including Quality Control (QC) Manager
- Field QC Manager
- Move specialty subcontractor
- METS Representative
- Specialized material supplier
- Key fabrication subcontractors

Starting weekly Readiness Meetings several weeks in advance of a work window involving a critical operation, such as a lateral slide or an SPMT move, is recommended. These meetings are for updating the status on the planning and progress of the pre-operation activities. The SR, RE, and contractor should create a meeting handout that lists all the pre-operation activities that are described in the approved work plan, site requirements, traffic signage changes, and public notices. The party responsible for completing the specific activities will provide an update on their progress in each meeting.

5.4.3 Prior to Ultra-High Performance Concrete Field Pour

Prior to placement of Ultra-High Performance Concrete (UHPC), a meeting should be held to review the authorized UHPC workplan. This meeting will confirm the following:

- The personnel that will be performing and inspecting the UHPC field pour are the ones constructing and inspecting the mock-ups.
- All material and equipment are on site and functioning properly.
- Quantities are sufficient for field casting. Quantities account for keyway geometry and overage due to fabrication and assembly tolerances, installation method, QC/QA testing, and waste.
- The UHPC manufacturer’s representative will be in attendance during field placement.
- The QA/QC plan for UHPC includes the number of cylinders to be made and the testing schedules that will be performed by the Contractor and by Caltrans.

A detailed description of the requirements of UHPC connections is in Section 4.8.3, Appendix D, and the checklists in Appendix E.

5.5 LAYOUT AND TOLERANCES

Establishing line and grade is key to the success of ABC projects. The impacts of layout errors are magnified when corrections need to be made within critical closure windows. As a result, extra survey support is needed to confirm working lines, grades, and key points, as discussed in Section 4.2.1. Refer to *AASHTO GSABC* Section 9.3 for further discussion the layout of ABC projects.

All prefabricated bridge elements are produced and erected to a tolerance. Fabrication tolerances include limits on camber, sweep, and angular distortion. These tolerances are specified in the plans and specifications, as discussed in Section 4.2.2. Element dimensions, layout, and grade must be verified prior to and after assembly or move. Refer to *AASHTO GSABC* Section 9.2 for further discussion of tolerances in ABC.

5.6 MOCK-UPS

Refer to Section 4.9.7 for mock-up requirements. Field staff performing the mock-up construction should be the ones who perform the field construction. Mock-ups should be built under the same field conditions, including atmospheric conditions, because placement and curing of cementitious materials are sensitive to temperature and humidity.

5.7 CONTRACTOR'S SUBMITTALS

ABC shop drawings, assembly plans, work plans, inspection, and testing are interdependent. Therefore, the special provisions may require that submittals, including shop drawings, be submitted at the same time and reviewed concurrently to verify that there are no conflicts.

5.7.1 Shop Drawing Review

The PE, the SR, and the METS representative are responsible for reviewing prefabricated bridge elements for conformance with the design concepts and compliance with the contract documents. Review consists of verifying controlling dimensions, confirming conformance with plans, checking construction sequence, reviewing material submittals, and any special handling requirements. Guidance on the review of shop drawings is provided in the following:

- *Bridge Design Process and Procedures Manual* (Caltrans 2018), Chapter 6.4
- *Bridge Design Memos* 5.29 and 6.12.
- *Bridge Construction Memos* 50-1.01C and 170-4.0
- *Prefabricated Bridge Element Checklist Appendix A*
- *AASHTO GSABC* Section 8.2

5.7.2 Mock-up Work Plan

Review of the mock-up work plan is important, as the methods used to construct the mock-up will be used to build the project. Details in the mock-up work plan should mirror the actual work to be performed in the construction of the bridge, including testing and inspection.

5.7.3 Assembly and Bridge Move Plans

Assembly and bridge move plans document the required coordination during closure(s) and describe all of the necessary steps and requirements for completing work within the scheduled work window(s).

5.7.3.1 Prefabricated Bridge Elements (PBEs)

The Assembly Plan is developed by the contractor, fabricators, and specialized material suppliers to provide a detailed plan of the means and methods for assembling PBEs. This plan should be reviewed by the PE, SR, and METS Representative for authorization. Checklists for reviewing the Assembly Plan are provided in Appendix A.

For a more detailed description of the Assembly Plan, see Section 4.9.10.1.3.

5.7.3.2 Bridge Moves

Bridge moves using lateral slide, SPMTs, and longitudinal/incremental launch methods require move plans detailing the contractor’s means and methods, as discussed in Sections 4.10.13, 4.11.7, and 4.12.6, respectively. Bridge systems constructed in a BSA using PBEs will require an Assembly Plan, as discussed in Section 5.7.3.1. The move plans and the assembly plans should be reviewed by the PE, SR, Geotechnical Engineer, and METS Representative for authorization.

Checklists for reviewing lateral slide and SPMT moves are provided in Appendices B and C, respectively.

5.7.4 Temporary Supports

The SR will review submittals for temporary supports for compliance with the contract documents and authorize in accordance with BCM C-48-3 Temporary Supports. The SR may request the PE and the Geotechnical Engineer to assist in the review for compliance with the assumptions and intent of the ABC design.

5.8 PRECAST CONCRETE ELEMENTS

The quality of ABC using precast concrete elements is highly dependent on the connections as they are sometimes located at highest stress regions or regions that are critical for seismic resistance. Precast elements are typically connected with grouted connections or closure joints filled with non-shrink grout, concrete, rapid strength concrete (RSC), or UHPC. To be constructible, the connections must account for misalignment of precast elements from fabrication and erection tolerances. Refer to *AASHTO GSABC* Section 8.3.2 for further discussion on the quality control of precast concrete elements in ABC.

5.8.1 Precast Surface Preparation

Closure joint interface surface preparation is key to achieving the desired friction and water infiltration resistance assumed in the design, as discussed in Section 4.9.5. *AASHTO GSABC* Article 10.6.1 recommends that interface connection surfaces requiring resistance against water infiltration should have an exposed aggregate finish, which can be achieved through pressure washing and surface retarding agents.

If an exposed aggregate surface is not specified, the closure joint surface must be cleaned of all laitance and other deleterious materials. In all cases, the closure joint surface must have a saturated surface dry (SSD) condition prior to placement of any cementitious closure joint materials, per *Standard Specification* (Caltrans 2018) Section 51-1.03D(4).

5.8.2 Pre-assembly Dry Fit

If specified in the special provisions, precast concrete elements must be preassembled or "dry fit" prior to authorizing them for construction. This is to demonstrate that the elements will fit together in the field, as discussed in Section 4.9.8. Pre-assembly, which is observed by the METS Representative, is particularly important for the following elements:

- Elements with grouted duct connections where rebar must align with the receiving elements within relatively tight tolerances.
- Precast prestressed concrete box girder and voided slab spans that must fit properly on abutment seats and bent caps. (Excessive sweep and camber in individual girders or panels may add up to cause problems during erection if they are not accounted for in the abutment and bent cap layout.)

5.8.3 Precast Element Inspection Prior to Transport

Final inspection and release of precast elements by METS just prior to shipping is very important for completing the assembly and erection of the elements within the desired work window. To ensure that the elements arrive to the jobsite ready for installation, which is especially important in ABC projects, the following items are to be verified prior to shipping:

- Dimensions of elements comply with shop drawings within allowable tolerances.
- Elements are properly labeled by the contractor.
- Openings for grouted sleeve connections are covered to prevent the intrusion of dirt and debris.
- Surface preparation is complete, including surface roughening and exposed aggregate finishes at the closure joint interfaces.

5.9 INSPECTION AFTER TRANSPORT

Upon arrival at the site or bridge staging area, the precast concrete elements must be inspected by the SR for the following.

- Element labels – mislabeled or misread labels can significantly delay assembly.
- Damage that occurred during transport – long and slender deck elements can easily crack if mishandled.
- Closure joint substrate preparation – see Section 5.8.1 for the importance of closure joint substrate preparation.
- Ducts are free of debris and moisture.

5.10 DESIGN SUPPORT DURING BRIDGE CLOSURE

The PE must be available to respond to requests for information (RFI) and answer questions during the bridge closure to minimize delay. If a full route closure over a weekend is specified, the PE needs to be available 24-hours per day during the closure, and preferably on-site during critical operations where complex adjustments might require the PE's inspection and concurrence.

5.11 CLOSEOUT AND LESSONS LEARNED

ABC is an on-going and evolving process that involves collaboration between the project team and the contractor. The contract documents describe how the bridge will be built but the contractor is required to develop the detailed work plans that use available materials and equipment necessary for building the bridge.

Because the PE may not know the means and methods best suited for most of the contractors bidding on the project, having a well-documented account of the project construction, including lessons learned, will help improve the quality and execution of future ABC projects. This account is documented in a project closeout report that will be prepared by the PE in collaboration with the ABC Branch and Structure Construction to include lessons learned and an as-built schedule of the overall ABC activities and closure durations. This collaborative approach will help improve ABC methods and working day estimates.

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ACCELERATED
BRIDGE
CONSTRUCTION

Chapter 6

RESOURCES

District 4

Richmond-San Rafael Bridge Seismic Retrofit,
Interstate 580, Marin County, CA

CONTENTS

6 RESOURCES 6-1
6.1 INTRODUCTION 6-1
6.2 CALTRANS FUNDED RESEARCH 6-1
6.2.1 Prefabricated Superstructure Systems 6-1
6.2.2 Prefabricated Substructure Systems 6-2
6.2.3 Precast Pile Cap 6-2
6.2.4 Prefabricated Bridge Element Systems 6-2
6.3 ABC RESEARCH NOT FUNDED BY CALTRANS 6-3
6.3.1 Precast Bent Cap System for Seismic Regions 6-3
6.3.2 ABC Dynamic Effects and Tolerances 6-3
6.4 ABC RESOURCES 6-3
6.4.1 AASHTO LRFD Guide Specifications for ABC 6-3
6.4.2 DES ABC Website 6-4
6.4.3 ABC-UTC Website 6-4
6.4.3.1 ABC Project Database 6-4
6.4.3.2 ABC Webinars 6-5
6.4.4 FHWA ABC Website 6-5
6.4.4.1 Lateral Slide Construction 6-6
6.4.4.2 Bridge Moves Using SPMT's 6-6
6.4.5 PCI-NE ABC Resources 6-6
6.4.6 SHRP 2 Innovative Bridge Designs for Rapid Renewal 6-7
6.5 REFERENCES 6-7

6 RESOURCES

6.1 INTRODUCTION

There are resources available to assist the design and construction engineering teams for all phases of Accelerated Bridge Construction (ABC) projects. These resources include research, guidance on design and construction, and examples with case histories and lessons learned. This information is presented throughout this manual and can be found on the ABC website and is summarized in this chapter to provide the reader a quick reference of available resources.

6.2 CALTRANS FUNDED RESEARCH

California Department of Transportation (Caltrans) ABC research has focused on the performance of rapid construction systems and connections, and the seismic resistance of prefabricated bridge elements and systems. The Division of Research, Innovation and System Innovation (DRISI) lists Caltrans funded research along with research summaries and links to the technical reports.

The Caltrans funded research on ABC can be divided into superstructure systems and substructure systems.

6.2.1 Prefabricated Superstructure Systems

There has been Caltrans funded research on Seismic Resistant ABC superstructure systems and connections at Iowa State University (ISU) and University of Nevada, Reno (UNR).

6.2.1.1 Girder Continuity – Seismic Resistance

Research at ISU, in cooperation with Caltrans, developed new precast girder to precast bent cap connections and evaluated the resistance under simulated seismic forces and displacements. A precast drop cap and precast inverted T-cap were included in this evaluation. The findings of the research culminated in Caltrans *Bridge Design Memo* 20.34. Both types of connections are considered standard and ordinary as defined in the *Seismic Design Criteria* (SDC) (Caltrans 2019; 2020), Section 7.2.1.2. A detailed description of the results of this research can be found in Report No.: 59A0695 (Snyder, et al. 2011) and CA16-2265 (Vander Werff, et al. 2015).

6.2.1.2 Full Depth Deck Panel Connections

An investigation of the connection between full depth deck panels and precast concrete girders has been conducted at the UNR. This investigation developed several connection details which were analyzed and tested to evaluate the resistance to seismic forces. The results of this research are available in a report by Shrestha, et al. (2017).

6.2.2 Prefabricated Substructure Systems

Caltrans is sponsoring ongoing research at the UNR to evaluate the seismic adequacy of ABC connections and systems. This research has led to the development of seismic resistant precast column to footing and precast column to bent cap connections using grouted duct connections. Large scale tests have verified the effectiveness of these connections under simulated seismic forces and displacements. The research is summarized in Report No. CA14-2176 (Tazarv and Saiidi 2014).

A new column pin connection detail has been developed at UNR in cooperation with Caltrans. This detail can be used in a wide range of applications including the top of columns, top of footings, and the top of shafts. Furthermore, this pin detail can be designed for compression only or to resist both tension and compression loads. The results of this research can be found in reports by Zaghi and Saiidi (2010) and Mehraein and Saiidi (2016).

An investigation in the development of bridge abutment design and construction for ABC is currently underway at ISU (Contract 65A0803) that utilize hollow core prefabricated elements, which can be filled with concrete on-site to complete the system. Materials, such as UHPC and fiber reinforced polymer are being investigated to increase element size while minimizing weight.

6.2.3 Precast Pile Cap

Caltrans has funded a research program with ISU to evaluate ABC pile-footing-column connection systems. The objectives of the research include developing ABC precast pile-to-precast footing connection details that will mobilize system strength to allow full plastic hinging of the column and test large scale models under realistic seismic forces and displacements. The project is currently underway and the results are anticipated in 2021.

6.2.4 Prefabricated Bridge Elements (PBEs)

An investigation of a two-span bridge using PBEs, including precast full depth deck panels, precast wide flange girders, integral precast bent caps, and precast columns is currently underway at UNR. This investigation includes shaking table tests of a large-scale model of the two-span bridge. The results demonstrated good performance using realistic earthquakes anticipated in zones of high seismicity. The research completed to date is summarized in a report by Benjumea, et al. (2019).

6.3 RELEVANT ABC RESEARCH NOT FUNDED BY CALTRANS

6.3.1 Precast Bent Cap System for Seismic Regions

The Transportation Research Board (TRB) National Cooperative Highway Research Program (NCHRP) funded a research project to evaluate precast concrete column and bent cap systems for seismic regions. A wide range of column to cap connection types were evaluated including emulative, which aims to replicate cast-in-place, jointed (where elements connect with unbonded post-tensioning tendons), and hybrid (which contains both bonded reinforcement and unbonded post-tensioning). Of all the connections evaluated, two emulative connections and three hybrid connections were studied with detailed analysis and structural tests. These studies demonstrated that practical precast column to precast bent cap connections can be designed for high-seismic regions. The research is summarized in NCHRP Report No. 681 (Restrepo, et al. 2011), NCHRP Report 698 (Marsh, et al. 2011) and NCHRP Report 935 (Saiidi, et al. 2020).

6.3.2 ABC Dynamic Effects and Tolerances

NCHRP funded a research project to investigate two important ABC issues under Project NCHRP 12-98 (Culmo, et al. 2017). The first established guidelines for fabrication and erection tolerances of Prefabricated Bridge Elements and Systems (PBES). This tolerance criteria for project specifications could be used for acceptance of fabricated elements and provides information on how a designer should detail a prefabricated bridge using the specified tolerances as the basis. The second determined the maximum anticipated dynamic effects that are imposed on the bridge system and the temporary supports during bridge system installations. The research covers the most common form of bridge systems including lateral slide and installations using self-propelled modular transporters (SPMTs).

The results of this research, *Guidelines for Prefabricated Bridge Elements and Systems Tolerances* (Culmo, et al. 2017a) and *Guidelines for Dynamic Effects for Bridge Systems* (Culmo, et al. 2017b), are available on the TRB website.

6.4 ABC RESOURCES

6.4.1 AASHTO LRFD Guide Specifications for ABC

The *AASHTO LRFD Guide Specifications for Accelerated Bridge Construction* (*AASHTO GSABC*) (AASHTO 2018) supplements the *AASHTO LRFD Bridge Design Specifications* (AASHTO 2017) and is intended for typical girder type bridges. Part 1 of the report includes design specifications for ABC. Part 2 includes construction specifications. Although the *AASHTO GSABC* are comprehensive, the incremental launch method (ILM) is not included.

However, many of the recommendations in the *AASHTO GSABC* are applicable to ILM, as discussed in Section 4.12.

The *AASHTO GSABC* was developed through the NCHRP project 12-102, which was published as Web-Only Document 242: *Recommended AASHTO Guide Specifications for ABC Design and Construction* (Culmo, et al, 2017). This report documents the results of a synthesis of past research regarding ABC, leading to the development of the recommended ABC guide specifications.

Supplementing the *AASHTO GSABC* are the *Guidelines for Prefabricated Bridge Elements and Systems Tolerances* (Culmo, et al. 2017a) and the *Guidelines for Dynamic Effects for Bridge Systems* (Culmo, et al. 2017b). These documents were developed based on the research in NCHRP 12-98, as discussed previously.

A discussion of Caltrans use of the *AASHTO GSABC* is provided in Section 1.1.1 of this Manual.

6.4.2 DES ABC Website

The Caltrans Division of Engineering Services (DES) ABC website has resources for design and construction of ABC projects. These resources include links to guidance materials, case studies, links to project plans and specifications, and lessons learned.

6.4.3 ABC-UTC Website

The Accelerated Bridge Construction – University Transportation Center (ABC-UTC) website hosted by the Florida International University (FIU) has extensive ABC databases of projects and research.

6.4.3.1 ABC Project Database

The ABC-UTC is working in cooperation with FHWA, bridge owners, and other bridge professionals to accumulate available completed construction projects in which ABC technologies are used, and research projects in which ABC technologies have been investigated. The Project Database has been expanded from its origin, the FHWA National ABC Project Exchange.

The database includes an interactive map showing the locations of ABC projects in the database. Each project listed in the database has detailed summaries including element weights, assembly/move-in methods, and relevant links to publications.

6.4.3.2 ABC Webinars

To facilitate transfer of the latest ABC knowledge to bridge owners and other bridge professionals, ABC-UTC hosts monthly webinars. These monthly webinars feature ABC projects, research, and training. The following is a list of brief descriptions and links to the webinars hosted on the ABC-UTC website.

- **Monthly Webinar**. The ABC-UTC is continuing the free, monthly webinars with featured presentations that the ABC Center at Florida International University first hosted in early 2011. These monthly webinars are archived on the website, and include recordings, presentation pdfs, and Q&A session pdfs.
- **In-Depth Web Training**. Annual in-depth web training was initiated in 2014 to provide more detailed coverage of select projects and topics related to ABC. These presentations are archived, and recordings and pdfs are available.
- **Research Seminar**. Started in January 2016, the web-based quarterly Research Seminars highlight ABC-UTC research products and the graduate students' contributions to the research projects on which they worked. These seminars are archived on their website, and recordings, presentation pdfs, and Q&A session pdfs are available.
- **Research Day**. Semi-annual one-day webinars provide updates by Principal Investigators on progress in their ongoing ABC-UTC research projects. These webinars are archived, and recordings and pdfs are available.

6.4.4 FHWA ABC Website

The Federal Highway Administration (FHWA) hosts a website dedicated to Accelerated Bridge Construction. This website has information and guidance materials on the planning, design, and construction of ABC.

The website includes guidance on ABC technologies including construction using PBES and structural placement methods including SPMTs and slide-in bridge construction (SIBC). There are also links to ultra-high performance concrete (UHPC), as used in ABC.

Guidance materials on the FHWA-ABC website include:

- *Accelerated Bridge Construction, Final Manual*, Publication No. FHWA-HIF-12-013 (FHWA 2011)
- *Contracting and Construction of Accelerated Bridge Construction Projects with Prefabricated Elements and Systems*, Publication No. FHWA-HIF-17-020 (Culmo, et al. 2013)
- *Engineering Design, Fabrication, and Erection of Prefabricated Bridge Elements and Systems*, Publication No. FHWA-HIF-17-019 (Culmo, et al. 2013a)

6.4.4.1 Lateral Slide Construction

The Federal Highway Administration (FHWA) hosts a webpage dedicated to Slide-in Bridge Construction (SIBC), which is referred to herein as lateral slide construction. As part of several ABC methods promoted by FHWA, the SIBC website links to a variety of key resources from across the country including documents developed by FHWA. The focus is on helping owner-agencies, designers, and construction contractors in implementing this technology.

The website has resources for design, construction, contracting, and public relations of ABC Projects. These resources include training presentations, guidance material, recorded webinars, and case studies. Guidance materials include:

- *Slide-In Bridge Construction Implementation Guide* (FHWA 2013) provides a full spectrum of information on SIBC including applications, roles and responsibilities, design information, case studies, and sample plans and specifications.
- *Slide-In Bridge Construction (SIBC) Cost Estimation Tool Guidelines* (FHWA 2015) The SIBC Cost Estimation Tool provides a method for determining the cost of lateral slides based on historical data. Detailed instructions and sample calculations are provided.

6.4.4.2 Bridge Moves Using Self-Propelled Modular Transporters (SPMTs)

The Federal Highway Administration (FHWA) hosts a webpage dedicated to bridge moves using self-propelled modular transporters (SPMTs). As part of several ABC methods promoted by FHWA, the SPMT website provides links to a variety of key resources from across the country including documents developed by FHWA. The focus is on helping owner-agencies, designers, and construction contractors in implementing this technology.

The website has resources for design, construction, contracting, and public relations of ABC Projects. These resources include recommendations on the use of SPMTs, case studies, articles, papers, and links to drawings and suppliers. FHWA guidance includes the *Manual on Use of Self-Propelled Modular Transporters to Remove and Replace Bridges* (FHWA 2007).

6.4.5 PCI-NE ABC Resources

Precast/Prestressed Concrete Institute (PCI) Northeast Chapter (PCI-NE) hosts a website dedicated to ABC using precast concrete elements. The website has guidance materials links to other websites and articles featuring ABC using precast concrete bridge elements.

ABC guidance materials on the PCI-NE website include:

- *Guidelines for ABC Using Precast/Prestressed Concrete Elements Including Guideline Details*, 2nd Edition, PCINE-14-ABC (PCI 2014)
- *Guideline Details for Precast Concrete Substructures* (PCI 2013)
- *Guidelines for Full Depth Deck Panel Guidelines*, 3rd Edition, PCINER-20-FDDP (PCI 2020)
- *Suggested Guide Details for Precast Approach Slabs* (PCI 2012)
- *Guidelines for Camber and Profile Management in Adjacent Beams*, PCINE-18-GCPMAB (PCI 2018)

6.4.6 SHRP 2 Innovative Bridge Designs for Rapid Renewal

The second Strategic Highway Research Program (SHRP 2) was a collaborative effort on behalf of FHWA, AASHTO and TRB to document and develop best practices on the rapid renewal of our transportation system. As part of this effort, ABC methods were investigated as part of the Innovative Bridge Designs for Rapid Renewal research project. This investigation resulted in the following documents:

- *Innovative Bridge Designs for Rapid Renewal* (TRB 2014) – summarizes the investigation and provides recommendations for successful implementation of ABC, including best practices and detailed comparisons of ABC methods and schedules.
- *Innovative Bridge Designs for Rapid Renewal: ABC Toolkit* (TRB 2013) – provides guidance on prefabricated bridge elements and the connections including plans, specifications, and construction concepts. Detailed sample calculations and Mathcad worksheets are available.
- *ABC Standard Concepts: The Lateral Slide Addendum Report* (TRB 2015) – provides recommendations on the lateral slide method, including sample plans and specifications.

6.5 REFERENCES

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Appendix A

PBE CHECKLISTS

District 2

Fort Goff Creek Bridge, Route 96,
Siskiyou County, CA

APPENDIX A PREFABRICATED BRIDGE ELEMENT CHECKLISTS

Table A-1 Prefabricated Bridge Element Checklist – Design

DESIGN	Provided (Originator)			Quality Control Check	Comments
	Yes	No	NA		
Meet the requirements of the Bridge and Structure Policies and Standards, as defined in *Structure Policy Directive* 1-3 or the Project Specific Design Criteria.					
Provide repetitive details, allowing the use of a single set of forms, small crews, and efficiency in casting. Elements that are identical are easily replaced by another identical element. Unique elements, or one-of-a-kind elements, come with more risk because damage to those elements could stop construction.					
Use simple details. Complex shapes or reinforcement patterns that reduce quantities typically do not overcome the extra cost and risk associated with their use.					
Minimize the number of connections. Fewer, larger connections are typically more cost effective than a larger number of smaller connections and provide fewer chances for geometric errors. Eliminate connections where possible.					
Verify that camber and deflection differences between elements within allowed tolerance are constructable.					
Establish and specify fabrication, erection, and assembly tolerances of prefabricated elements and systems. Provide as much tolerance in the system as possible to accommodate minor geometric inconsistencies.					
Evaluate potential crane locations, prefabricated element delivery truck locations, crane reach limitations, and site geometry to determine appropriate element size and weights.					

DESIGN	Provided (Originator)			Quality Control Check	Comments
	Yes	No	NA		
Balance the number of elements required with the size of the element and access to the site. Larger elements in areas easy to access can provide the fastest construction but, in areas with difficult access, smaller sections can be faster to place.					
Verify that each element is constructable and can be fabricated, transported, and erected.					
Verify that traffic handling, staging, and temporary support requirements are provided.					

Table A-2 Prefabricated Bridge Element Checklist – Plans

PLANS	Provided (Originator)			Quality Control Check	Comments
	Yes	No	NA		
Precast concrete element details and notes: • Length, width, and height • Reinforcing and prestressing in the element • Reinforcement clearances between block-outs or other connection elements • Rebar placement requirements and clearances for highly reinforced elements • Prestress tendon, duct, and anchorage clearances • Minimum reinforcement and prestress strand spacing • Connection elements • Appropriate traffic handling and staging • Temporary bracing and support provisions					

PLANS	Provided (Originator)			Quality Control Check	Comments
	Yes	No	NA		
• Deflection					
Connection details and notes: • Connection materials • Connection sizes • Construction sequence • Leveling requirements • Construction tolerances • Closure pours • Time limitations or minimum concrete/grout strengths at each construction step					
Complete plan and elevation views of the structure.					
Appropriate notes, sheet references, and ABC logo.					

Table A-3 Prefabricated Bridge Element Checklist – Specifications

SPECIFICATIONS	Provided (Originator)			Quality Control Check	Comments
	Yes	No	NA		
Assembly Plan: • Preassembly requirements – dry fit prior to transport • Submit shop drawings for abutments, columns, bent caps, columns, girders, and deck panels concurrently • Extended review time (45 days) • Templates for column rebar in grouted duct connections • Temporary support requirements					

Materials SSP 51-4.02: • Galvanized Corrugated Metal Pipe for pocket and socket connections, per ASTM A760 • Galvanized Corrugated Metal Duct for grouted duct connections, ASTM A653 Strip Steel, 26 gauge • Value Engineering Change Proposal of prefabricated elements allowed/not allowed • See Appendix E for Ultra-High Performance Concrete implementation checklists. Tolerances SSP 51-4.03 and SSP 90-4.03: • Specify fabrication and erection tolerances not covered or different from the PCI *Tolerance Manual for Precast and Prestressed Concrete Construction, MNL 135-00*, e.g., abutment wall elements.					

Table A-4 Prefabricated Bridge Element Checklist – Shop Drawings

SHOP DRAWINGS	**Conforms to plans and specifications**		**Comments**
	Yes	**No**	
Verify principal controlling dimensions: • Length, width, and height of assembled item • Horizontal distance between bearings, pin centerlines, or other points of support • Elevation of seats or other supports • Bent and abutment identifications • Orientation of structure (north arrow), skew(s) • Allowance for tolerance in fabrication and placement defined • Adjustments for special bearings, expansion joints, or other items not adequately covered by the contract plans to compensate for temperature or other variables • Marks to identify orientation and position on the bridge of each member			

<table>
<tr><th rowspan="2">SHOP DRAWINGS</th><th colspan="2">Conforms to plans and specifications</th><th rowspan="2">Comments</th></tr>
<tr><th>Yes</th><th>No</th></tr>
<tr><td>Check element for conformance with plans:
• Shape
• Length including corrections for shrinkage or vertical geometry
• Fabrication and erection tolerance defined
• Location of lifting devices defined
• Additional reinforcing defined
• Bearing plates, leveling devices, and vertical adjustment procedures defined
• Reinforcing details and spacing match plans
• Extended prestressing strands or reinforcement identified
• Concrete strength at release (f’ci)
• Concrete strength at 28-days (f’c)
• Camber and deflection at erection</td><td></td><td></td><td></td></tr>
<tr><td>Check post-tensioning for conformance with plans:
• Location of splices
• Strand or high-strength rod size and material
• Center of Gravity of strands with proposed strand pattern
• Jacking forces and detensioning pattern
• Location of blockouts
• Refer to Structures Technical Policy 5.29 for additional information on precast concrete element review</td><td></td><td></td><td></td></tr>
<tr><td>Confirm that details and materials follow the latest revision to contract plans.</td><td></td><td></td><td></td></tr>
<tr><td>Review special needs for elements:
• Special handling instructions or temporary fixtures for lifting, positioning, and transportation
• Protection of critical components and connections</td><td></td><td></td><td></td></tr>
</table>

SHOP DRAWINGS	Conforms to plans and specifications		Comments
	Yes	No	
• Dimensional controls required for shop and field assembly			
Verify design and stress calculations stamped by a CA PE are provided.			
Answer any questions noted on drawings as “engineer verify” or similar.			

Table A-5 Prefabricated Bridge Element Checklist – Work Plans

WORK PLANS	Conforms to plans and specifications		Comments
	Yes	No	
Check Assembly Plan: • Placement sequence defined • A work area plan depicting items such as utilities overhead and below the work area, drainage inlet structures, and protective measures • Equipment required to lift precast elements including cranes, excavators, lifting slings, sling hooks, and jacks defined • Equipment locations and operation limits defined • Method for providing temporary support defined • Procedures for controlling horizontal and vertical tolerance defined • Bedding concrete process (forming and placing) defined • Grouting procedures (forming and placing) defined • Closure pour procedures (forming and placing) defined • Curing requirements and timelines defined • Detailed schedule with sequence and duration of events demonstrating assembly is completed within time requirements			
Confirm that details and materials follow the latest revision to contract plans and specifications.			

Verify that temporary support design and stress calculations stamped by a CA PE are provided.			

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CONSTRUCTION

Appendix B

LATERAL SLIDE CHECKLISTS

District 4

San Francisco-Oakland Bay Bridge East Tie-In,
Interstate 80, San Francisco County, CA

APPENDIX B LATERAL SLIDE CHECKLISTS

Table B-1 Lateral Slide Checklist for Structure Design Project Engineer During Design

Structure Design Project Engineer (PE)	Applicable to Project? (Y/N)	Item Addressed (Y/N)	Comments
Advance Planning Study Verify suitability of lateral slide			
Verify there is available space for a lateral slide system.			
Identify potential utility conflicts and determine potential impacts to cost and schedule.			
Identify means of removing the existing structure including methods and route.			
Site is located in an open area with access to a staging yard.			
Geometry (e.g., alignment of supports relative to each other, skew, profile grade) is suitable for lateral slide.			
Check the roadway beneath the bridge for restrictions due to geometry, grade, and existing features or facilities that must be accounted for in the lateral slide system design and move (e.g., curved alignments may require taking portions of the roadway for the temporary supports and steep grades may require the new bridge be built high, moved, and then lowered).			
Confirm that the temporary abutments and bents can be constructed with the existing bridge in place.			
Confirm existing and new layouts, profile grades, and super-elevations are suitable for lateral slide.			
Identify traffic impacts, such as partial or full road closures, and staged			

Structure Design Project Engineer (PE)	Applicable to Project? (Y/N)	Item Addressed (Y/N)	Comments
construction.			
Identify needs for retaining walls both permanent and temporary.			
Coordinate with Caltrans ABC Specialists and Project Development Team (PDT) to justify/confirm the assumptions for lateral slide and feasibility.			
Type Selection Investigate final structure location, lateral guide, and jacking systems. Review and accept lateral slide concept for final design. Select structure type and confirm removal plan of existing structure			
Determine the type of structure including foundations and connections to foundations.			
Identify approximate dimensions of the structure.			
Identify approximate weight of the structure.			
Investigate lateral guide and jacking systems. Verify that the assumed lateral slide system and the temporary supports identified during APS and proposed in the General Plan for Type Selection can be installed, and the bridge can be moved.			
Confirm that the proposed structure can resist applied jacking forces.			
Coordinate with Caltrans ABC Specialists and PDT to justify/confirm the assumptions for lateral slide and feasibility.			
Identify bridge system construction area and layout			
Identify potential temporary support locations. Verify that the temporary abutments and bents can be constructed with the existing bridge in place.			
If not investigated previously, investigate potential temporary support locations for conflicts with buried utilities and conflicts with the existing bridge, as shown in the as-built plans.			
Review potential traffic impact during construction of the bridge system.			

Structure Design Project Engineer (PE)	Applicable to Project? (Y/N)	Item Addressed (Y/N)	Comments
Verify minimum vertical clearance.			
Inter-Discipline Coordination			
Request Preliminary Foundation Report (PFR). Coordinate with the geotechnical engineer to ensure the geotechnical investigation includes potential impact areas. Include temporary support structures and the permanent foundations.			
Investigate undermining of existing foundations due to construction of new foundations.			
Work with District PE and PDT to identify the utility owner and obtain the type, size, location, and depth of buried utility lines near the temporary supports.			
Coordinate with other disciplines to obtain required design information.			
PS&E Develop final plans, specification, and estimate. Establish requirements for the lateral slide plan			
Design the connections between the girders, the diaphragms, and the deck. Verify that the deck can perform as a horizontal diaphragm. Design the deck for moving loads.			
Specify requirements for mitigation of above ground obstructions such as signs, trees, power lines and poles, light poles, buildings, etc. Design adequate vertical and horizontal clearance for structure and lateral slide equipment.			
Inter-Discipline Coordination			
Coordinate with the Geotechnical Engineer on the temporary and final foundation design. Verify that the geotechnical design information used for the final design is incorporated in the Final Foundation Report. Provide plans for mitigating geotechnical issues.			
Coordinate with the District regarding utilities that are in conflict with the			

Structure Design Project Engineer (PE)	Applicable to Project? (Y/N)	Item Addressed (Y/N)	Comments
bridge construction. This is particularly important for utilities that must be protected in place and utilities that are to be installed in the new bridge after the bridge move. Provide plans for mitigating utility issues.			
Coordinate with other disciplines to obtain required design information.			
Complete Structure Project Documents			
Provide plans or specifications for any site preparation required to accommodate the lateral slide system, including mitigation of any clearance issues and fit issues between the structure superstructure and the permanent abutments and bents.			
Identify components built in place.			
Identify components built elsewhere and moved into place.			
Identify horizontal and vertical jacking points.			
Design diaphragms, girders, and deck elements to resist jacking forces during lateral slide.			
Incorporate any commitments made in clearing the construction area on the plans, in the specifications, or within the limitations of operations.			
Indicate temporary support connection to existing and new supports. Evaluate existing supports and strengthen or modify as required.			
Prepare specifications defining and specifying project requirements including stress and deflection requirements during the lateral slide.			
Establish requirements for bridge move shop drawings, geometric control system shop drawings, and work plans (bridge move work plan and contingency work plan).			
Provide on the plans the allowable differential horizontal and differential vertical deflections and twist, which are measured as the upward or downward deflection of one corner relative to the plane defined concurrently by the elevations of the other corners. Define the tolerances			

Structure Design Project Engineer (PE)	Applicable to Project? (Y/N)	Item Addressed (Y/N)	Comments
that the structure must be constructed to on the plans.			
Specify a trial slide to verify lateral slide system efficacy, and static and dynamic friction coefficients.			
Require that the lateral slide system be reversable for both the trial and the actual slides.			
Establish prequalification of bidders.			
Submit Resident Engineer (RE) Pending File information on the potential lateral slide systems, or other pertinent information when these items are not included in the plan set.			

Table B-2 Lateral Slide Checklist for PE and Structure Representative During Construction

PE/Structure Representative	Applicable to Project (Y/N)	Item Addressed (Y/N)		Comments
		PE	Structure Rep.	
General				
Provide design support during construction.				
Attend Pre-bid Meeting.				
Review shop drawings				
Confirm that shop drawings for the lateral slide bridge move system meet the requirements specified in the project plans and specifications.				
Verify that the bridge move system is reversible for both the trial slide and the actual move.				
Confirm that a vertical jacking system is provided to remove slide plates				

PE/Structure Representative	Applicable to Project (Y/N)	Item Addressed (Y/N)		Comments
		PE	Structure Rep.	
or roller systems.				
Verify that the contractor supplied temporary supports meet specified requirements in Section 48-3.01C(2). Include loads applied from the sliding system, and construction live loads.				
Review all required submittals before final move activities begin, including demolition of existing structures when required.				
Confirm that temporary support systems have a means of vertical adjustment due to settlement.				
Confirm that the bridge move system shop drawings and calculations are signed and sealed by a California-registered Civil Engineer who is not employed by the entity that prepared the drawings.				
Review work plans				
Confirm that the bridge move work plan includes a sequence of operations and demonstrates that the move will be completed within the allotted time.				
Verify that the bridge move work plan lists tolerances to be maintained, maximum speed of slide, and braking. Verify that the bridge move work plan includes a protocol for when the slide can begin, be stopped, and resumed. The protocol should include who has authority to make those decisions.				
Review the organization chart showing personnel and lead persons for all activity along with the communication plan to remain in contact throughout the move operations.				
Verify the experience and qualifications of the supervisory and survey instrument operating personnel, particularly regarding the observational precision required.				
Check that the bridge move plan has maximum wind speed and stream				

PE/Structure Representative	Applicable to Project (Y/N)	Item Addressed (Y/N)		Comments
		PE	Structure Rep.	
flow limits that, when exceeded, the moving operation cannot proceed.				
Confirm that the geometric control system will be in place to monitor deflections and settlement throughout construction and will remain in place prior to the move and throughout move operations.				
Verify that the geometric control system can continuously monitor displacements and alignments during the bridge move, including control points on the bridge system and the permanent abutments.				
Verify that the geometric control system provides means and methods of monitoring tolerances during the move and after completion.				
Confirm that the contingency work plan addresses risk factors that may jeopardize the bridge move schedule, quality of finished product, and safety.				
Confirm that the contingency work plan includes risk management and traffic handling plans for equipment failure, inclement weather, and excessive differential displacements.				
Trial lateral slide to occur a minimum of five-days prior to the slide of the bridge to its final position. The trial slide must move the bridge system forward and move it back to its original location, per the project specifications.				
Perform field walk through and final assessment				
Inspect the structure after lateral slide.				

Table B-3 Lateral Slide Checklist for Geotechnical Engineer

Geotechnical Engineer	Applicable (Y/N)	Item Addressed (Y/N)	Comments
Advance Planning Study, Structures Preliminary Geotechnical Report			
Conduct preliminary geotechnical investigation. Identify issues regarding ground bearing capacity, slope stability, and underground utilities. .			
Collaborate with the PE on preliminary foundation design(s) and support the PDT in identifying potential geotechnical issues and requirements.			
Final PS&E			
Collaborate with the PE on the foundation design and support the PDT in identifying geotechnical issues and requirements to be accounted for in the final PS&E. Finalize the Bridge Foundation Report per the Draft PS&E comments. Sign and stamp Bridge Foundation Report.			
Construction			
Provide design support during construction.			
Attend pre-bid meeting(s).			
Review shop drawings.			
Assist PE and SR in documenting lessons learned on the foundation design and construction issues for the final lessons learned report			

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Appendix C

SPMT CHECKLISTS

District 8

High Grove Underpass, Interstate 215,
Riverside County, CA

APPENDIX C SELF-PROPELLED MODULAR TRANSPORTER (SPMT) MOVE CHECKLISTS

Table C-1 SPMT Move Checklist for Structure Design Project Engineer (PE) During Design

Structure Design Project Engineer (PE)	Applicable to Project? (Y/N)	Item Addressed (Y/N)	Comments
Advance Planning Study Identify potential SPMT application, possible Bridge Staging Area (BSA), and Travel Path (TP).			
Identify potential BSAs			
Identify potential utility conflicts and determine potential impacts to cost and schedule.			
Identify means of removing the existing structure including methods and route.			
Verify that the BSA is adequate for construction activities. The staging area requires space to build the entire structure, move equipment in and out of the staging area, and maintain required traffic around the staging area. List the assumptions used to determine required space.			
Identify potential grade impacts along the TP. Examine grades along the TP and grades along the supports.			
Identify potential obstacles such as utilities (buried or overhead) or existing structures along or under the TP.			
Identify any potential utility conflicts/relocation.			
Identify potential permanent or temporary retaining walls.			
Coordinate with ABC Specialist, District Project Engineer, and PDT to justify/confirm the assumptions for SPMT move and feasibility.			

Structure Design Project Engineer (PE)	Applicable to Project? (Y/N)	Item Addressed (Y/N)	Comments
Confirm layouts, profile grades and super-elevations are suitable for SPMT moves.			
Identify traffic impacts, such as partial or full road closures, and staged construction.			
Identify needs for retaining walls both permanent and temporary.			
Type Selection Select structure type. Investigate final structure location, confirm BSA, and TP. Review and accept SPMT move concept for final design. Confirm removal plan of existing structure.			
Select structure type			
Determine the type of structure, including temporary structures, foundations, and connections to foundations.			
Identify the approximate dimensions of the structure.			
Identify the approximate weight of the structure.			
List assumed weight and dimensions of the lifting system during lift and transport.			
Verify that the bridge system can be lifted and transported using the assumed lift points.			
Coordinate with ABC Specialist, District Project Engineer, and PDT to justify/confirm the assumptions for SPMT move and feasibility.			
Confirm BSA, TP and SPMT layout			
Assess the potential BSAs and TPs. Identify potential areas of improvement for ground bearing capacity or slope stability. Consider the areas of influence beneath the SPMT at the lift location, along the TP, and at the final location.			
Conduct subsurface investigation of potential BSAs and TPs through identification of buried utilities and collecting as-built plans.			

Structure Design Project Engineer (PE)	Applicable to Project? (Y/N)	Item Addressed (Y/N)	Comments
Confirm that SPMTs system can move the bridge from the BSA to the final location.			
Confirm that the TP is within the SPMT's tolerances for grade.			
Strengthening of structures along the travel path are identified. Confirm that the necessary strengthening will be feasible.			
Confirm depth, size, location, and type of utility. Estimate the amount of time that the SPMT will spend over the utility and the effect on the applied load. Identify utilities requiring mitigation during the move. List the utility owners' conditions for mitigating sensitive underground utilities at the BSA and along the TP.			
Review potential traffic impacts as the SPMTs proceed along the TP.			
Consider the impact to the project of any local restrictions such as site protection, noise restrictions, structures, and roadways that are along the TP and near the BSA and bridge site.			
Verify that proposed staging area provides suitable access to the TP.			
Inter-Discipline Coordination			
Initiate Preliminary Foundation Report (PFR). Coordinate with the geotechnical engineer to ensure the geotechnical investigation includes potential impact areas. Include areas of influence beneath the loaded SPMT, temporary support structures, TP, and the permanent foundation. Collaborate with the geotechnical engineer on the foundation design and information required for the foundation report			
Coordinate with the roadway design team to determine the type of ground surface model required to evaluate the TP.			
Identify the utility owner and obtain the type, size, location, and depth of all buried utility lines.			
Coordinate with other disciplines to obtain required design information.			

Structure Design Project Engineer (PE)	Applicable to Project? (Y/N)	Item Addressed (Y/N)	Comments
PS&E Develop plans, specification, and estimate. Establish requirements for SPMT move plan			
Design the BSA and the TP			
Specify requirements for mitigation of ground bearing capacity at the area of influence beneath the SPMTs along the entire TP length.			
Document areas where carousel movements or sharp turns are required. These areas require special preparation to ensure wheels do not auger in.			
Provide slope stabilization details where required.			
Confirm depth, size, location, and type of utility. Estimate the amount of time that the SPMT will spend over the utility and the effect on the applied load. Identify utilities requiring mitigation during the move. List the utility owners' conditions for mitigating sensitive underground utilities at the BSA and along the TP.			
Specify requirements for mitigation of above ground obstructions such as signs, trees, power lines and poles, communication lines, light poles, buildings, etc. Ensure adequate vertical and horizontal clearance for the SPMTs and the bridge system.			
Define requirements for load ratings of structures along the TP. Define the rating levels required for the owner of the structure to grant the SPMT contractor permission to cross the structure.			
Inter-Discipline Coordination			
Coordinate with the geotechnical engineer. Obtain, review, and use the Final Foundation Report.			
Coordinate with utility owners at the BSA, along the TP, and at the final structure location. Confirm written agreements have been obtained from utility owners to drive over utilities and limits for planned or emergency parking over utilities.			

Structure Design Project Engineer (PE)	Applicable to Project? (Y/N)	Item Addressed (Y/N)	Comments
Coordinate with other disciplines to obtain required design information.			
Prepare final plans and specifications			
Provide plans for any site preparation required to accommodate the SPMTs along the TP, including mitigation of any clearance issues and fit issues between the structure superstructure and the permanent abutments or obstacles along the TP.			
Provide plans for mitigating geotechnical and utility issues.			
Identify components to be built in place.			
Identify components to be built elsewhere and moved into place.			
Identify lift points. List reactions at lift points. Provide lift points and design details.			
Incorporate any commitments made in clearing the TP on the plan set, in the specifications, or within the limitations of operations.			
Prepare specifications defining and specifying project requirements including stress and deflection requirements during the move.			
Provide the allowable maximum twist in terms of the amount (in decimal feet) that one corner of the span may deflect up or down relative to the plane defined by the other three corners. Provide this information at the centerline of the lift point on the exterior girders for each support location.			
Provide the anticipated deflections at all final support points, lift points, and midpoints between supports under all structural and superimposed dead loads when the SPMT lifts the structure.			
Complete structure project documents			
Submit structure project documents.			
Submit RE Pending File information on the potential BSAs, TPs, or other pertinent information when these items are not included in the plan set.			

Structure Design Project Engineer (PE)	Applicable to Project? (Y/N)	Item Addressed (Y/N)	Comments
Include as-built plan set when demolition of an existing structure is required and when TP crosses an existing structure.			
Submit contract documents for Plans, Specifications, and Estimates (PS&E) review.			
Finalize plan set per the PS&E comments.			

Table C-2 SPMT Move Checklist for PE and Structure Representative (SR) During Construction

PE/Structure Representative (SR)	Applicable to Project (Y/N)	Item Addressed (Y/N)		Comments
		PE	Structure Rep.	
General				
Provide design support during construction.				
Attend Pre-bid Meeting.				
Review shop drawings				
Verify that the contractor supplied temporary supports meet specified requirements.				
Confirm that shop drawings for the BSA, TP, temporary support system, lifting apparatus, and lift points, etc. meet the requirements specified in the project plans and specifications.				
Review all required submittals before final move activities begin, including demolition of existing structures when required.				
Verify that the contractor-supplied temporary supports meet specified requirements in Section 48-3.01C(2). Include loads applied from the moving				

PE/Structure Representative (SR)	Applicable to Project (Y/N)	Item Addressed (Y/N)		Comments
		PE	Structure Rep.	
system and construction live loads.				
Review all required submittals before final move activities begin, including demolition of existing structures when required.				
Confirm that temporary support systems have a means of vertical adjustment due to settlement.				
Confirm that the SPMT move system shop drawings and calculations are signed and sealed by a California registered Civil Engineer that is not employed by the entity that prepared the drawings.				
Review work plans				
Confirm that the bridge move work plan includes a sequence of operations and demonstrates that the move will be completed within the allotted time.				
Verify that the bridge move work plan lists tolerances to be maintained, maximum speed of move, and braking. Verify that the bridge move work plan includes a protocol for when the move can begin, be stopped, and resumed. The protocol should include who has authority to make those decisions.				
Check that the bridge move plan has maximum wind speed limits that, when exceeded, the moving operation cannot proceed.				
Review the organization chart showing personnel and lead persons for all activity along with the communication plan to remain in contact throughout the move operations.				
Verify the experience and qualifications of the supervisory and survey instrument operating personnel, particularly regarding the observational precision required.				
Review the geometric control work plan. The geometric control work plan details the measuring equipment, procedures, and locations of geometry control reference points on the superstructure, in the staging area, along the				

PE/Structure Representative (SR)	Applicable to Project (Y/N)	Item Addressed (Y/N)		Comments
		PE	Structure Rep.	
TP, and at the final structure site.				
Confirm that the geometric control system will be in place to monitor deflections and settlement throughout construction and will remain in place prior to the move and throughout move operations.				
Verify that the geometric control work plan includes a geometry control procedure for monitoring the distortion (twist) and relative deflections at support locations of the as-constructed concrete surface of each span.				
Verify the bridge move plan includes lateral and longitudinal location reference points on the superstructure that correspond to, or can reference, appropriate lateral and longitudinal location reference points at the erection site.				
Confirm that the contingency work plan addresses risk factors that may jeopardize the bridge move schedule, quality of finished product, and safety.				
Confirm that the contingency work plan includes risk management and traffic handling plans for equipment failure, inclement weather, and excessive differential displacements.				
Trial move to occur a minimum of five-days prior to the move of the bridge system to its final position. The trial move must lift the bridge system off of the supports, travel within the BSA, and move it back to its original location, per the project specifications.				
Perform field walk through and final assessment				
Inspect the structure after placement in final location.				

Table C-3 SPMT Move Checklist for Geotechnical Engineer

Geotechnical Engineer	Applicable (Y/N)	Item Addressed (Y/N)	Comments
Advance Planning Study, Structures Preliminary Geotechnical Report Identify SPMT Move project, possible BSA, and TP.			
Conduct preliminary geotechnical investigation. Identify issues regarding ground bearing capacity, slope stability, and underground utilities. Assume structure move equipment exerts a maximum force of 2 ksf for preliminary investigations. Collaborate with the PE on preliminary foundation design(s) and support the PDT in identifying potential geotechnical issues and requirements.			
Final PS&E			
Collaborate with the PE on the foundation design and support the PDT in identifying geotechnical issues and requirements to be accounted for in the final PS&E. Finalize the Bridge Foundation Report per the Draft PS&E comments. Sign and stamp Bridge Foundation Report.			
Construction			
Provide design support during construction.			
Attend pre-bid meeting.			
Review shop drawings.			
Assist PE and SR in documenting lessons learned on the foundation design and construction issues for the final lessons learned report			

Caltrans ACCELERATED BRIDGE CONSTRUCTION

Appendix D

UHPC IMPLEMENTATION

District 3

Echo Summit Sidehill Viaduct, Highway 50, El Dorado County, CA

CONTENTS

APPENDIX D. CALTRANS IMPLEMENTATION OF ULTRA-HIGH PERFORMANCE CONCRETE D-1

D.1 INTRODUCTION D-1

D.2 PRECAST SUBSTRATE PREPARATION D-1

D.3 FORMWORK D-2

D.4 MIXING D-2

D.5 PLACEMENT D-3

D.6 CURING D-3

D.7 RATE OF STRENGTH GAIN D-4

D.8 FINISHING D-4

D.9 STRENGTH AND LOADING D-4

D.10 MOCK-UPS D-5

D.11 POLYESTER CONCRETE OVERLAY ON UHPC DECK JOINT D-6

D.12 QUALITY CONTROL/QUALITY ASSURANCE TESTING REQUIREMENTS AND METHODS D-6

D.12.1 Alternatives to a Cylinder Test to Determine Compressive Strength D-7

D.12.1.1 Definitions D-7

D.12.1.2 Cube Testing D-8

D.12.1.3 Maturity Method D-8

D.12.1.3.1 Implementation of The Maturity Method D-9

D.12.1.3.2 Process D-9

D.12.1.3.3 Develop the Maturity Curve D-9

D.12.1.2.4.1 Presentation of Data: D-11

D.12.1.2.4.2 Validate Maturity Curve D-11

D.12.1.3.4 Estimate the In-Field Strength of UHPC D-12

D.12.1.3.5 Verifying Opening Age Strength D-12

D.12.1.3.6 Reference Material for Caltrans Maturity Method Implementation D-12

D.13 WORK PLANS D-13

D.13.1 Example UHPC Work Plan D-13

D.13.2 Example UHPC Mock-Up Work Plan D-15
D.13.3 Example Maturity Method Work Plan D-16
D.13.4 Example UHPC Construction Checklists D-17
D.14 REFERENCES D-17

APPENDIX D. CALTRANS IMPLEMENTATION OF ULTRA-HIGH PERFORMANCE CONCRETE

D.1 INTRODUCTION

This appendix provides information for the successful implementation of Ultra-High Performance Concrete (UHPC) field cast connections of precast concrete bridge elements used on Caltrans bridge projects. Information in this document has been derived from the Federal Highway Administration (FHWA) UHPC publications *Design and Construction of Field-Cast UHPC Connections* (Graybeal 2019) and *Bond of Field-Cast Grouts to Precast Concrete Elements* (Graybeal 2017) as well as experience gained on UHPC Caltrans projects. A link to the website for FHWA UHPC publications and a list of Caltrans UHPC projects are available in Section 4.8.3.

D.2 PRECAST SUBSTRATE PREPARATION

Proper preparation of the precast substrate is essential for interface bonding between the UHPC and the precast concrete element. When executed properly, the interface bond strength exceeds the strength of the precast concrete element.

Studies by the FHWA have shown that the best interface bond strength results from an exposed aggregate preparation of the precast concrete surface to receive the UHPC (Graybeal 2017). An exposed aggregate surface is easily achieved through the use of form retarder and pressure washing. It is important to note that mechanically or form roughened surfaces do not provide equivalent results and are not acceptable for UHPC applications.

Additionally, it is critical that the precast concrete surface be clean to eliminate contaminants that inhibit bond and is pre-wet to a saturated surface dry (SSD) condition immediately prior to UHPC placement to prevent the dehydrating effect of dry concrete against freshly placed UHPC. Due to the absence of an approved method of measuring the SSD condition, the contractor is directed to continually pre-wet the surface for a minimum of two hours before placement of the UHPC.

To summarize, a properly prepared UHPC substrate must be a clean, saturated surface dry, exposed aggregate surface.

Because proper surface preparation plays such an important role in long-term performance, substrate requirements should be clearly communicated to the contractor through the contract plans and specifications, during shop drawing and work plan review, as well as fabrication and construction inspection.

D.3 FORMWORK

Formwork must be constructed of nonabsorbent material. Formwork must be watertight and able to resist the hydrostatic pressures from UHPC in the unhardened state.

For deck-grade joints, top forming is required to hold the UHPC in place. Deck-grade joint forms are constructed to produce a 3/8-inch over pour to account for subsidence and grinding.

“Chimneys” are employed (typically in the form of a bucket with a hole cut out of the bottom directly above the UHPC) to provide a pressure head. The pressure head created by the chimney ensures that the connection voids are completely filled.

D.4 MIXING

UHPC is delivered in proportioned and premixed sealed bags. The mix components are sensitive to temperature and moisture and must be stored in a dry, climate-controlled environment prior to use. The shelf life of the premix must not be exceeded at the time of mixing. The date of manufacture for the UHPC must be no more than 18 months before the UHPC is placed. The age of the material at the time of field placement may not exceed the lesser of the manufacturer’s recommendation or 18 months from the date of manufacturing.

UHPC is mixed onsite in small batches. A UHPC manufacturer’s representative must be present for mixing and placing UHPC.

High shear mixers are recommended for the efficient production of UHPC due to a combination of increased energy input requirements, low water content, and the absence of coarse aggregate. A minimum of two mixers is required to provide a continuous flow of UHPC for placement and provide back-up in the event of mixer malfunction. Mixers should be sized based on the UHPC delivery rate required for the project.

The fluidity of UHPC is temperature sensitive. Methods for controlling UHPC temperature during mixing are an important component of quality control, as detailed in the contractor’s work plan.

Mix quality of UHPC is assessed through an onsite slump cone flow test. This test is completed immediately after mixing in order to assess consistency between batches and acceptance for casting per Caltrans specifications. The UHPC must be thoroughly mixed and free of clumps when placed.

D.5 PLACEMENT

Typically, UHPC is conveyed by bucket for small amounts, or wheelbarrows and motorized buggies for larger pours. The effectiveness of motorized buggies is dependent on the training of the operator and the means of directing the flow of UHPC from the buggy to the connection. These items are to be addressed in both the UHPC work plans and during mock-up.

Pouring UHPC down a chute or pumping is problematic and discouraged. Allowing the UHPC to flow along a channeled surface can cause the fibers to align and weaken the UHPC matrix. Pumping can easily lead to overheating the UHPC. When the temperature of UHPC exceeds 80 degrees Fahrenheit (F), the UHPC can lose its workability and may not self-consolidate. If the contractor proposes these methods, the method must be demonstrated in advance, preferably prior to and during the mock-up phase and be accompanied with a well-vetted, documented work plan.

UHPC is self-consolidating and does not require vibration. Vibration of UHPC is not allowed as this action may cause the fibers to settle to the bottom of the pour. Rodding is acceptable where two successive pours meet.

UHPC pours are to be continuous to avoid cold joints. UHPC does not bond well to itself once hardened. In the event a pour is interrupted, a bulkhead is preferable to leaving a joint partially filled with UHPC. It is beneficial to texture and/or roughen the face of the bulkhead surface.

To address subsidence and ensure connection voids are filled, a pressure head must be sustained. Chimneys are to be checked throughout the pour to ensure they are adequately filled with UHPC.

Tight spaces can restrict UHPC flow. To support effective UHPC flow, provide a minimum clear spacing of 1.5 times the fiber length in connection detailing, as discussed in *AASHTO LRFD Guide Specifications for Accelerated Bridge Construction* (AASHTO GSABC) (AASHTO 2018) Section 3.6.2.4.3.

D.6 CURING

The focus of curing UHPC is moisture retention and maintaining a minimum temperature to attain the minimum required strength. Installation of formwork or other approved covering should commence immediately after placement to prevent the loss of mix water.

UHPC should remain sealed from exposure to the external environment until attaining a compressive strength of at least 12 ksi.

UHPC should not be subjected to freezing temperatures before attaining a compressive strength of 10 ksi. In cases where external heat is applied, UHPC temperature should not exceed 160 degrees F or manufacturer's recommendation.

UHPC cylinders taken at the time of field placement should be cured in similar environmental conditions as the in-place material.

The UHPC is to remain undisturbed until it reaches a compressive strength of 12 ksi and fully loaded at 14 ksi. Construction activities or adjacent traffic resulting in relative movement of the field-cast UHPC connections before it is set can weaken the connection. This issue becomes of particular importance when scheduling work near the UHPC connection after placement, or on projects with staged construction. Means and methods for preventing relative movement during cure of UHPC are to be developed by the contractor and included in the UHPC workplan.

D.7 RATE OF STRENGTH GAIN

The rate of compressive strength gain of UHPC is highly dependent on cure temperature and mix design. Warmer temperatures lead to faster strength gain. When considering manufacturer's claims regarding the rate of strength gain of a given UHPC material, it is critical to know the assumed UHPC cure temperature and how that relates to the construction conditions of a particular project.

In cases where rapid cure rates are important to the critical path, the specifications should include a chosen external curing temperature for heat to be applied during curing and require pre-heating of precast elements receiving the UHPC. When possible, it is helpful to schedule UHPC placement during warmer months of the year.

D.8 FINISHING

Once the forms are removed the joints are ground to bring them to deck level and remove any UHPC laitance that may form. Grinding and grooving can be performed on UHPC surfaces and are easier if performed before the UHPC reaches its full compressive strength. Grinding and grooving can be started when the UHPC attains 12 ksi if the equipment is relatively light (hand operated machinery). For heavier machinery, grinding or grooving may be started at 14 ksi.

D.9 STRENGTH AND LOADING

The compressive strength of 14 ksi is the strength at which the UHPC is mature enough to be fully loaded and at which the rebar development length equations of *AASHTO GSABC* Section 3.6.2.4 are applicable.

The 28-day compressive strength of UHPC is a minimum of 21 ksi. Due to a flattening of the rate of strength gain curve in early strength UHPC mixes, the number of days to achieve 21 ksi for early strength UHPC is extended to 56 days. Achieving a compressive strength of 21 ksi demonstrates that the UHPC has fully matured and indicates that the expected durability properties have been obtained.

It is important to keep precast elements stable during placement and curing of UHPC. Differential movement of the precast elements during the curing period (up to 12 ksi) can degrade the bond of the UHPC to the substrate (precast concrete and reinforcing steel). Preventing loading to the structure while the UHPC attains strength will mitigate structural deformations that lead to weakening the connection and compromising durability.

D.10 MOCK-UPS

Mock-ups of UHPC connections of prefabricated elements serve several purposes and are essential for producing quality connections. Mock-ups require the contractor to demonstrate means, methods, and capability of constructing connections with a new material that behaves quite differently from conventional concrete, grout, or rapid strength concrete. Mock-ups provide an opportunity for the contractor to learn, test, and correct means and methods to deliver a quality product at a rate that supports the accelerated construction schedule before the actual construction. Mock-ups also benefit Caltrans by educating construction administration and quality assurance staff on proper inspection and testing methods. It is important that the contractor and Caltrans staff participating in the mock-up are the same individuals performing and inspecting the work in the field.

The fabrication of the precast concrete mock-up elements demonstrates that the fabricator can control the dimensions and rebar locations necessary for fit-up and, very importantly, produce the exposed aggregate surface required for an effective UHPC to precast concrete interface bond. Precast concrete elements for the mock-up are to be fabricated using the same mix design and reinforcing steel specified for the bridge elements to verify that the means and methods employed on the mock-up will be effective for the field connections. This includes the use of epoxy coated or galvanized rebar.

The mock-up also serves to educate the contractor on watertight forming, developing formwork that can resist the full hydrostatic head expected during field installation, curing techniques including moisture containment, supplemental heating when required, and proper test cylinder preparation.

Due to the fluid nature of UHPC, mock-ups are to be built at the same profile and cross-slope as the field installation to show the contractor can contain and form the material within the pour space.

The mock-up shall employ the same means and methods that will be used for the field installation, which includes equipment and staff.

The mock-up must demonstrate that the UHPC:

- Completely fills all voids;
- Is free of clumps;
- Does not leak during placement;
- Fully encapsulates reinforcement and embedments;
- Has a uniform distribution of steel fibers;
- Attains a compressive strength of 14 ksi within the time specified; and
- Is free of laitance when the exposed UHPC surfaces are ground to the specified elevation.

Typically, two mock-ups are performed for each connection detail.

D.11 POLYESTER CONCRETE OVERLAY ON UHPC DECK JOINT

It is common practice to place a polyester concrete overlay on top of precast deck elements to provide a smooth riding surface and to match grade. The use of UHPC in deck joints (Echo Summit Viaduct Replacement, 03-3F5304) raised the question of cure requirements for the UHPC prior to polyester concrete placement. In response, the Office of Structural Materials performed validation tests to determine the proper hydration and corresponding compressive strength of UHPC required prior to polyester concrete overlay placement, and the report entitled *Estimating UHPC Strength with Maturity Method, Echo Summit Sidehill Viaduct* (Caltrans 2018) is available on the ABC website. The tests demonstrated that polyester concrete to UHPC interface bond strength surpassed the requirements set forth in Caltrans Standard Specifications for that of Portland Cement Concrete at a UHPC compressive strength of 12 ksi. Caltrans special provisions require the UHPC to reach a compressive strength of 14 ksi prior to polyester concrete placement to avoid heavy construction loading until the design strength of the connection is fully developed.

The polyester concrete overlay also provides a uniform appearance to a bridge deck with UHPC connections. The steel fibers at the surface of the UHPC tend to rust over time and the UHPC connections are a different color than the rest of the deck. While neither of these issues influences the performance or durability of the deck, they can lead to a confusing lane line appearance and an undesired aesthetic.

D.12 QUALITY CONTROL/QUALITY ASSURANCE TESTING REQUIREMENTS AND METHODS

Proprietary UHPC material performance testing includes tests for compressive strength, durability, chloride penetrability, and flow (ASTM C1856 with modifications), Alkali-silica reaction (ASTM C1567 with modifications), soluble chlorides (California Test 422), soluble sulfate (California Test 417), and soundness (CT 214). ASTM C1856 “Standard Practice for Fabricating and Testing Specimens of Ultra-High Performance Concrete” (ASTM 2017) references the standard concrete cylinder compression test, ASTM C39, with minor modifications including the size of cylinder, rate of loading, and the requirement to end-grind both ends of the cylinders.

Caltrans project special provisions on UHPC material testing include modifications to ASTM C1856 such that a compressive test represents not more than 25 cubic yard of concrete and consists of the average of compressive strength of 5 cylinders. In addition, Caltrans specifications require cylinders to be prepared using an automatic concrete cylinder end-grinding machine. These modifications result from lessons learned on previous Caltrans UHPC projects in order to promote the accuracy and consistency of UHPC compressive strength test results. Caltrans is currently evaluating the inclusion of a direct tension cracking strength and interface bond test in the acceptance criteria.

D.12.1 Alternatives to a Cylinder Test to Determine Compressive Strength

Due to accelerated construction schedules and project location, compressive strength testing by breaking cylinders in a laboratory setting is not always feasible for mock-up and production testing. Testing UHPC cylinders on site is problematic due to testing machine capacity and cylinder end preparation. Two approaches that provide alternatives to cylinder testing to estimate compressive strength of UHPC are cube testing and the use of the maturity method.

D.12.1.1 Definitions

Accelerated Heat Curing: Using external heat to promote high early strength concrete.

Automated Concrete Cylinder End Grinding Machine: An automated, fixed end grinder that laps each end of the concrete cylinder by passing a diamond tipped grinding blade perpendicular to the axis of the cylinder that is capable of grinding multiple 3 inch x 6 inch cylinders in one operating cycle.

Chosen External Curing Temperature: External curing temperature of UHPC for which the strength-maturity relationship is established by conducting maturity testing during prequalification of UHPC.

Maturity Curve: The relationship between the maturity index and the strength of the concrete.

Maturity Index: The maturity index is a value that represents the progression of concrete curing. Depending on the maturity function used to calculate the maturity index, the units are expressed in either degree-hours (Time-Temperature Function) or hours (Equivalent Age).

Maturity Instruments: Instruments that compute and display the maturity index directly from the temperature history of the cementitious mixture in degree-hours.

Maturity Method: A technique for estimating concrete strength that is based on the assumption that samples of a given concrete mixture attain equal strengths if they attain equal values of maturity index.

Opening Age: Minimum age of UHPC corresponding to a compressive strength of 14 ksi.

Validation Test: Testing, through concrete cylinder breaks and monitoring of the maturity index, to confirm the validity of the maturity curve used to estimate the UHPC compressive strength.

Verification Test: Verify that the compressive strength of UHPC is equal to or greater than 14 ksi through cylinder breaks.

D.12.1.2 Cube Testing

Cube testing addresses the challenges of test machine capacity and surface preparation by testing smaller UHPC specimens that are formed into cubes that do not require grinding. Cube testing can be conducted in a lab or with a mobile lab onsite. Caltrans funded research is currently being conducted at Iowa State University (Contract 65A0779) to determine the efficacy of using cubes in lieu of cylinders. The desired outcome of the research is recommendations for cube size and a converting factor (ratio) to compare compressive strength results of cube and cylinder specimens.

D.12.1.3 Maturity Method

The maturity method is a useful alternative when the schedule of the project does not support the traditional method of breaking cylinders at an offsite laboratory to determine compressive strength.

The maturity method is a non-destructive method used to estimate the real-time strength development of in-place concrete. It is based on the principle that concrete strength is directly related to its hydration temperature and relies on the measured temperature history of the UHPC to estimate strength development during the curing period.

The maturity method is used to determine the age for stripping forms and loading the UHPC connection with construction equipment. The age for opening the structure to traffic is verified by cylinder breaks.

Maturity is specific to the mix design; therefore, the maturity method requires pre-calibration of a concrete mix before it can be used for estimating the concrete strength in a project. When the mix design is changed, a new maturity relationship must be developed. Once the maturity calibration curve is developed and validated for a specific mix, it can be used for onsite estimation of compressive strength of concrete in real time.

Refer to the National Institute of Standards and Technology "The Maturity Method: From Theory to Application" (Carino and Lew 2001), for a summary of the theory of the maturity method and how it is implemented.

D.12.1.3.1 Implementation of The Maturity Method

The Caltrans requirements for the implementation of the maturity method for UHPC are based on ASTM C1074-19 "Standard Practice for Estimating Concrete Strength by the Maturity Method" (ASTM 2019) with modifications related to UHPC properties, information from validation tests performed by the Office of Structural Materials is in the report entitled *Estimating UHPC Strength with Maturity Method, Echo Summit Sidehill Viaduct* (Caltrans 2018), which is available on the ABC website, and the lessons learned from the first application of the Maturity Method with UHPC on the Echo Summit Sidehill Viaduct (EA 03-3F5304).

D.12.1.3.2 Process

Key considerations for the use of the Maturity Method for high, early strength UHPC with accelerated heat curing applications are summarized below.

The development of a maturity-strength relationship for UHPC requires four steps. These include:

1. Develop the maturity curve.
2. Validate the maturity curve.
3. Estimate of the compressive strength of the UHPC that is placed in the field.
4. Verify the opening age strength prior to opening the structure to traffic.

D.12.1.3.3 Develop the Maturity Curve

Number of Data Points: The maturity-strength curve is based on the average compressive strength of test specimens at a specified age. The ASTM C1074 standard requires a minimum of five points representing five different ages. However, experience has shown that for accelerated strength UHPC, the curve is more meaningful with seven points. The age of testing should therefore be customized to optimize the calibration curve of the concrete for the specific applications with a minimum of seven points. For example, a recommended series of age breaks for a project requiring targeted strength within 18 hours of placement is 10, 12, 14, 16, 18, 20, and 24 hours. This sequence captures the typical dwell time that is followed by rapid strength gain of the UHPC. Due to fresh properties of UHPC, age breaks corresponding to strengths below 10 ksi are difficult to test and can lead to inconclusive data. Samples for determining 28- or 56-day strength are not included in the maturity curve data and can be tested through conventional means to demonstrate compliance.

Number of Calibration Cylinders: ASTM C1074 states that for each age of the UHPC selected for testing, a comprehensive test represents the average compressive strength of three cylinders made from the material taken from a single batch of concrete. Experience has shown that a larger sample size is beneficial for higher strengths where variation in individual compressive strength results is more common. Caltrans requires five cylinders for each age of the UHPC to be tested.

Maturity instruments: Only maturity instruments that directly display the maturity index are allowed. Temperature loggers are not allowed to calculate the maturity index. Maturity instruments that monitor temperature and compute and display the maturity index are to be embedded in UHPC specimens. Due to the potential of the steel fibers in the UHPC blocking the Bluetooth signal when the maturity instrument is fully embedded in material, it is recommended that the instrument lead be embedded in the UHPC with the box portion of the instrument left outside of the UHPC. Caltrans specifications require maturity instruments in at least five specimens. One instrumented cylinder is provided to the department to accompany the quality assurance (QA) cylinders. The remaining instrumented cylinders provide an average maturity index value and redundancy of equipment for quality control (QC). In addition, two maturity instruments (one for QC and one for QA) are to be left out of a specimen to log ambient curing conditions. Maturity instruments must be capable of continuously logging and storing maturity data, be accurate to within +/- 1 degree Celsius when calibrated, take readings every 15 minutes, and print data or download into a spreadsheet.

Time interval for data recording: Judgment should be used in selecting the time intervals to record maturity data in mixtures that result in rapid changes in early-age temperature due to accelerated hydration. Maximum data collection time intervals of 15 minutes deliver adequate data points to develop the maturity-strength relationship for early high strength UHPC and is compatible with the recording capabilities of maturity instruments on the market.

Curing QC cylinders: All cylinders and the ambient monitoring maturity instrument must be placed together under specific curing conditions to ensure that the temperature and curing conditions are the same for the concrete cylinders that are being tested for strength and the ones containing the maturity instruments. Cure the cylinders to develop the maturity curve at the same external heat that is anticipated in the field. For example, if the specifications call for an accelerated heat cure in the field of 120 degrees F, the cylinders are to be cured in an environmental chamber at 120 degrees F. Do not allow the UHPC internal temperature to exceed 160 degrees F (or manufacturers recommendation) to avoid damage to the material. Avoid disturbing cylinders during the curing process.

Curing QA cylinders: Cylinders can be carefully transferred to the Caltrans testing facility in a thermal container for QA testing after eight to ten hours or an anticipated strength of 10 ksi. Place cylinders in a temperature-controlled chamber under similar conditions as the QC cylinders. Keep the cylinder with a maturity instrument with the QA cylinders.

End preparation of cylinders: Proper end preparation of UHPC cylinders or strength testing is paramount. Due to the high stress of UHPC, end-cap caps are not used for compressive strength testing. Cylinder ends must be ground smooth using an automated concrete cylinder end-grinding machine.

Building the Strength-Maturity Relationship: For each age selected, the average strength is obtained by breaking the cylinders in compliance with ASTM C1856 with California modifications. The corresponding maturity index is recorded for the cylinder breaks and the strength and the maturity index are correlated. Plotting compressive strength vs. the maturity index develops the maturity curve.

D.12.1.2.4.1 Presentation of Data:

General: Project ID, Tester, Location, Curve #, Mix Information, Report Date, Casting Date, Casting Time, Datum Temperature, External Curing Temperature, Ambient Temperature, Estimated Required Maturity Index for Opening

Maturity Curve: X-axis – Maturity Index (C-hours), Y-axis – Compressive Strength (psi)

For each specimen: Specimen ID, Age of Break (hours), Average Diameter, Average Length, Total Test Load (lbs.), Failure Type, Compressive Strength (psi), and maturity index recording from maturity instruments.

D.12.1.2.4.2 Validate Maturity Curve

The relationship developed between the maturity index and the strength of the concrete is validated by cylinder breaks. Four sets of five cylinders are tested at ages that bound the targeted strength of 14 ksi. For example, a recommended series of age breaks for a project requiring targeted strength within 18 hours of placement is 10, 12, 14, 16, 18, 20, and 24 hours. The cylinders are cured at the same external temperature as those used to establish the curve. The maturity value is recorded for each age tested. The validation data points are plotted against the maturity curve. The curve is validated if the validation data points fall within the ten percent limits of the curve. Validation breaks are typically conducted during the UHPC installation mock-up. Ambient curing temperature for QA, QC, and mock-up are to be monitored and recorded with maturity instruments.

D.12.1.3.4 Estimate the In-Field Strength of UHPC

To estimate the in-place concrete strength in the field, maturity instruments are placed in the UHPC field application at the specified location and frequency. UHPC compressive strength is estimated by applying the in-field maturity index reading to the authorized maturity curve.

D.12.1.3.5 Verifying Opening Age Strength

As a safety precaution, the opening age strength of 14 ksi is verified through cylinder breaks before the structure is opened to traffic.

D.12.1.3.6 Reference Material for Caltrans Maturity Method Implementation

Refer to the following references from the American Society of Testing Materials (ASTM) for maturity method implementation:

- *ASTM C1074-19e1, Standard Practice for Estimating Concrete Strength by the Maturity Method* (ASTM 2019)
- *ASTM C1856 / C1856M-17, Standard Practice for Fabricating and Testing Specimens of Ultra-High Performance Concrete* (ASTM 2017)

Refer to the following report on the Caltrans ABC website for an example of strength-maturity curve development:

- *Estimating UHPC Strength with Maturity Method, Echo Summit Sidehill Viaduct, EA# 03-3F530* (Caltrans 2018)

Refer to the following guidance materials for developing maturity method specifications from the Minnesota Department of Transportation (MnDOT) Concrete Maturity webpage.

- *Estimating Concrete Strength by the Maturity Method* (MnDOT 2017)
- Special Provision 2461.3.G.6, *Development of Maturity-Strength Relationship* (MnDOT 2020)

Refer to the following sample specification from the New York Department of Transportation (NYSDOT):

- Specifications Item 557.6601NN39, *UHPC Joint Headers* (NYSDOT 2015)

Refer to the following from the National Institute of Standards and Technology (NIST) for a discussion on the development of the maturity method:

- *The Maturity Method: From Theory to Application* (Carino and Lew 2001)

D.13 WORK PLANS

Work plans are developed by the contractor to communicate the means and methods, from procurement to finishing, for the successful implementation of UHPC in a project. The work plans are a combination of the requirements as called out on the plans and specifications, manufacturers' recommendations, and best practices identified during the prequalification and mock-up stages.

UHPC projects require a UHPC Work Plan and a Mock-up Work Plan. In cases where the maturity method is included in the specifications, a Maturity Method Work Plan is also required.

The authorized UHPC work plans shall be available onsite during UHPC placement and shall be reviewed and discussed by both Caltrans and the contractor's staff prior to prequalification, mock-up, and field installation by those who will be doing the work, inspection, and QC/QA.

The following sections are examples of the requirements for each type of work plan. These requirements should be modified as necessary to align with the specific project:

D.13.1 Example UHPC Work Plan

- QC plan including:
  - Name of laboratory that will perform QC testing
  - Equipment list
  - Test setup
  - Sampling method
  - Qualifications of laboratory personnel
  - Means and methods for end grinding cylinders including grinding machine model information
  - Frequency and type of tests for:
    - Prequalification
    - Mock-up
    - Production
  - Qualifications of laboratory personnel
- Means and methods for UHPC receiving surfaces to achieve surface finish of exposed aggregate with minimum amplitude of 1/8 inch, an average amplitude of 1/3 of the size of the aggregate, and a maximum amplitude of ½ the size of the aggregate.

- Manufacturer's mix design
- Method of calculating quantity of UHPC material to have on hand for the complete placement of UHPC with allowances for keyway geometry and overages due to fabrication and assembly tolerances, installation method, QC/QA testing, and waste.
- Means and methods for storing UHPC raw materials under contractor's possession and on the job site per manufacturer's recommendations including methods for keeping material dry and within allowable temperature ranges
- Mixing Equipment and methods including
  - Method for controlling mix temperatures (if using ice, provide information on storing ice and determining volume of water if using ice)
  - Weighing equipment
  - Shear mixer model, number of mixers, operational information, and estimated output rate in cubic feet per hour
  - Site locations of equipment
- UHPC connection casting procedures
  - UHPC placement sequence and schedule
  - UHPC formwork means and methods including:
    - Forming vents and seals for leak prevention
    - Setting top forms for deck-level connections at a minimum of 3/8 inch above the top of deck to allow for overfilling
    - Securing nonabsorbent top forms to resist hydrostatic pressure
    - Anticipated chimneys and bulkhead locations
  - Number and locations of maturity sensors (if required)
  - Means and methods for ensuring SSD connection interfaces (UHPC receiving surfaces pre-wet for a minimum of two hours immediately before UHPC placement)
  - Means and methods for preheating girder keyways (if appropriate due to environment and/or schedule)
  - Conveyance equipment
  - Means and methods for UHPC placement including providing hydrostatic head and over filling joints by approximately 3/8 inch
  - Prevent vibration of UHPC during placement
  - Contingency plan if pouring operations are interrupted by weather, equipment malfunctions, or other issues)

        - Means and methods of forming bulkhead
- UHPC Curing procedures including means and methods for:
    - Minimizing moisture loss from fresh UHPC
    - Preventing vibration of UHPC during curing
    - Preventing relative displacement of UHPC joint until UHPC has reached a compressive strength of 14 ksi
    - Providing accelerated heat curing for UHPC to achieve the minimum compressive strength in the required amount of time as specified (if appropriate due to environment and/or schedule)
- Means and methods for grinding UHPC surfaces
- Continency plan for repair of partially filled joints and cold joints
- Copy of QC Manager's certification
- Copy of the manufacturer's instructions
- Product material safety data sheets

D.13.2 Example UHPC Mock-Up Work Plan

- Location of fabricating PC concrete components of mock-ups
- Means and methods for surfaces of concrete members to receive UHPC to achieve exposed aggregate finish with a minimum amplitude of 1/8 inch, an average amplitude of 1/3 of the maximum aggregate size, and a maximum amplitude of ½ the size of the maximum aggregate size
- Location of performing the mock-up work
- Locations and details of devices for lifting and handling mock-ups
- Methods for the mock-up to replicate the geometry of the structure and demonstrate the maximum hydrostatic head expected in UHPC placement in the field
- UHPC connection casting procedures
    - UHPC formwork means and methods including:
        - Forming vents and seals for leak prevention
        - Setting top forms for deck-level connections at a minimum of 3/8 inch above the top of deck to allow for overfilling
        - Securing non-absorbent top forms to resist hydrostatic pressure
        - Anticipated chimneys and bulkhead locations

    - Number, locations, and installation details of maturity sensors, as required
    - Means and methods for ensuring SSD connection interfaces (UHPC receiving surfaces pre-wet for a minimum of two hours immediately before UHPC placement)
    - Means and methods for preheating girder keyways, if appropriate due to environment and/or schedule
    - Conveyance equipment
    - Means and methods for UHPC placement including providing hydrostatic head and over filling joints by approximately 3/8 inch
    - Prevent vibration of UHPC during placement
- UHPC Curing procedures including means and methods for:
    - Minimizing moisture loss from fresh UHPC
    - Providing accelerated heat curing for UHPC to achieve the minimum compressive strength in the required amount of time specified, if appropriate due to environment and/or schedule
- Means and methods for grinding UHPC surfaces
- Means and methods for saw cutting the mock-ups
- Proposed schedule for casting PC concrete mock-up components, placing UHPC, testing specimens, and saw cutting

D.13.3 Example Maturity Method Work Plan

- The chosen external curing temperature
- Means and methods for maintaining the external curing temperature throughout the maturity testing
- Methods and equipment to be used for measuring, logging, storing, retrieving, and/or downloading the maturity index of in-place UHPC. Only maturity instruments that directly display maturity index are allowed
- Frequency of maturity index readings
- Accuracy range of equipment when calibrated to manufacturer’s recommendations
- Methods to be used for compressive strength testing of UHPC specimens for specified testing intervals
- Means and methods for:
    - Establishing the maturity curve at prequalification to determine the compressive strength of UHPC up to 14 ksi

- Validating the maturity curve at mock-up
- Using the authorized maturity curve to determine the compressive strength of UHPC placed in the field

- Templates for submittal of strength-maturity relationship data and sample graph showing compressive strength versus maturity index for the chosen temperature

D.13.4 Example UHPC Construction Checklists

Checklists for the construction of UHPC connections for prefabricated bridge elements are included in Appendix E.

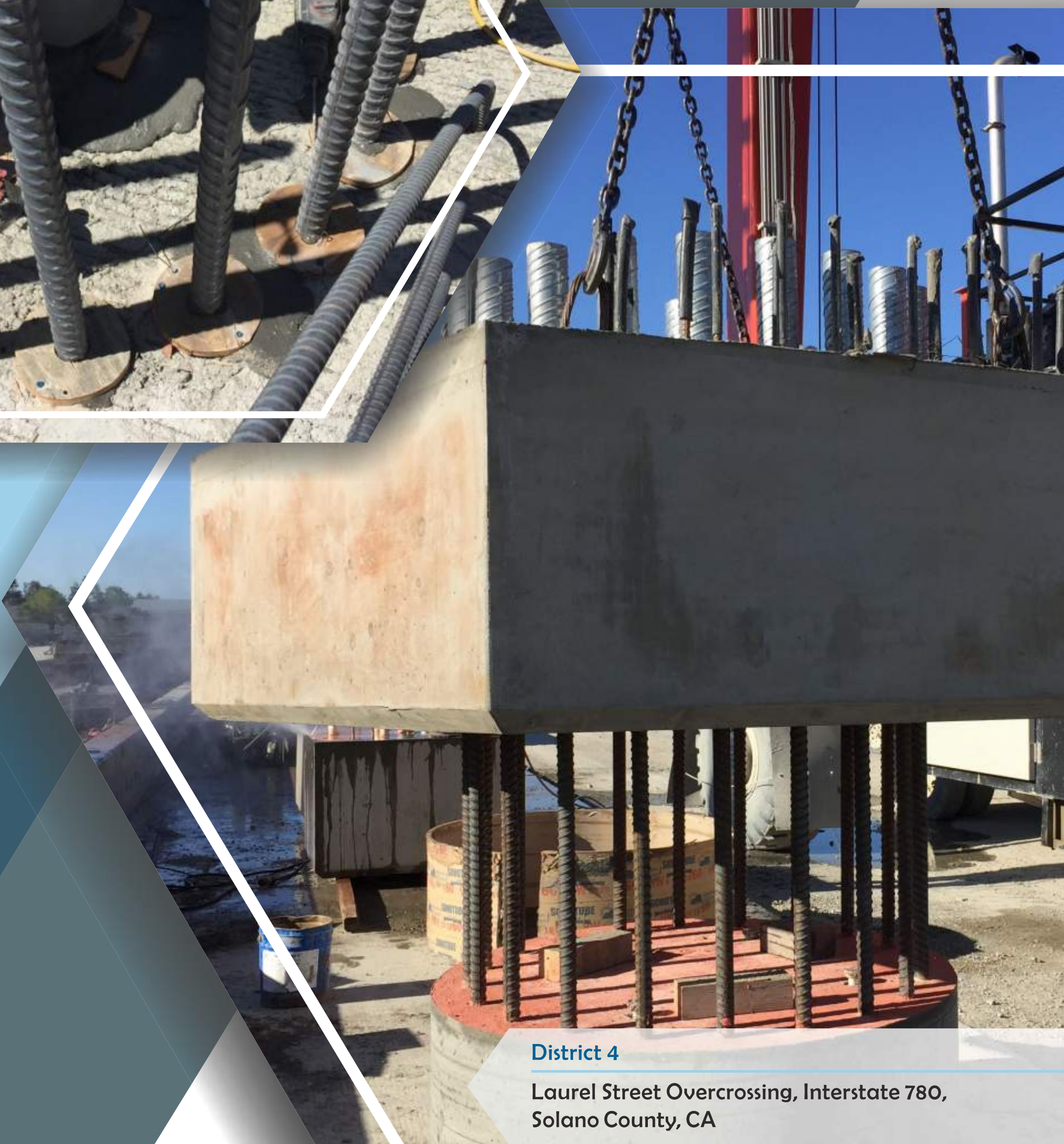
D.14 REFERENCES

1. Graybeal, B. (2019). TechNote: Design and Construction of Field-Cast UHPC Connections, Report No. FHWA-HRT-19-011. FHWA, Washington, DC.
2. Graybeal, B. (2017). TechNote: Bond of Field-Cast Grouts to Precast Concrete Elements, Report No. FHWA-HRT-16-081. FHWA, Washington, DC.
3. AASHTO (2018) *AASHTO LRFD Guide Specifications for Accelerated Bridge Construction*, 1st Edition. American Association of State Highway Transportation Officials, Washington D.C.
4. Caltrans. (2018). *Estimating UHPC Strength with Maturity Method, Echo Summit Sidehill Viaduct*, EA# 03-3F530*,* Office of Structural Materials. California Department of Transportation, Sacramento, CA.
5. ASTM. (2017). *ASTM C1856 / C1856M-17, Standard Practice for Fabricating and Testing Specimens of Ultra-High Performance Concrete*. ASTM International, West Conshohocken, PA.
6. Carino, N. and Lew, H. (2001). “The Maturity Method: From Theory to Application,” *Structures Congress and Exposition*. National Institute of Standards and Technology, Gaithersburg, MD.
7. ASTM. (2019). *ASTM C1074-19e1, Standard Practice for Estimating Concrete Strength by the Maturity Method*. ASTM International, West Conshohocken, PA.
8. MnDOT. (2017). *Estimating Concrete Strength by the Maturity Method*. Minnesota Department of Transportation, St. Paul, MN.
9. MnDOT. (2020). *Development of Maturity-Strength Relationship*. Special Provision 2461.3.G.6, Minnesota Department of Transportation, St. Paul, MN.
10. NYSDOT. (2015). *UHPC Joint Headers*, Specifications Item 557.6601NN39. New York State Department of Transportation, Albany NY.

ACCELERATED BRIDGE CONSTRUCTION

Appendix E

UHPC CHECKLISTS



District 4

Laurel Street Overcrossing, Interstate 780, Solano County, CA

APPENDIX E ULTRA-HIGH PERFORMANCE CONCRETE (UHPC) CHECKLISTS

E.1 INTRODUCTION

These checklists for the construction of Ultra-High Performance Concrete (UHPC) connections for prefabricated bridge elements are intended as technical assistance. Additional technical assistance on the construction of UHPC connections can be found in Appendix D.

This document follows the flow of a project construction schedule in phases of Pre-Award, Preconstruction, Mock-up Casting, Field Casting, Post-Placement, and Project Closeout. Each phase contains subsections with introductory text and checklists, specific to UHPC only. Personnel using this construction checklist should be knowledgeable in bridge construction and UHPC technology, as discussed in Section 4.8.3 and Appendix D.

Depending on the type of UHPC connection and the project specifications, not all the items in the following checklists may be applicable. The user will need to determine which items are pertinent to their specific project.

Where applicable, the appropriate UHPC test standard is referenced or specified.

Note that the following terminology is used throughout these checklists:

- ASTM – American Society of Testing and Materials
- QA/QC – Quality assurance and quality control
- SSD – Saturated surface dry
- UHPC – Ultra-high performance concrete

E.2 Phase 1: Pre-Award Checklist

The pre-award checklist is used at the bid opening to determine if the contractor has met the minimum qualifications in the project specifications.

If this information is required by the project specifications, and it is not validated during pre-award, then it would be included in the preconstruction submittals. If Caltrans has a prequalified list of authorized suppliers, some of the requirements of this section may have been previously submitted and would not be required in the project specific submittals.

Table E.2-1 UHPC Checklist – Phase 1: Pre-Award

Phase 1: Pre-Award	Yes	No	NA	Comments
UHPC Material Acceptance: • Material supplier meets project specifications for: ▪ Strength properties ▪ Durability properties ▪ Other properties required by the project specifications ▪ UHPC supplier has supplied all test data required by the project specifications				
Contractor and Subcontractor Acceptance: • QC Manager for UHPC work meets the project specifications.				
Testing Laboratory's Acceptance (Note: The general contractor must confirm that these requirements are met): • Testing laboratory has equipment for (in accordance with ASTM C1856/C1856M): ▪ End grinding of cylinders ▪ Testing 3 inch x 6 inch cylinders ▪ Testing flexural prisms (if allowed)				

E.3 Phase 2: Preconstruction Checklist

The preconstruction checklist includes items that the contractor will submit for authorization before construction. Following the award of the contract, a preconstruction meeting should be held to review the submittals.

A full review of all submittals should be completed in accordance with Caltrans' normal procedural requirements, and a confirmation given to the contractor of authorization.

Table E.3-1 UHPC Checklist – Phase 2: Preconstruction

Phase 2: Preconstruction	Yes	No	NA	Comments
Construction Submittals • UHPC Work Plan • Maturity Method Work Plan (if applicable) • Mock-up Work Plan • Prequalification Test Results and Trial Batch Test Reports (including strength-maturity relationship data when strength-maturity testing is being used)				
QA/QC – Prequalification • Testing as required by the project specifications, • Perform maturity method testing to develop strength-maturity relationship, if required (ASTM C1074)				

E.4 Phase 3: Mock-up Checklist

The purpose of the mock-up casting is for the contractor to benefit from self-learning. Mock-up casting provides valuable lessons for contractors with little experience using UHPC, and even for the most experienced and qualified contractors. The mock-up casting also provides an advance trial of the project specific details and methods for all parties involved in the project.

Means and methods used for mock-up casting are to represent the means and methods to be used for field casting. This includes equipment and staff.

The project specifications may also require a trial batch prior to a full mock-up casting. For a trial batch follow the relevant section requirements of the mock-up casting checklist.

During the post mock-up casting review, the checklist provides several critical items to confirm. During this review, ensure any lessons learned during the mock-up casting are incorporated into the field casting phase and a new set of submittals are prepared, reviewed, and authorized before commencing the field casting phase.

Table E.4-1 UHPC Checklist – Phase 3: Mock-up Casting

Phase 3: Mock-up Casting	Yes	No	NA	Comments
Preconstruction Meeting • UHPC preconstruction meeting held at least 5 days before starting mock-up work. Review of Mock-up Work Plan, UHPC Work Plan, and Maturity Method Work Plan (if required) attended by the Engineer, UHPC manufacturer's representative (either in person or remotely), and the contractor's field QC manager				
Submittals prior to mock-up work • Authorized UHPC Work Plan and Mock-up Work Plan (copies available at mock-up construction site) • Strength-Maturity Reports – informational submittal of strength-maturity relationship data (if required) including compressive strength results and maturity index values and a plot graphing maturity index versus compressive strength of the specimen at the chosen external curing temperature of the specimen				

Phase 3: Mock-up Casting	Yes	No	NA	Comments
Construction of Mock-up • Mock-up is assembled in accordance with the Mock-up Work Plan • Mock-up forms and methods of UHPC placement and cure similar to those used in production work				
Personnel • All personnel are wearing proper personal protective equipment (for example: vests, safety boots, hardhats, glasses/goggles, gloves, and dust masks, where required) • Personnel performing mock-up work are the same as those who will be performing the production work • UHPC material supplier representative is on-site				
Safety • Safety data sheets (SDS) for the UHPC are available • All on-site personnel received a safety briefing by the UHPC supplier and contractor • Material supplier has reviewed the batching, transporting, and casting procedure with the on-site personnel				
Environmental • Operations are compliant with local environmental regulations • Rejected batches of UHPC have a designated disposal area (rejected batches are dumped in predesignated plastic or metal bins, then removed when hardened) • Wastewater or clean up water from mixers or other sources disposed of in accordance with environmental regulations				
UHPC Materials (pre-batching check for raw materials stored on-site) • Premix ▪ Correct product provided (product on-site matches product submittals)				

Phase 3: Mock-up Casting	Yes	No	NA	Comments
▪ Quantities are sufficient for mock-up casting ▪ Shelf life has not been exceeded (production date stamp on package or shipping tag: age of product is the lesser of 18 months or limit set by manufacturer recommendations. ▪ Stored properly – kept clean, dry, and within temperatures recommended by manufacturer • Fiber Reinforcements ▪ Correct product provided (product on-site matches product submittals) ▪ Quantities are sufficient for mock-up casting ▪ No signs of deterioration (excessive corrosion, such that balling occurs in the fibers) ▪ Stored properly – kept clean, dry, and within temperatures recommended by manufacturer • Chemical admixtures ▪ Correct product provided (product on-site matches product submittals) ▪ Quantities are sufficient for mock-up casting • Water ▪ Quantity is sufficient for mock-up casting ▪ Quality is acceptable (potable) • Ice (in hot weather up to 100 percent ice may be used in place of water) ▪ Quantity is sufficient for mock-up casting ▪ Stored properly – freezing temperature maintained				
Formwork • Formwork is installed as shown on the work plan submittals • Forms are clean and clear of debris and buildup of old concrete • Forms are made of nonabsorbent material				

Phase 3: Mock-up Casting	Yes	No	NA	Comments
• Formwork appears to be tightly sealed and designed to support the full hydrostatic pressure head of the UHPC in its plastic state • UHPC connection pours have been broken into isolated sections as shown on the submittals. • Top forms for deck-level connections are prepared and adequate hold downs for the top forms are available • Top forms for deck-level connections are set at a minimum of 3/8 inch above the top of deck to allow for overfilling, in accordance with project specifications • Chimneys for maintaining hydrostatic head are prepared and ready for installation with proper attachments • Maturity instruments are installed per manufacturer recommendations and per Mock-up Work Plan (if required)				
Prefabricated Elements • Mock-up prefabricated elements are fabricated with the same components and concrete mix as the field elements • Surface texture in connection areas that will be in contact with UHPC is an exposed aggregate finish with minimum amplitude of 1/8 inch, an average amplitude of 1/3 inch of the size of the aggregate, and a maximum amplitude of ½ the size of the aggregate • Precast concrete surfaces in connection areas are SSD (prewet continuously for a minimum of 2 hours) • The seal between the prefabricated elements and the supporting structures or adjacent elements are tight (grout tight – UHPC typically does not contain coarse aggregates, and seals need to be better than conventional practices and designed to support the full hydrostatic pressure head of the UHPC in its plastic state) • Prefabricated element rebar, studs or other connectors extend the proper distance into the connections, have proper lap splice length, and have a minimum clear distance of 1.5 times the fiber				

Phase 3: Mock-up Casting	Yes	No	NA	Comments
length to other objects, including to lapping rebar, or are in full contact with lapping rebar				
Equipment • Mixers (preferably a minimum of two) ▪ Size is adequate to provide a continuous flow of UHPC for placement ▪ In proper working condition ▪ Clean and free of a buildup of old concrete ▪ Power supply is adequate, and power is connected to mixers with the correct polarity such that mixers rotate in the correct direction (an electrician may be required – only required for mixers with electric motors) ▪ Charging point screen is used over mixer (check size of mesh opening [max 1.5 inches x 1.5 inches] and safety switch; for UHPC with longer fibers, mesh size opening may need to increase) ▪ Fins and blades are clean, with an acceptable level of wear, and properly spaced ▪ Gates working properly, tightly sealed, and clean (not leaking) • Buggies, wheelbarrows, and buckets ▪ Clean and free of a buildup of old concrete ▪ Gates (if available) working properly and tightly sealed ▪ Sprayed with a thin layer of authorized form release to prevent buildup and facilitate cleanup (caution: apply lightly to avoid contamination of the UHPC)				
QA/QC • QA/QC drawings and procedures are readily available on site and at the job office				

Phase 3: Mock-up Casting	Yes	No	NA	Comments
• QA/QC testing area is located close to the mixers on a level surface not impacted by vibrations from equipment and protected from disruptions due to the construction process and environmental conditions • Testing equipment ▪ Slump flow apparatus (ASTM C1856/C1856M) ▪ 3 inch x 6 inch cylinder molds (including six extra molds) (ASTM C1856/C1856M) ▪ Other molds or testing equipment if required by the project specifications (ASTM C1856/C1856M) ▪ Thermometer ▪ Funnel and 3 inch x 6 inch hand scoop for casting and placing of samples ▪ Camera • Batching records (as required by the project specifications; the following is an example) ▪ Name and location of batch plant (if not batched on-site) ▪ Date ▪ Name of contractor (if applicable) ▪ Name of batcher ▪ Specific job designation ▪ Amount of UHPC in cubic yards or cubic feet (per batch and total) ▪ Mass of each material component added to mixer ▪ Mixer identification number and/or batch number ▪ Time of water addition ▪ Time of discharge ▪ Mixing time ▪ Temperature (batch and ambient) ▪ Flow				

Phase 3: Mock-up Casting	Yes	No	NA	Comments
▪ Material identification and supplier ▪ Amount of water added after initial batching ▪ Amount of admixture added after initial batching ▪ Batch from which the cylinder specimens were collected • Testing frequency (as required by the project specifications) ▪ Slump flow – every batch (ASTM C1856/C1856M) ▪ Temperature – every batch meets project specifications ▪ Compressive strength (ASTM C1856): ♦ Five cylinders for each age break specified for QC & QA in project specifications ♦ Five cylinders instrumented with maturity sensors (one for the Department) when Maturity Method is being used				
Weighing and Batching • Mix design available at the mixer • Scales available • Procedure reviewed by batching personnel • Temperature is within project specifications • Flow is within project specifications • All ingredients are properly mixed • UHPC is free of clumps				
Transporting • Wheelbarrows, buggies, or buckets are available with no leaks or excessive buildup of old concrete and the size, quantity, and condition are acceptable • Methodology of moving the fresh UHPC from the mixer to the connection location is predetermined • Pathway from mixer to filling points (connections) are safe, clearly marked, and clear of obstacles or uneven surfaces that may cause segregation during transporting of the UHPC				

Phase 3: Mock-up Casting	Yes	No	NA	Comments
Placing The following are typical steps for filling connections. The contractor may decide to try an alternative method however, the alternative method should be validated in the mock-up casting. • Chutes or funnels to direct the filling are available • The connection areas to be filled with UHPC are clean and free of debris • All precast concrete surfaces in contact with UHPC are SSD (prewet continuously for a minimum of 2 hours) • Filling started from low point, placing fresh material into previously placed material • UHPC is placed into connection area in a manner that prevents discontinuous flow and unintended cold joints, and separate pours are intermixed with a rod where needed • Top forms on deck-level connections are installed as filling of connection proceeds • Top forms tapped with a hammer periodically to ensure connections are full (sound of tap will change – hollow versus solid) • Chimneys added at high points (chimneys may also be added at the connection intersections) • A hydrostatic head is maintained in chimneys • Formwork checked periodically for leaks during casting – including at underside of the deck • Chimneys checked periodically to ensure they are adequately filled with UHPC				
Curing • Top forms on deck-level connections installed immediately after filling connections with UHPC				

Phase 3: Mock-up Casting	Yes	No	NA	Comments
Post Mock-up Casting Acceptance • Mixing procedures were acceptable • Transporting and placing methods were acceptable • Formwork did not leak during or after casting • All connections are full to proper height and acceptable (for deck-level connections the top forming method was acceptable and procedures ensured adequate pressure against top forms) • All batches of UHPC were tested for temperature and flow • Compressive strength met specifications • All documentation for mock-up casting was received • QA/QC documents signed and dated by responsible party • Contractor team held a mock-up casting debriefing • Mock-up casting was accepted after visual inspection of saw-cut specimen				

E.5 Phase 4: Field Casting Checklist

To obtain high quality connections, it is important that the field casting operations are properly executed. The purpose of the previous phases of the checklist were to help ensure proper preparation for field casting. The field casting checklist is used during construction to help ensure, and document, that the field casting operations are conducted in accordance with the project specifications.

Many of the checklist items to consider in the Phase 3 Mock-up Casting checklist also apply to the Phase 4 Field Casting checklist.

Table E.5-1 UHPC Checklist – Phase 4: Field Casting

Phase 4: Field Casting	Yes	No	NA	Comments
Preconstruction Meeting • UHPC preconstruction meeting held at 1–3 days before starting field casting work. Review of UHPC Work Plan attended by the Engineer and the contractor's field QC manager				
Submittals • All changes from the lessons learned during the mock-up casting have been made to the QA/QC drawings, installation/assembly drawings, formwork drawings, and other submittals prior to commencement of field casting • Copy of authorized UHPC Work Plan available at job site • Copy of authorized Maturity Method Work Plan available at job site (if required) • A plot of the validated maturity curve (compressive strength versus maturity index) available at the job site (if required)				
Personnel • All personnel are wearing proper personal protective equipment (for example: vests, safety boots, hardhats, glasses/goggles, gloves, and dust masks, where required) • UHPC material supplier representative is on-site				
Safety • Safety data sheets (SDS) for the UHPC are available • All on-site personnel received a safety briefing by the UHPC supplier and contractor • Material supplier has reviewed the batching, transporting, and casting procedure with the on-site personnel				
Environmental • Operations are compliant with local environmental regulations				

Phase 4: Field Casting	Yes	No	NA	Comments
• Rejected batches of UHPC have a designated disposal area (rejected batches are dumped in predesignated plastic or metal bins, then removed when hardened) • Wastewater or clean up water from mixers or other sources disposed of in accordance with environmental regulations				

UHPC Materials (pre-batching check for raw materials stored on-site)
• Premix
  ▪ Correct product provided (product on-site matches product submittals
  ▪ Quantities are sufficient for field casting
  ▪ Shelf life has not been exceeded (production date stamp on package or shipping tag: age of product is the lesser of 18 months or limit set by manufacturer recommendations
  ▪ Stored properly – kept clean, dry, and within temperatures recommended by the manufacturer
• Fiber Reinforcements
  ▪ Correct product provided (product on-site matches product submittals)
  ▪ Quantities are sufficient for field casting
  ▪ No signs of deterioration (excessive corrosion, such that balling occurs in the fibers)
  ▪ Stored properly – kept clean and dry
• Chemical admixtures
  ▪ Correct product provided (product on-site matches product submittals)
  ▪ Quantities are sufficient for casting
• Water
  ▪ Quantity is sufficient for casting
  ▪ Quality is acceptable (potable)				

Phase 4: Field Casting	Yes	No	NA	Comments
• Ice (in hot weather up to 100 percent ice may be used in place of water) ▪ Quantity is sufficient for casting ▪ Stored properly – freezing temperature maintained				
Formwork • Formwork is installed as shown on the work plan submittals • Forms are made of nonabsorbent material • Forms are clean and clear of debris and buildup of old concrete • Formwork appears to be tightly sealed and designed to support the full hydrostatic pressure head of the UHPC in its plastic state • All formwork is made from a non-absorbent material or is coated with a non-absorbent material so that the formwork does not pull moisture from the fresh UHPC • UHPC connection pours have been broken into isolated sections as shown on the accepted submittals • Materials and detail on site for bulkhead forming • Top forms for deck-level connections are prepared and adequate hold downs for the top forms are available • Top forms for deck-level connections are set at a minimum of 3/8 inch above the top of deck to allow for overfilling, in accordance with project specifications • Chimneys for maintaining hydrostatic head are prepared and ready for installation with proper attachments • Maturity instruments are installed per manufacturer recommendations and per UHPC Work Plan (if required)				
• Prefabricated Elements • Surface texture in connection areas that will be in contact with UHPC is an exposed aggregate finish with minimum amplitude of 1/8 inch, an average amplitude of 1/3 of the maximum aggregate				

Phase 4: Field Casting	Yes	No	NA	Comments
size, and a maximum amplitude of ½ the nominal maximum aggregate size. • Precast concrete surfaces in connection areas are SSD (prewet continuously for a minimum of 2 hours) • The seal between the prefabricated elements and the supporting structures or adjacent elements are tight (grout tight – UHPC typically does not contain coarse aggregates, and seals need to be better than conventional practices and designed to support the full hydrostatic pressure head of the UHPC in its plastic state) • Prefabricated element rebar, studs, or other connectors extend the proper distance into the connections, have proper lap splice length, and have a minimum clear distance of 1.5 times the fiber length to other objects, including to lapping rebar, or are in full contact with lapping rebar				
Equipment • Mixers (a minimum of two) ▪ Size is adequate to provide a continuous flow of UHPC for placement ▪ In proper working condition ▪ Clean and free of a buildup of old concrete ▪ Power supply is adequate, and power is connected to mixers in the correct polarity such that mixers rotate in the correct direction (an electrician may be required – only required for mixers with electric motors) ▪ Charging point screen is used over mixer (check size of mesh opening [max 1.5 inches x1.5 inches] and safety switch; for UHPC with longer fibers, mesh size opening may need to be increased) ▪ Fins and blades are clean, with an acceptable level of wear, and properly spaced ▪ Gates working properly, tightly sealed, and clean (not leaking) • Buggies, wheelbarrows, and buckets				

Phase 4: Field Casting	Yes	No	NA	Comments
▪ Clean and free of a buildup of old concrete ▪ Gates (if available) working properly and tightly sealed ▪ Sprayed with a thin layer of authorized form release to prevent buildup and facilitate cleanup (caution: apply lightly to avoid contamination of the UHPC) External Heating Equipment (as applicable) Equipment for external heating on site				
QA/QC • QA/QC drawings and procedures (as authorized with all revisions from mock-up casting) are readily available on site and at the job office • QA/QC testing area is located close to the mixers on a level surface not impacted by vibrations from equipment and protected from disruptions due to the construction process and environmental conditions • Testing equipment ▪ Slump flow apparatus (ASTM C1856/C1856M) ▪ 3 inch x 6 inch cylinder molds (including six extra molds) (ASTM C1856/C1856M) ▪ Other molds or testing equipment if specified in the project specifications (ASTM C1856/C1856M) ▪ Thermometer ▪ Funnel and 3 inch x 6 inch hand scoop for casting and placing the samples ▪ Camera • Batching records (as required by the project specifications; the following is an example) ▪ Name and location of batch plant (if not batched on-site) ▪ Date				

Phase 4: Field Casting	Yes	No	NA	Comments
▪ Name of contractor (if applicable) ▪ Name of lead batcher ▪ Name of assistant batcher ▪ Specific job designation ▪ Amount of UHPC in cubic yards or cubic feet (per batch and total) ▪ Mass of each material component added to mixer ▪ Mixer identification number and/or batch number ▪ Time of water addition ▪ Time of discharge ▪ Mixing time ▪ Temperature (batch and ambient) ▪ Flow ▪ Material identification and supplier ▪ Location where batch is placed in the structure ▪ Amount of water added after initial batching ▪ Amount of admixture added after initial batching ▪ Batch from which the cylinder specimens were collected ▪ Name of tester and testing assistant(s) (can be the same personnel responsible for batching) • Cylinders are cured in similar environmental conditions as the in-place material • Testing frequency, as required by project specification ▪ Slump flow – every batch (ASTM C1856/C1856M) ▪ Temperature – every batch meets project specifications ▪ Compressive strength (ASTM C1856): ♦ Five cylinders for each age break specified for QC & QA ♦ One cylinder with maturity instrument for the Department when Maturity Method is being used				

Phase 4: Field Casting	Yes	No	NA	Comments

Weighing and Batching
• Mix design available at the mixer
• Scales available
• Procedure (as previously accepted) reviewed by batching personnel
  ▪ Weighing and batching personnel know their assigned responsibilities
  ▪ Weighing and batching personnel know the procedures for their assigned responsibilities
• Temperature is within project specifications
• Flow is within project specifications
• Authorized batching process followed – confirmed periodically throughout the day
• All ingredients are properly mixed
• UHPC is free of clumps				

Transporting • Wheelbarrows, buggies, or buckets with no leaks or excessive buildup of old concrete are available and the size, quantity and condition are acceptable • The methodology of moving the fresh UHPC from the mixer to the connection location is predetermined • Pathway from mixer to filling points (connections) are safe, clearly marked, and clear of obstacles or uneven surfaces that may cause segregation during transporting of the UHPC				
• Placing • The following are typical steps for filling connections. The contractor may decide to try an alternative method however, a mock-up casting should be arranged prior to allowing an alternative placing method. Any lessons learned from the mock-up casting should be implemented during the field casting phase.				

Phase 4: Field Casting	Yes	No	NA	Comments
• Chutes or funnels to direct the filling are available • The connection areas to be filled with UHPC are clean and free of debris • All surfaces of prefabricated elements in contact with UHPC are SSD (continuously prewet for a minimum of 2 hours) • Fill started from low point, placing fresh material into previously placed material • UHPC is placed into connection area in a manner that prevents discontinuous flow and prevents unintended cold joints – separate pours are intermixed with a rod where needed • Top forms on deck-level connections are installed as filling of connection proceeds • Top forms tapped with a hammer to periodically to determine if connections are full (sound of tap will change – hollow versus solid) • Chimneys added at high points (chimneys may also be added at the connection intersections) • A hydrostatic head is maintained in chimneys • Formwork checked periodically for leaks during casting – including at underside of the deck • Chimneys checked periodically to ensure they are adequately filled with UHPC				
Curing • Top forms on deck-level connections installed immediately after filling connections with UHPC or • Acceptable curing is applied immediately after casting				

Phase 4: Field Casting	Yes	No	NA	Comments
Temperature Control and Monitoring (if required) • Maturity system is installed with recording system • Adequate number of maturity monitoring points used to represent the connections cast • Temperature/strength acceptance criteria is determined				

E.6 Phase 5: Post-Placement Checklist

During the post-placement period, it is critical to ensure the UHPC experiences no moisture loss and has maintained a minimum temperature to attain the required compressive strength before loading the connections.

Table E.6-1 UHPC Checklist – Phase 5: Post-Placement

Phase 5: Post-Placement	Yes	No	NA	Comments
Curing • Curing maintained until UHPC has reached required strength, as required in project specifications (curing methods should commence immediately to prevent the loss of mix water) • If heat is applied to accelerate curing, the heaters and covers over the UHPC connections are checked periodically to ensure that the air temperature specified for the accelerated cure is maintained until the UHPC has reached the required strength.				
Temperature Control and Monitoring (if required) • Maturity system recording and monitoring is readily accessible • Maturity acceptance criteria is determined and accepted • Person responsible for temperature control and monitoring are identified and on-site • Approval process for meeting criteria is clear and accountable				

Phase 5: Post-Placement	Yes	No	NA	Comments
QA/QC • Maturity (time/temperature/strength) curves used to verify the in-situ compressive strength (if required) and QA/QC cylinders broken to verify the compressive strength or • Cylinders broken to verify 14 ksi prior to opening bridge to public				
Timing of Loading • Structure not loaded until UHPC has reached required compressive strength • Relative displacement of adjacent girders prevented until UHPC in the joint has reached required compressive strength				
Formwork Removal • Formwork not removed until UHPC has reached required compressive strength				
UHPC Joint Repair • Materials and repair procedure on site in the event of cold joint repair or partially filled joint repair				
Grinding • Structure not loaded with grinding equipment until UHPC has reached required compressive strength per project specification • Grinding commenced as soon as practical after attaining required compressive strength (waiting longer than necessary increases the amount of time and number of grinding blades needed to obtain an acceptable surface profile)				

E.7 Phase 6: Project Closeout

The project closeout should follow normal closeout procedures and ensure the checklist aspects are included.

Table E.7-1 UHPC Checklist – Phase 6: Project Closeout

Phase 6: Project Closeout	Yes	No	NA	Comments
QA/QC Records Review, Documentation and Acceptance • Batch records have been received • Compressive strength data have been received and authorized • All contractor submittals have been received and authorized • QA/QC documents signed and dated by responsible party • All checklists reviewed and all deficiencies have been resolved				
Environmental and End of Project Treatment • Any rejected batches of UHPC have been disposed in an acceptable manner				

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ACCELERATED BRIDGE CONSTRUCTION

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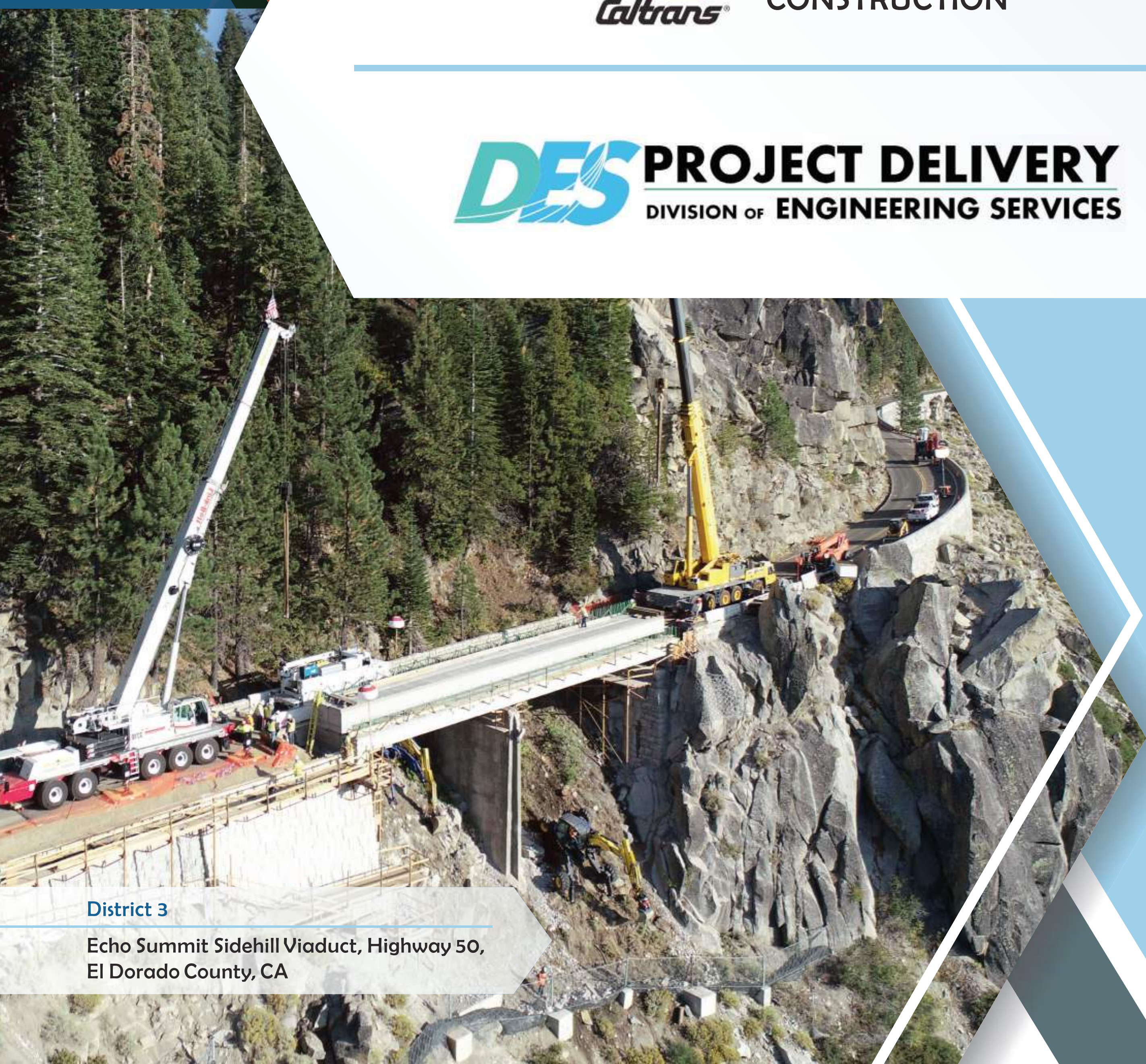

District 3

Echo Summit Sidehill Viaduct, Highway 50,
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