State of California
Department of Transportation
Division of Engineering Services

Reinforced Concrete Construction Manual

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Acknowledgements

The 2025 *Reinforced Concrete Construction Manual* represents the culmination of over a century of collective experience and guidance from Structure Construction staff. As reinforced concrete practices evolve to meet new engineering and construction challenges, the need for a formal, comprehensive construction manual was recognized by former Office F Area Construction Managers Robert Crain and Peter Strykers, whose foresight laid the foundation for this effort.

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Signed,

JOHN LAMMERS
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TABLE OF CONTENTS

Chapter 1	Introduction	Page
1-1	Purpose and Scope	1-2
1-2	Reinforced Concrete	1-2
1-3	Statement of Structure Construction Policy	1-3
1-4	Contract Specifications and References	1-3
1-5	Cal/OSHA References	1-4
1-6	Definitions and Acronyms	1-5

Chapter 2	Preconstruction Planning	Page
2-1	Introduction	2-2
2-2	Contract Documents	2-2
2-3	Other Reference Documents	2-7
2-4	Cooperation and Coordination	2-8
2-5	Critical Path Method Schedule	2-9
2-6	Falsework Design	2-9
2-7	Concrete Mix Designs	2-9
2-8	Prestress Shop Drawings	2-9
2-9	Line and Grade Control	2-10
2-10	Concrete Quality Control	2-11

Chapter 3	Forms	Page
3-1	Introduction	3-2
3-2	Specifications	3-2
3-3	Forming System	3-2
3-4	Form Workmanship	3-14
3-5	Formwork Design	3-17
3-6	Formwork Design Review	3-18
3-7	Formwork Removal	3-19

Chapter 4	Reinforcement	Page
4-1	Introduction	4-2
4-2	Technical Resources	4-2
4-3	Contract Requirements and Preparation	4-3
4-4	Construction	4-5
4-5	Corrosion Protection	4-15

4-6 Headed Bar Reinforcement 4-21
4-7 Splices 4-22
4-8 Drill and Grout Dowels/Drill and Bond Dowels 4-40

Chapter 5 Concrete Page

5-1 Introduction 5-3
5-2 Technical Resources 5-3
5-3 Quality Assurance 5-3
5-4 Planning Concrete Pours 5-5
5-5 Concrete Batching and Delivery 5-7
5-6 Concrete Conveyance 5-12
5-7 Placing Concrete 5-21
5-8 Construction Joints 5-27
5-9 Concrete Placement Protection 5-29
5-10 Finishing Plastic Concrete 5-30
5-11 Curing Concrete 5-34
5-12 Common Concrete Defects 5-45
5-13 Concrete Surface Finish 5-52
5-14 Concrete Architectural Features 5-58
5-15 Concrete Placement During Extreme Temperatures 5-63
5-16 Mass Concrete 5-71
5-17 Placing Concrete Under Water 5-72
5-18 Environmental Stewardship 5-75
5-19 Public Safety for Bridge Construction Over Traffic 5-80

Chapter 6 Bridge Construction Practices for Cast-In-Place (CIP) Bridges Page

6-1 Introduction 6-2
6-2 Substructure 6-2
6-3 Superstructure 6-9
6-4 Other Bridge Elements 6-16

Chapter 7 Bridge Deck Construction Page

7-1 Introduction 7-3
7-2 Bridge Deck Preconstruction Planning 7-3
7-3 Bridge Deck Forms 7-11
7-4 Bridge Deck Formwork Construction 7-19
7-5 Bridge Deck Reinforcement 7-33
7-6 Pre-Pour Construction Activities 7-37

7-7 Bridge Deck Concrete 7-47
7-8 Deck Concrete Placement 7-47
7-9 Finishing Roadway Surfaces 7-54
7-10 Curing Bridge Decks 7-58
7-11 Testing Roadway Surfaces 7-60
7-12 Pedestrian Overcrossings 7-66

Chapter 8 Precast Concrete Page

8-1 Introduction 8-2
8-2 Advantages of PC Concrete Members 8-2
8-3 Preparation and Fabrication 8-3
8-4 Precast Prestressed Concrete Girders and Slabs 8-13
8-5 Accelerated Bridge Construction 8-23

Chapter 1: Introduction

Table of Contents

Chapter 1: Introduction 1
1-1 Purpose and Scope 2
1-2 Reinforced Concrete 2
1-3 Statement of Structure Construction Policy 3
1-4 Contract Specifications and References 3
1-5 Cal/OSHA References 4
1-6 Definitions and Acronyms 5

1-1 Purpose and Scope

The *Reinforced Concrete Construction Manual* has been issued by the Department of Transportation's Division of Engineering Services (DES), Structure Construction (SC). The intended purpose is to provide an educational resource and administrative support to SC staff who are in responsible charge of the construction of reinforced concrete structures on State highway projects. Proper use of the *Reinforced Concrete Construction Manual* requires a thorough understanding of the principles of civil engineering design and construction, and familiarity with the relevant contract documents and *Contract Specifications*.

The scope of this manual is to provide a resource for typical construction of reinforced concrete structures on State highway projects and is not intended to cover all possible scenarios. Engineering judgment will be required to determine the applicability of this manual to any specific reinforced concrete structure or member.

1-2 Reinforced Concrete

Concrete is the most widely used construction material in the world, with Portland Cement Concrete (PCC) being the most common type. The key materials needed to produce concrete – rock, sand, water, admixtures, and cement – are abundant and relatively inexpensive. Cement itself is produced largely from limestone, one of the most abundant minerals on Earth.

Additionally, byproducts from industrial processes such as fly ash, blast furnace slag, and silica fume – which would otherwise constitute a waste disposal challenge – can be incorporated into PCC. These materials, known as Supplementary Cementitious Materials (SCMs), partially replace cement in the concrete mix and may enhance the concrete properties. While most SCMs are industrial byproducts, some, such as natural pozzolans and metakaolin, are naturally occurring materials.

With proper material selection, including the use of non-reactive aggregates and suitable admixtures, concrete remains a cost-effective, low-maintenance material that is known for its durability and high compressive strength. It is a versatile building material that has been used in virtually every type of civil infrastructure.

One limitation of concrete is its relatively low tensile strength. As a result, its early use was generally limited to heavy, short-span, compression-based structures such as arches. This limitation was addressed with the development of reinforced concrete. Reinforced concrete is a composite material that incorporates a high tensile strength material, typically bar reinforcement, into a PCC matrix. The result is a material that efficiently resists both compressive and tensile forces, leading to its widespread use in

bridge construction. Further enhancements to basic reinforced concrete, such as the development of prestressing technology and the addition of specialty admixtures to the basic components described above, have further extended its viability. Today, reinforced concrete is ubiquitous in bridge construction. Even structures with major structural steel components also extensively incorporate reinforced concrete.

1-3 Statement of Structure Construction Policy

SC policy is to construct reinforced concrete structures to the highest quality standards while ensuring the work is carried out in a safe, controlled manner that protects the public, workers, and the environment. This is accomplished by a comprehensive review and authorization process for applicable shop drawings and work plans. This is further achieved by verifying that the details and requirements of all authorized shop drawings, work plans, and contract requirements are properly implemented in the field, with an emphasis on the use of best construction practices.

1-4 Contract Specifications and References

Some of the key requirements for the construction of reinforced concrete structures can be found in the following *Contract Specifications* and references:

1. Caltrans *Contract Specifications*:
    a. Section 5, *Control of Work*:
        i. Section 5-1.02, *Control of Work – Contract Components*: Item 1.6 – *Supplemental Project Information*, includes permits and agreements negotiated by the State that are part of the contract and can include work and restrictions that can have a major impact on the means and methods used to construct reinforced concrete structures.
    b. Section 6, *Control of Materials*
        i. Outlines various requirements of materials to be incorporated into the project, including processes for documentation, testing, and acceptance. This section also includes requirements for material sources and facilities that are authorized for Caltrans projects.
    c. Section 7, *Legal Relations and Responsibility to the Public*:
        i. Contains provisions related to public safety and references applicable Cal/OSHA requirements.
    d. Section 12, *Temporary Traffic Control*:
        i. Specifies requirements for maintaining temporary access routes for pedestrians during construction.
    e. Section 14, *Environmental Stewardship*:

i. Emphasizes environmental consideration in the design and construction of bridges and other transportation structures, since many are either habitat for biological resources or are adjacent to such habitat.

f. Section 51, *Concrete Structures*

i. Provides requirements for constructing structural concrete facilities such as concrete bridges and their various components, retaining walls, etc. Minor concrete facilities, such as curb and gutter, are not necessarily covered. Some material requirements are also addressed.

g. Section 52, *Reinforcement*

i. Covers the fabrication and installation of reinforcement, typically bar reinforcing steel.

h. Section 83, *Railings and Barriers*

i. Provides requirements for constructing railings and barriers, including concrete barriers to be constructed on bridges and other structures.

i. Section 90, *Concrete*

i. Details material specifications for various types of concrete, including structural concrete. Also includes provisions for quality control, curing, and protection.

2. Project *Special Provisions*:

a. Define project-specific requirements and restrictions above and beyond what are in the *Standard Specifications* and will frequently include requirements outlined in the project permits and agreements.

3. *Information Handout*:

a. Contains supplemental project-specific permits and agreements, including railroad and other stakeholder agreements, environmental permits, foundation report, asbestos report, and lead report when applicable.

1-5 Cal/OSHA References

There are many specific Cal/OSHA regulations related to the construction of reinforced concrete structures, and those references will not be covered in this section specifically. Rather, this section highlights some general areas of importance regulated by Cal/OSHA in relation to the construction of reinforced concrete structures, some of which will be discussed in this manual. Key hazards and safety concerns associated with the construction of reinforced concrete structures that are addressed in various safety regulations include:

1. Falls from elevated work areas
2. Formwork and falsework design, installation, and removal

3. Impalement hazards
4. Concrete placement operations
5. Public safety
6. Heavy construction equipment and traffic.

1-6 Definitions and Acronyms

Americans with Disabilities Act (ADA) – Federal civil rights law that prohibits discrimination against individuals with disabilities in all areas of public life. It requires public and private entities to provide reasonable accommodations and ensure accessibility in transportation, employment, and public spaces. It became law in 1990.

As-built Drawings – Historical record and detailed documentation of the final constructed state of a bridge or other structure, including any deviations from the original design and modifications implemented during construction, maintenance, or retrofit. May be referred to as “as-builts”.

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.

APA – The Engineered Wood Association, formerly known as the American Plywood Association. A nonprofit trade association comprised of structural wood product manufacturers and experts. They develop and maintain performance standards, testing methods, and certification programs for the industry.

ASTM – ASTM International, formerly known as American Society for Testing Materials. An international nonprofit organization that develops and establishes standards for a variety of products and processes.

Authorized Material List (AML) – A catalog of products that meet the requirements set in the *Contract Specifications* and are prequalified and preauthorized for use on Caltrans construction projects. It includes authorized products for mechanical couplers (service and ultimate splice systems), concrete admixtures, cementitious materials, etc.

Bar Reinforcement – Steel bars cast into concrete structures to improve structural integrity, primarily by enhancing resistance to tensile forces. Also referred to as bar reinforcing steel, reinforcing bar, reinforcement, and rebar.

Bulkhead – Formwork that acts as a vertical barrier or edge for a concrete pour, confining the concrete placed during a concrete pour to a specific area. It may function to separate different sections of a concrete structure, such as at a construction joint.

Cal/OSHA; California Department of Industrial Relations, Division of Occupational Safety and Health (DOSH) – Regulatory agency within the California Department of Industrial Relations responsible for protecting and improving the health and safety of workers in California.

Construction Safety Orders (CSO) – Regulations that outline safety standards and requirements for the construction industry. The CSO are part of the California Code of Regulations, Title 8, Division 1, Chapter 4, Subchapter 4, and are enforced by Cal/OSHA.

Constructability Review – Iterative review of project plans, specifications, and estimate, performed at various stages during project development. The purpose is to assure that these documents effectively define the project, are free of conflicts, and are both biddable and buildable using current industry means, methods, and technologies. Refer to Bridge Construction Memo (BCM) D-2, *SC Responsibilities for Constructability Review*, for additional information.

Construction Joint – Interface between separate, adjoining concrete placements.

Contract Documents – Combined documents described in *Standard Specifications* Section 5-1.02, *Control of Work – Contract Components*, including the standard specifications, revised standard specifications, special provisions, supplemental project information, project plans, standard plans, change orders, permits, licenses, agreements, and certifications that encompass the definition and scope of work as agreed to by Caltrans and the Contractor.

Contract Specifications – Portion of the contract documents that include the special provisions, revised standard specifications, and standard specifications.

Cross Slope – Slope that is perpendicular to the direction of travel. It is transverse (or radial) with respect to the centerline of bridge or roadway. Also known as crossfall or superelevation.

Division of Engineering Services (DES) – Division and lead project delivery organization of Caltrans responsible for the design and construction engineering/ contract administration of bridges and other transportation structures within Caltrans right-of-way. This includes oversight of bridges constructed by other agencies within Caltrans right-of-way or by other agreement outside Caltrans right-of-way.

Data Interchange for Materials Engineering (DIME) – Online database developed by Caltrans Materials Engineering & Testing Services (METS) for contractors and Caltrans staff to input sample information and test data, including data for concrete materials.

Epoxy-Coated Prefabricated Reinforcement – Bar reinforcement that is cut to the specified length and bent to the required shape prior to being epoxy coated and may not be bent after coating.

Falsework – Temporary structure used to support the permanent structure until it becomes self-supporting.

Gang Forms – Large, prefabricated panels designed to be hoisted and placed as a unit during concrete forming.

Holiday – Discontinuity or incomplete section in a coating. It may or may not be discernible to a person with normal or corrected vision.

Hopper – Container or funnel-shaped device used to hold and help convey poured concrete in a controlled manner from one location to another, typically used in combination with equipment like a concrete pump, truck mixer, or chute.

Lift – In terms of concrete placement, a horizontal layer of poured or placed concrete. Subsequent lifts, or layers, may be placed on top.

Lot of Material – Quantity of material, as defined in the *Contract Specifications*, for the specific material, treated as a single unit for sampling purposes. For example, a "lot" of bar reinforcement splices is one hundred and fifty (150), or fraction thereof, of the same coupler model for each bar size, deformation pattern, and hoop diameter. Also referred to as a "lot".

Materials Engineering and Testing Services (METS) – Subdivision within Caltrans DES. METS performs material inspection services on behalf of the Resident Engineer, typically at the place of fabrication, and authorizes the shipment of materials from the fabrication shop to a construction project.

Operator and Procedure Prequalification – Requirement of the splice prequalification report; splice operators and procedures must be certified. Splice test samples must be prepared and tested no more than two (2) years before the submittal.

Patching Material – For epoxy-coated reinforcement, liquid two-part epoxy coating used to repair areas of damaged epoxy coating.

Precast/Prestressed Concrete Institute (PCI) - Trade institute and association representing the precast and prestressed concrete industry. It plays a key role in developing and maintaining technical standards, and promoting the use of precast concrete in construction.

Prefabricated Bridge Element (PBE) – Single prefabricated structural component of a bridge assembled in place, typically using ABC methods. It is feasible to use PBEs in a bridge system installation.

Resident Engineer's Pending File (RE Pending File) – Compilation of project guidance and information collected by the project engineer(s) necessary to administer a construction contract. For projects with structures work, project engineers from the

District and DES compile and distribute the RE Pending File components separately. Refer to BCM C-2, *Using the Resident Engineer's Pending File for Structure Work*, for additional information.

Running Slope – For pedestrian facilities, the slope that is parallel to the direction of travel. Also known as profile slope or profile grade for a bridge or roadway.

Splice Prequalification Report – Report that documents the contractor's proposed splicing system, splice locations, splicing operators, and certified splice test results for bar reinforcement.

Structure Maintenance & Investigations (SM&I) – Subdivision within Caltrans Maintenance responsible for inspecting and recording condition data, load rating analysis, and the preservation of in-service state and local agency owned bridges and tunnels.

Skew – In terms of bridges, angle between the centerline of bridge and centerline of supports (e.g., bent or abutment). Bridges with supports that are not transverse with respect to the bridge centerline are typically referred to as "skewed".

Soffit – Underside of a structure, commonly associated with the underside of a concrete box girder bridge.

Splicing Quality Control Manager (QCM) – Contractor designated person who is responsible for both field and administrative work regarding the quality of all service splices or ultimate butt splices for bar reinforcement.

Structure Construction (SC) – Subdivision within Caltrans DES responsible for the administration of bridge (and other structures) construction contracts within Caltrans right-of-way or oversight thereof. This subdivision provides engineering oversight for construction projects throughout California, ensuring that projects are built in compliance with plans and specifications.

Tailgating – Method of placing concrete directly from the concrete truck mixer, conveyed using the truck-mounted chute, into its final location.

Tining – Surface finishing technique for bridge deck and roadway surfaces, used to provide grooved texture on concrete surfaces while the concrete is plastic.

Chapter 2: Preconstruction Planning

Table of Contents

Chapter 2: Preconstruction Planning 1
Table of Contents 1
2-1 Introduction 2
2-2 Contract Documents 2
2-2.01 Plans and Specifications 2
2-2.02 Standard Plans 7
2-3 Other Reference Documents 7
2-4 Cooperation and Coordination 8
2-5 Critical Path Method Schedule 9
2-6 Falsework Design 9
2-7 Concrete Mix Designs 9
2-8 Prestress Shop Drawings 9
2-9 Line and Grade Control 10
2-10 Concrete Quality Control 11

2-1 Introduction

Reinforced concrete construction requires extensive planning, preparation, and cooperation to ensure the timely completion of a quality product. It is necessary to thoroughly understand the contract documents and enforce the contract requirements. Review *Contract Specifications,* Section 51, *Concrete Structures;* Section 52, *Reinforcement*; and Section 90, *Concrete.*

This chapter provides general guidelines to prepare for projects involving the construction of reinforced concrete structures. Subsequent chapters of this manual give additional guidance for the construction of specific reinforced concrete members.

2-2 Contract Documents

The *Contract Specifications* and project plans are the primary components of the contract documents. Review of these documents will be discussed later in this chapter.

Before their release, Structure Construction (SC) staff should have been given an opportunity to perform a constructability review of the contract documents. Obtain a copy of the constructability review to become familiar with issues that were raised during project development and how, or if, they were addressed.

Another resource that SC staff should also review is the project's supplemental project information; this may include an *Information Handout* which is available to the Contractor as part of the contract bid documents. It typically includes copies of permits and agreements the Department has made with local agencies. It may also include reports from previous site investigations. The Contractor must take into consideration the material in the *Information Handout* when planning for construction. For example, the *Information Handout* may govern how the Contractor is allowed to stage their work.

Other project-related documents worth reviewing include the Resident Engineer's (RE) Pending File and bidder inquiries. The RE Pending File may contain design assumptions or recommendations that SC staff should be aware of. Bidder inquiries may reveal potential discrepancies in the contract documents that potential bidders encounter during the bidding process.

2-2.01 Plans and Specifications

Whether or not SC staff performed a constructability review of the contract documents, it is good practice to look out for issues that should have been addressed during the development of the project. Specifically, for bridge construction projects, verify that the roadway plans and structure plans agree with each other, including the following:

1. For utilities:
    a. Verify the locations of utility tie-in between both sets of plans are coordinated. For new bridge construction, utilities are typically placed within bridge cells, utility openings, and concrete barriers.
    b. Verify that the specified material type called for is consistent between both sets of plans and meets the material requirements.
2. Verify that the elevation where roadway and approach slab or other structural improvements meet, matches and results in a smooth continuous profile (refer to Chapter 7, *Bridge Deck Construction,* for additional discussion).
3. Verify that the stage construction plans in both plan sets match and are realistic.

Bring any discrepancies found to the Resident Engineer's attention and discuss means to mitigate, if necessary.

Perform a preliminary review of the project plans for items that could complicate the Contractor's work, or require coordination between different bridge elements, which may include:

1. Complex forming details.
2. Special requirements or restrictions for construction joints.
3. Bar reinforcing steel (rebar) congestion.
4. Difficult geometry, e.g., high skews, small radius curves, high cross slope or superelevation, varying section dimensions, etc.
5. Added embeds, blockouts (see Figure 2-1), drainage facilities, and utility facilities.
6. Areas with limited access for placing rebar or pouring concrete.

The Contractor may need to plan ahead of time to ensure these items are addressed. Procuring accessories for utility facilities, in particular, may require additional planning if they need to be obtained by the utility owner.

Figure 2-1. Blockout for Soffit Access Opening

For projects with structural concrete members, the minimum specified yield strength of rebar and the required 28-day compressive strength for structural concrete are usually shown in the project plans. These can be found in the “General Notes” section of the project plans (Figure 2-2).

REINFORCED CONCRETE:	fy = 60 ksi f'c = 3.6 ksi (unless noted otherwise)

Figure 2-2. Specified Rebar and Concrete Strength

However, projects with multiple structural concrete members, or types, may have varying 28-day compressive strength requirements. These different strength requirements are usually reflected graphically in the project plans. Figure 2-3 is an excerpt from a project plan sheet showing the different concrete strength requirements and concrete types for the structure. Verify that the Contractor submits concrete mix designs for the various types and requirements shown. A single concrete mix design may be used for multiple concrete types, provided it meets the requirements for all. Refer to Section 2-6 for additional discussion regarding concrete mix designs.

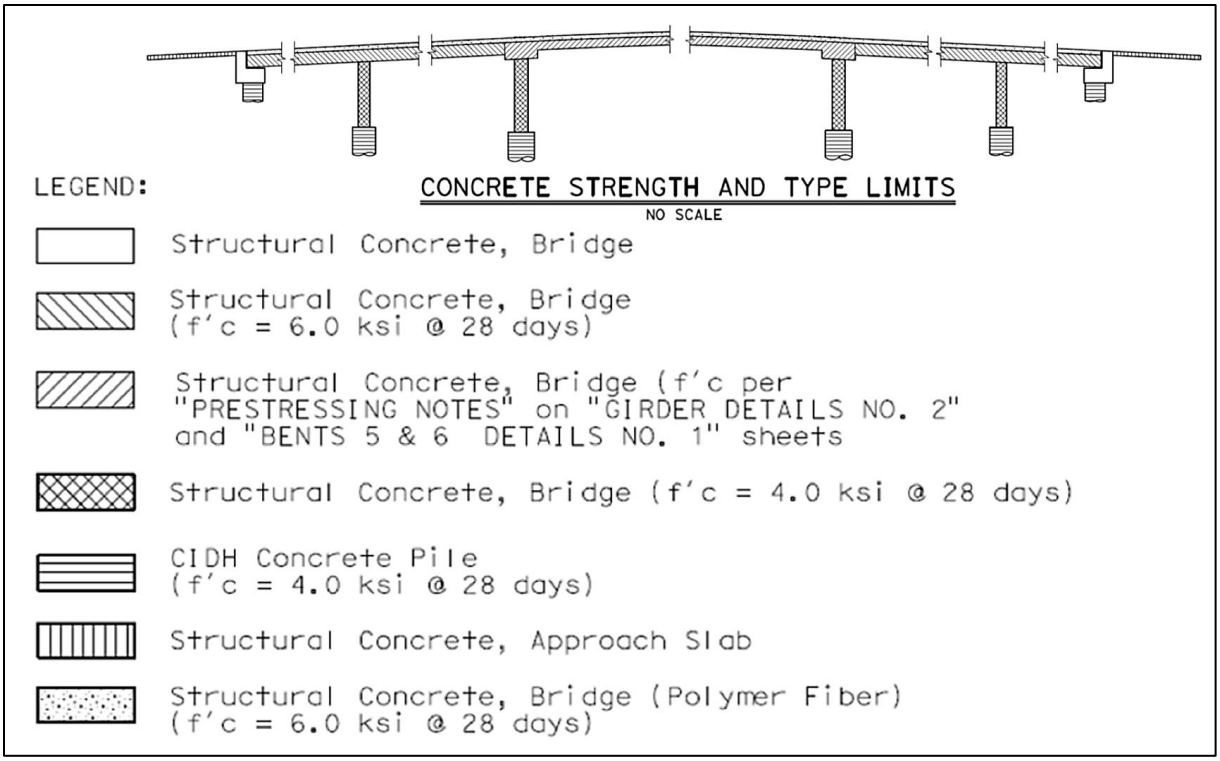

Figure 2-3. Concrete Strength and Type

Check for project-specific requirements for concrete and rebar. Below are examples of such requirements:

1. Projects in locations identified as corrosive environments or freeze-thaw areas will have concrete material-related requirements and coating requirements for rebar.
2. Projects with large-volume concrete structure(s), located in high-temperature environments, or containing other conditions that may lead to high heat of hydration for concrete may have portions of their structures identified as mass concrete. This case would trigger the requirements of *Contract Specifications*, Section 51-6, *Concrete Structures – Mass Concrete*.
3. Colored concrete may be specified for structures with architectural features, which would require a work plan complying with *Contract Specifications*, Section 51-1.01C(6), *Concrete Structures – General – Submittals – Colored Concrete*.

Make a note of unfamiliar specifications or details and discuss them with the Structure Specification Engineer or Bridge Design (BD) Project Engineer as soon as possible. This review may form the basis of early discussions with the Contractor to ensure that they understand potential challenges in the contract and have developed plans to address them.

In addition, review the contract documents to determine the quantity, type, and location of reinforced concrete in the contract. Concrete and bar reinforcing steel are usually paid as separate items. Estimate the quantities of concrete and bar reinforcing steel in the bridge elements. Compare quantity calculations with the designer's calculations, which are typically found in the RE Pending File. Resolve these quantities with the pay quantities in the contract documents. This information will be helpful in evaluating the Contractor's falsework design, forming system, placement plans, and construction schedule. Having the quantities on hand will also help with making accurate and timely progress payments.

The calculation of concrete placed in a pay period is relatively easy compared to determining the weight of various bars of differing sizes and configurations placed in the same period. To facilitate monthly partial pay estimates, establish the average pounds of rebar per cubic yard of a concrete item, commonly referred to as the "rebar factor", and pay for rebar commensurate with the estimated concrete quantity. Bar lists, which the Contractor must submit for each rebar shipment, can also be used to calculate payment for reinforcement.

In preconstruction meetings and discussions, verify that the Contractor is aware of the effect of bridge geometry on forming and rebar detailing particularly for bridges with a cross slope (superelevation). Measurements shown on the project plans usually show dimensions along the vertical and horizontal planes. Projects with large or transitioning cross slopes contain language within *Contract Specifications*, Section 51-1.03A, *Concrete Structures – General – Construction,* stating that fact. Consider the effects of deck cross slope with respect to the dimensioning of the typical section. As illustrated in Figure 2-4, for sloping exterior girders, the actual distance along exterior girders is different between the left and right sides. This requires different size forms and different lengths and shapes of reinforcing stirrups. Even the straight transverse bar reinforcement across the deck is longer, and the truss bars must accommodate a slightly longer interval between girders as opposed to the horizontal distance shown in the plans.

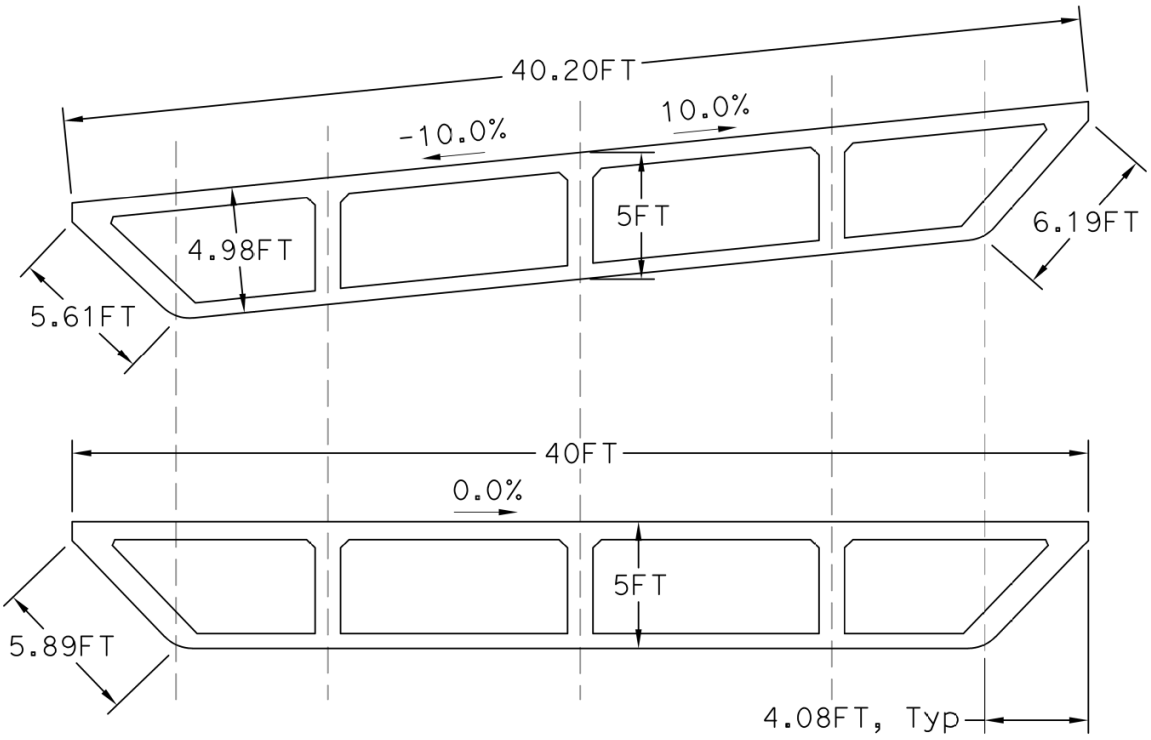

Figure 2-4. Effect of Cross Slope on Bridge Geometry

Other features that may cause errors in detailing and fabrication of rebar include varying girder spacing, varying section thicknesses, skewed features such as bents and abutments, tight horizontal curves, and varying section depths and girder heights. Refer to Chapter 4, *Reinforcement*, for further discussion regarding the effects of bridge geometry on rebar detailing.

2-2.02 Standard Plans

Make a list of all standard plan sheets referenced in the project plans. The *Standard Plans* are contractual supplements to the project plans. Project plans often list applicable Standard Plan details on an “Index to Plans” sheet. Verify that all details are incorporated during construction. For example, the “wall offset value” for Type I retaining walls, reinforcement of utility openings in concrete, and detailing on prestressing, are found in the *Standard Plans*.

2-3 Other Reference Documents

Additional construction guidance for SC staff can be found in the *Bridge Construction Records and Procedures Manual*. SC staff should review applicable memos and integrate their guidance with the contract documents. The Caltrans *Construction Manual*

provides construction administration procedures and defines quality control test requirements and acceptance testing procedures. Be familiar with applicable California Tests for checking the Contractor's quality of work.

2-4 Cooperation and Coordination

Effective bridge construction is the result of continuous communication and cooperation between the Contractor and the Department. SC staff should establish a good working relationship with the Contractor before the start of construction and develop a regular schedule for jobsite meetings.

With the Resident Engineer, schedule the preconstruction conference as outlined in *Contract Specifications,* Section 8-1.03, *Prosecution and Progress – Preconstruction Conference.* Additionally, although not always contractual, it is advisable to schedule specific pre-operation or pre-job meetings before the start of certain field activities.

Remind the Contractor that they are required to provide Form CEM-3101, *Notice of Materials to be Used,* to the Department. This document forms the basis of an orderly acceptance of material incorporated into the work. Material may require offsite inspection and release before arriving at the jobsite. Offsite inspection requires coordination with Caltrans Materials Engineering and Testing Services (METS). The Structure Representative should involve the local METS Representative in discussions with the Contractor as soon as possible, and in no case later than the preconstruction conference. Refer to *Construction Manual*, Section 6-202, *Sampling and Testing – Responsibilities for Acceptance of Manufactured or Fabricated Materials and Products,* for a list of materials requiring offsite fabrication and inspection, including items such as epoxy-coated reinforcing and mechanical couplers.

Establish what level of inspection[1] is necessary for various concrete construction activities and critical points during the activities when inspections must be performed. Coordinate with the Contractor if any critical points require them to pause, or hold, their activities so that they can schedule work accordingly. For any type of inspection, utilizing a checklist of items to inspect is a good practice. Such a checklist can be developed based on the contract requirements, as well as other technical resources.

Determine activities that will require traffic control, work windows, or any other accommodation for public safety. Discuss Storm Water Pollution Prevention Plan (SWPPP) measures necessary for concrete pours and the location of washout facilities.

[1] Caltrans internal use only

2-5 Critical Path Method Schedule

Contract Specifications, Section 8-1.02, *Prosecution and Progress – Schedule,* requires the Contractor to submit a Critical Path Method (CPM) schedule outlining the activities necessary to complete the work. Review the CPM schedule to determine the Contractor's schedule for activities that will require preparatory work, and for review and authorization of submittals. Verify that the review times allowed per the contract for various submittals are accounted for in the CPM schedule. *Contract Specifications*, Section 5-1.23*, Control of Work – Submittals,* states the time allotted to the Department for review of submittals unless stated elsewhere within the *Contract Specifications*. Verify that there is adequate time provided for approval of mix designs, required test panels or mock-ups, and to obtain satisfactory results from test samples.

2-6 Falsework Design

Bridge construction using reinforced concrete often requires falsework. Good quality falsework is designed and built to properly handle all construction loads anticipated at every stage of construction. Furthermore, one of the greatest safety concerns on any construction project is the use of temporary structures. For these reasons, some of the most important duties of construction personnel are the review and authorization of the falsework design and ensuring its proper construction, use, monitoring, and removal. Refer to the SC *Falsework Manual* and *Contract Specifications,* Section 48-2, *Temporary Structures – Falsework,* for a thorough understanding of falsework.

2-7 Concrete Mix Designs

The requirements for concrete mix designs are in *Contract Specifications*, Section 90, *Concrete*. The Contractor must submit concrete mix designs for review. The mix design may not be used on the project until authorized by the Structure Representative. As discussed earlier in this chapter, project-specific concrete requirements may be included in the contract documents. These must be addressed, if applicable to the mix design being reviewed. The SC *Concrete Technology Manual*, Chapter 3, *Review of Concrete Mix Designs*, covers concrete mix design review in detail. The SC *Concrete Technology Manual* also contains information on concrete components, including supplementary cementitious materials, admixtures, proper batching, and delivery of concrete to the jobsite.

2-8 Prestress Shop Drawings

Construction of reinforced concrete bridges makes extensive use of prestressing. Prestressing is a method of taking advantage of the high compressive strength of reinforced concrete by applying an eccentric compressive force to components of the

bridge, thereby reducing the tensile load when in service. The project plans will indicate the magnitude and location of the prestressing force, but the specific sequence and location of how the force is applied is left to the Contractor. The details of the prestressing system are included in the shop drawings provided by the Contractor, for the Department's review. The BD Project Engineer typically performs an in-depth review, with the Structure Representative reviewing concurrently. Components of the prestressing system, such as prestressing steel, ductwork, and anchorages, will be permanently incorporated into the reinforced concrete. Standard plan details may require additional reinforcing. Review *Contract Specifications,* Section 50, *Prestressing Concrete*, and the SC *Prestress Manual* to become familiar with prestressing as it relates to reinforced concrete bridge construction.

2-9 Line and Grade Control

District surveyors provide staking to establish line and grade for construction projects. These are often referred to as "control stakes" because they provide the location and elevation upon which the location and elevation of all bridge components and elements, and other structures are based. For the Department's policy regarding furnishing control stakes, refer to Caltrans' *Surveys Manual*, Chapter 12, *Construction Surveys*.

The first surveying responsibility of SC staff is to verify the accuracy of the control stakes. It is not necessary to recreate the entire survey, but rather spot-check stakes at each location to verify that they are correct. One method for SC staff to check the locations of control stakes is to compare the theoretical coordinates of the control stakes with the coordinates of what has been staked. Use a total station, set up with the project control points, to obtain the coordinates of the staked locations. Compare both theoretical and actual coordinates, verifying that they are within acceptable tolerances. Another method involves comparing the theoretical horizontal distance between control stakes versus their measured distance as staked in the field. This can be achieved using a total station, electronic measuring device, or even a tape measure to measure the horizontal distance accurately.

Use the bridge deck contour plots (also known as 4-scales) to compute grades and elevations for bridge components and elements. Before construction, obtain the bridge deck contour plots, verify that they are correct, and then develop grades to be used for control. The instructions for obtaining and checking the bridge deck contour plots are provided in BCM C-4, *Bridge Deck Contours and Geometrics.* The bridge deck contours may also be available as an electronic file for use in CAD software from the BD Project Engineer.

2-10 Concrete Quality Control

Adhering to a sound quality control (QC) program for concrete production ensures that concrete material incorporated into the project by the Contractor meets the contract requirements. It is also crucial for ensuring that a functional and durable concrete structure is built. Unless specified otherwise, *Contract Specifications*, Section 90-1.01D(10)(b)(i), *Concrete – General – Quality Assurance – Quality Control – Cast-In-Place Structural Concrete Members – General,* requires the Contractor to develop and follow a QC program for all concrete used in CIP structural concrete members. It also details the requirements of the QC program. The Contractor summarizes their QC program in a QC plan and then submits the plan to the Department for review and authorization. Amendments and addendums to an authorized QC plan necessitate a new round of review for authorization.

The QC plan must identify key personnel and facilities involved in the QC program, including the QC manager, QC inspectors and testers, and the testing facility. Qualifications and certifications for each must be included. The QC manager and QC inspectors are responsible for rejecting the batched concrete if it does not comply with the specified requirements. The Contractor's means of sampling, testing, and inspecting concrete during production must also be described in the plan. The required types and frequencies of testing are stated in the *Contract Specifications*, Section 90-1.01D(10)(b)(iv), *Concrete – General – Quality Assurance – Quality Control – Cast-In-Place Structural Concrete Members- Quality Control Testing Frequencies*.

The Contractor must regularly submit documentation of their QC inspection and testing. *Contract Specifications,* Section 90-1.01C(8)(b), *Concrete – General – Submittals – Testing – Cast-In-Place Structural Concrete Members,* requires the Contractor to submit concrete test results to the METS *Data Interchange for Materials Engineering (DIME)* webpage. Instructions for submitting sample and test information are explained on the webpage. Additionally, the Contractor is to provide QC summary reports complying with *Contract Specifications*, Section 90-1.01C(12), *Concrete – General – Submittals – Concrete Materials Quality Control Summary Report for Cast-In-Place Structural Concrete Members*.

Under *Contract Specifications*, Section 90-1.01D(9), *Concrete – General – Quality Assurance – Preconstruction Meeting for Cast-In-Place Structural Concrete Members*, schedule a meeting with the Contractor and representative of each concrete plant after the QC plan is authorized and before construction of CIP structural concrete members begins. In this meeting, discuss the Contractor's quality control for concrete production. Address key items from the QC plan, such as concrete sampling and testing and the roles of the QC personnel. Remind the Contractor of their responsibility to reject non-compliant material and to submit test reports and results.

Chapter 3: Forms

Table of Contents

Chapter 3: Forms 1
Table of Contents 1
3-1 Introduction 2
3-2 Specifications 2
3-3 Forming System 2
3-3.01 Form Fasteners 7
3-3.02 Form Liners 9
3-3.03 Steel Forms 10
3-3.04 Fiber Form Tubes 12
3-3.05 Permanent Steel Deck Forms 12
3-4 Form Workmanship 14
3-5 Formwork Design 17
3-6 Formwork Design Review 18
3-6.01 Lateral Loading 18
3-6.02 Unit Weight of Concrete 18
3-6.03 Rate of Placement 18
3-6.04 Temperature 19
3-6.05 Vibration 19
3-6.06 Admixtures 19
3-7 Formwork Removal 19
3-7.01 Form Release 19

3-1 Introduction

Concrete is a unique building material in that it may be cast into a desired shape at the building site while in the plastic state and retain that shape after hardening. Concrete is given its intended shape using forms, which must be built in such a manner that the resulting concrete member will be the correct size and shape. Forms also serve to control the alignment, elevation, and position of concrete members within the completed structure.

Formwork, also known as forms, is the system used to hold freshly placed concrete in its desired shape until it hardens - from sheathing or form panels to all supporting members, hardware, and necessary bracing. Concrete forms also render texture and surface characteristics to the concrete surface. As such, the quality of workmanship in the forming system often determines the amount of subsequent work needed to achieve the required surface finish.

See *Construction Manual*, Section 4-5103D, *Forms*, for a list of items to address when inspecting forms.

3-2 Specifications

Contract Specifications, Section 51-1.03C(2), *Concrete Structures – General – Construction – Preparation – Forms*, contains requirements for concrete forms, which include the structural adequacy and appearance of the finished product. The requirements for forming exposed surfaces are extensive and detailed.

3-3 Forming System

For most cast-in-place (CIP) concrete structures, the forming system will consist of a form surface material or sheathing, studs, walers, and kickers, all adequately braced to retain the concrete within the required line, grade, and dimensions. The forming system also includes forming accessories such as ties, anchors, and spreaders.

Sheathing is the forming material that is in direct contact with the concrete and is therefore the element that renders the texture and surface characteristics of the formed concrete. Plywood is by far the most common sheathing material; however, depending on the type of construction and surface finish required, form sheathing can be surfaced lumber, steel, or, in some cases, synthetic materials, such as form liners. The APA – The Engineered Wood Association's publication, *Concrete Forming: Design/Construction Guide*, is an excellent source of technical information on plywood sheathing material and form design.

If used for forming exposed or visible surfaces, plywood must at least meet the requirements for U.S. Product Standard PS 1 for Exterior B-B (Concrete Form) Class I Plywood. Figure 3-1 shows a typical APA grade stamp on plywood.

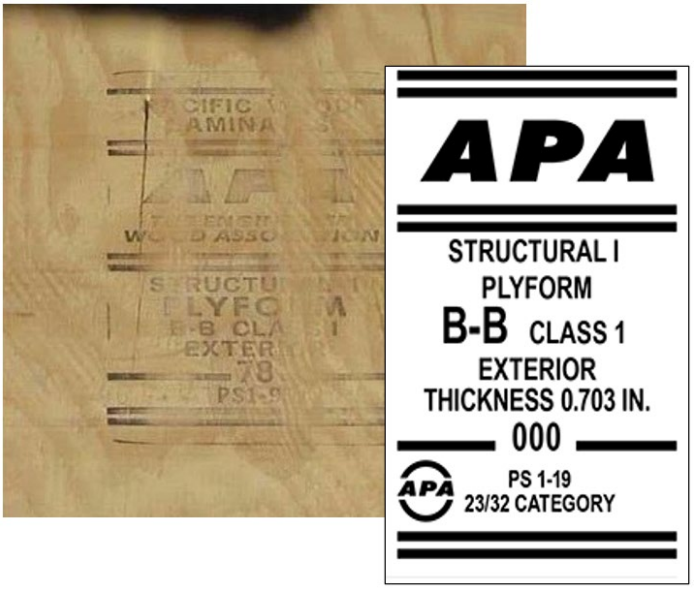

Figure 3-1. Illustration of APA PS 1 Grade Stamp

Other sheathing material may be used in forms for exposed concrete surfaces, provided it produces a smooth, uniform concrete surface substantially equal to that which would result from the use of the specified plywood, such as metal forms. Steel and polyvinyl chloride (PVC) are materials that may be acceptable for forming exterior surfaces. Increasingly, form liners are being specified as a sheathing material for exposed concrete surfaces to render architectural treatment to the formed concrete surface.

The form sheathing is reinforced by a system of studs and walers to allow it to withstand the load imposed by wet concrete. For jobsite-built plywood forms used for such custom-built bridge components and elements as abutments, retaining walls, and box girder superstructures, studs are vertical form elements, usually made of dimensional lumber, to which the sheathing is attached. Essentially, studs serve as sheathing reinforcement that allows the sheathing to confine the freshly placed concrete. The studs are spaced to limit the deflection of the sheathing between the studs. Walers are horizontal form components that support the vertical studs. Walers are usually installed in pairs against the studs, facilitating the use of concrete ties that are inserted and secured to keep the forms from separating. The actual stud and waler spacing is governed by specified deflection criteria, lateral concrete load, and allowable stresses. Figure 3-2 shows typical wall forming using studs and walers.

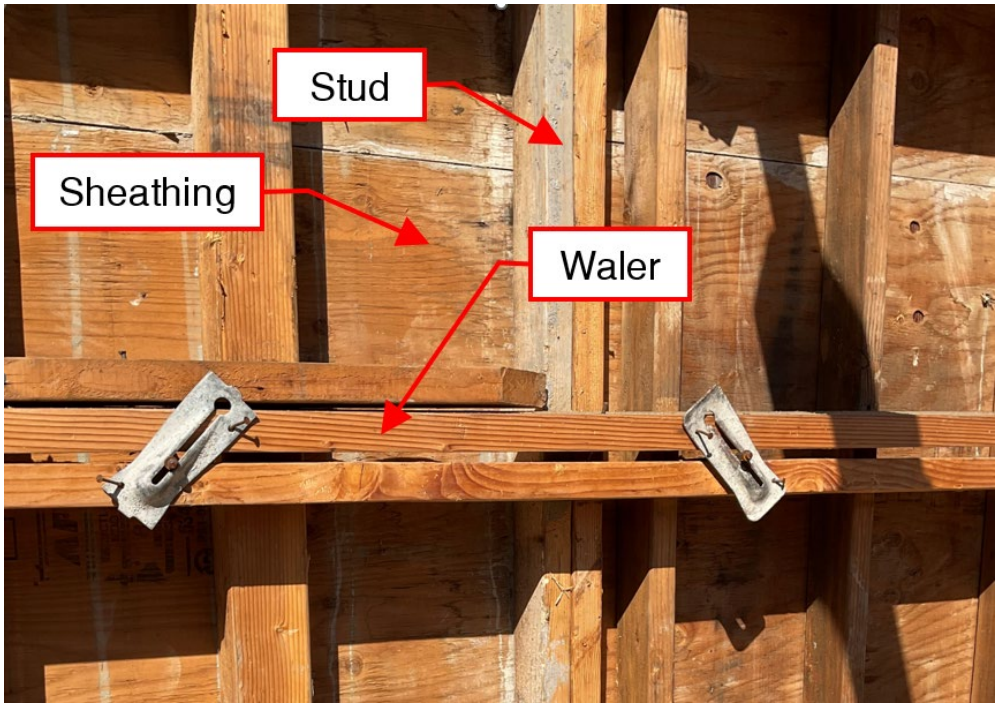

Figure 3-2. Wall Forming Using Studs and Walers

Vertical concrete forms must be braced to transfer all horizontal loads to the support and to prevent instability. Kickers are braces installed diagonally between the form and the ground or a stable platform, keeping vertical forms plumb and providing stability to the whole system. Kickers are important because if not properly braced, the forms may deflect or shift, in which case remedial work may be necessary to obtain the required lines and grades. Figure 3-3 illustrates typical forms braced with kickers.

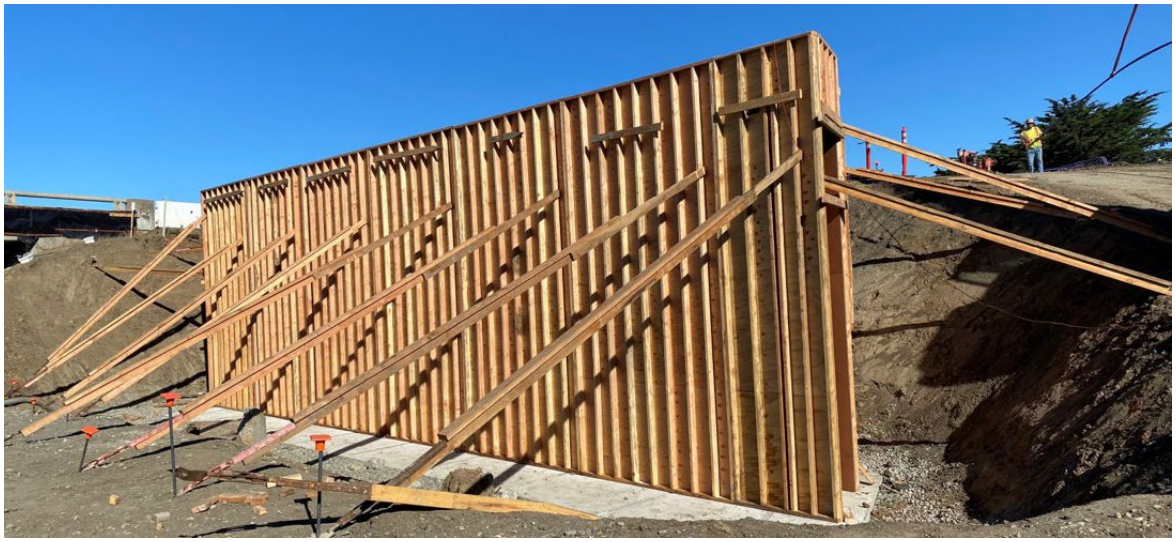

Figure 3-3. Concrete Forms Braced with Kickers

Gang forms are typically used for the construction of large-scale structures such as tall retaining walls and CIP concrete bridges. On concrete bridges, they may be installed on conventional falsework systems to form the bridge soffit. These prefabricated panels typically consist of an 8- by up to 40-foot-long panel comprised of plywood nailed to 2-by-8-inch joists, or similar; see Figure 3-4. When the soffit gang form panels are erected onto the falsework stringers, they are typically placed with a gap between each panel, which aids in the erection and removal of the panel system. This gap is typically bridged with a form filler panel (filler strip of plywood), as illustrated in Figure 3-5. Figure 3-6 depicts a typical completed soffit that was formed with gang forms.

Figure 3-4. Typical Gang Form

Figure 3-5. Form Filler Panel

Figure 3-6. Completed Soffit with Gang Forms

Chamfers are wooden triangular-shaped fillets used at form panel intersections to prevent mortar runs and bevel the corners of panel joints. Forms for exposed surfaces must be constructed with triangular fillets not less than ¾ by ¾ inches attached to produce smooth, straight chamfers at all exposed sharp edges of the concrete. They are also used as grade strips or pour strips to delineate the top of the pour within the forms. Chamfers are also commonly used to create the drip grooves for concrete box girder bridges. These drip grooves are detailed in Standard Plan B7-1, *Box Girder Details*. See Figure 3-7 for chamfers used in construction.

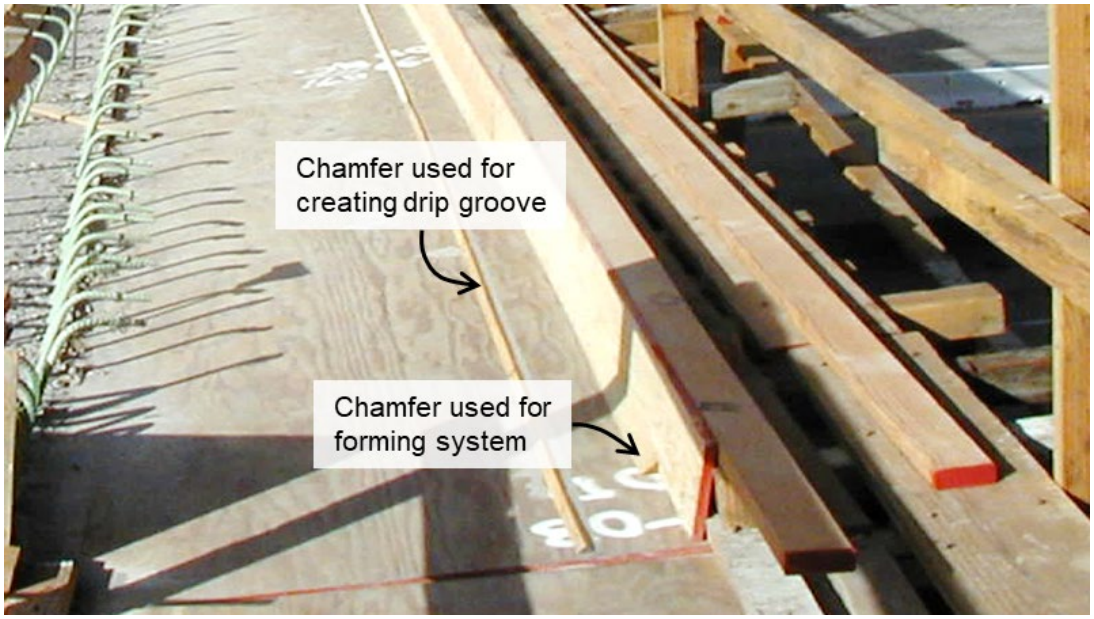

Figure 3-7. Chamfers Used for Bridge Construction

Expanding foam may be used to fill incidental gaps and ensure forms are effectively placed flush against concrete in areas around columns and abutments. Care must be taken when determining the product's expansion capabilities. Excess foam that protrudes into the concrete section must be trimmed off.

3-3.01 Form Fasteners

Form fasteners are bolts, clamps, or other devices used as necessary to prevent the forms from spreading during concrete placement. The requirements for form fasteners are provided in *Contract Specifications*, Section 51-1.03C(2)(a), *Concrete Structures – General – Construction – Preparation – Forms – General* and Section 51-1.03F(2), *Concrete Structures – General – Construction – Finishing Concrete – Ordinary Surface Finish*. Form fasteners and anchors must be a type that can be removed in accordance with ordinary surface finish specifications, without chipping, spalling, heating, or otherwise damaging the concrete surface. Remove metal fasteners to a minimum of 1 inch below the concrete surface.

Note: Using twisted wire loops to hold forms in position is not permitted, except as specified by *Standard Special Provisions*, Section 51-4.03G, *Precast Concrete Members – Construction – Deck Panels*.

Concrete form ties, also known as snap ties, he-bolts, she-bolts, taper ties, tie rods, or form clamps are tensile units used to prevent the spreading of the forms during concrete placement. The most common ties used in bridge construction consist of an internal tension unit and an external holding device. Ties can have built-in spacers or spreaders to keep the forms a set distance apart. Some ties are designed so that they can be removed, or have portions of them removed, at a certain depth from the surface of the concrete. There are two basic types of internal tension units: continuous single-member and internal disconnecting member.

Continuous single-member ties consist of a single-piece tensile unit and a specially designed holding device that is used to hold the tensile unit tight against the exterior of the form. Some of these ties have an integral form-spreading feature that is built into the tie. The common concrete snap-tie used in bridge construction is snapped at a predetermined depth where the rod section has been weakened to facilitate "snapping." Some single-member ties, such as she-bolts and taper ties, may be pulled and completely removed from the concrete.

The internal disconnecting member has an inner tensile unit with a threaded sleeve connection to a removable external member (bolt). The internal member remains in the concrete, while the outer is removed by unthreading from the coupling sleeve. This type of tie is available for light or medium loads but finds its greatest application under heavier construction loads.

Tie wedges are metal plates used in conjunction with concrete ties to distribute the load from the concrete tie to a larger area on the formwork element, usually the form walers. Wedge shaped in profile, the tie wedge slips over the head of a snap tie and is used to tighten the snap tie against the form by driving the wedge until there is no slack in the concrete tie. After the tie is sufficiently tensioned, the tie wedge is nailed to the form to ensure that it will not move and loosen during concrete placement. Figure 3-8 shows various examples of form fasteners.

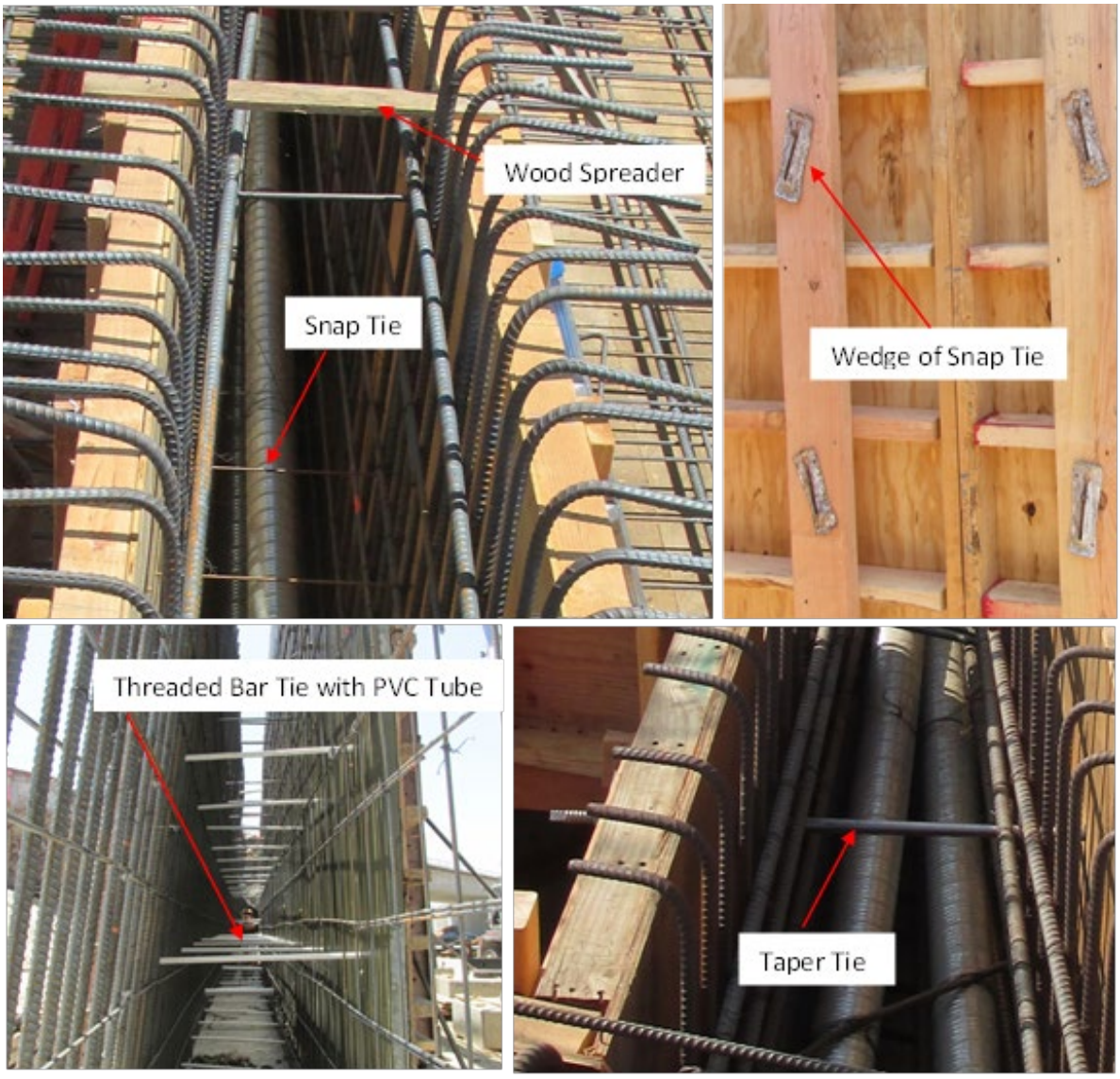

Figure 3-8. Examples of Form Fasteners

Spreaders are devices that maintain the correct spacing between the opposite faces of a formed element, such as those of walls or box girder bridge stems. Spreaders may be integral or fabricated with concrete ties. They may also be custom-made, usually from dimensional (typically 2-by-4-inch) lumber, cut in the field to the exact width of the

formed element. Contractors sometimes employ a concrete tie with both an integral spacer and a custom-made wood spreader to ensure that the correct width is maintained, especially as the ties are tightened. Wood spreaders cannot be left embedded in the concrete and must therefore be removed during the pour. Contractors commonly tether these spreaders to adjacent stirrups to ensure they don't fall into the concrete during placement.

Form anchors are devices that are cast into the concrete for later use in supporting forms or for lifting pre-cast members. There are two basic parts: the embedded anchoring device, whose design varies with the load to be carried and the strength of concrete in the structure; and the bolt or other external fastener, which is removed after use, leaving a set-back hole that must be patched.

3-3.02 Form Liners

Projects may require the use of form liners to create a specified concrete surface texture for CIP concrete structures. The term "form liner" refers to any sheet, plate, or layer of material attached directly to the inside face of forms to provide a desired surface texture or pattern to the finished concrete. While plywood, hardboard, and steel can be used as form liners, the term generally refers to material described in *Contract Specifications*, Section 51-1.03G(2), *Concrete Structures – General – Construction – Concrete Surface Textures – Form Liners.*

Elastomeric liners are made of rubber-like plastic formulations that are flexible enough to be peeled away from cast concrete surfaces. They require structurally adequate support and are usually attached to form sheathing. Elastomeric liners are durable material and can be frequently reused with reasonable care. Figure 3-9 illustrates retaining wall forms utilizing form liner.

Inspect form liners prior to every use to ensure the integrity of the surface. Verify that form liner panels are properly assembled and aligned. For fractured rib texture, verify that the raised surface between the ribs has random texture. This will safeguard against repetitive fractured surfaces or secondary shadow patterns, which are not allowed per *Contract Specifications*, Section 51-1.03G(1), *Concrete Structures – General – Construction – Concrete Surface Textures – General*.

Ensure that form liners do not reduce the specified thickness of the concrete element. For example, when verifying formwork for a retaining wall, avoid the common mistake of measuring to the form sheathing (plywood) instead of the innermost point of the liner texture. Refer to the project plans for details on wall thickness, and the relationship between the layout line (LOL) and the architectural treatment.

Form liners must be released from cured concrete such that the surfaces of concrete are not damaged. After they are released, form liners that are to be reused must be properly cleaned and maintained in accordance with the manufacturer's instructions.

Figure 3-9. Form Liner Panel

3-3.03 Steel Forms

In bridge construction, steel forms are commonly used for casting columns (Figure 3-10) and barrier rails (Figure 3-11). Most of these elements have standardized shapes and sizes. The durable nature of steel forms makes them economical for repeated use. Steel forms for barrier rails come in straight 10-foot sections and may not be suited to form barrier rails with tight radii. Steel forms are also commonly used in pre-casting yards where repeated use of a standard form is the norm. Inspect steel forms for dents, creases, or other damage upon delivery. Minor damage can be repaired with an acceptable filler material.

Figure 3-10. Steel Forms for Columns

Figure 3-11. Steel Forms for Barrier Rails

3-3.04 Fiber Form Tubes

Fiber form tubes are typically used in bridge construction to form the exposed portion of "pile-extension" columns in slab bridges. Fiber form tubes are complete units with no extra fastenings and require only a minimum of external bracing to keep them plumb. Where the columns are exposed, the inner surface is coated with polyethylene. Tubes can be saw cut to length. Cut sections can be adapted to form half-round and quarter-round surfaces. They are also used to form the voids in voided slab bridges, as illustrated in Figure 3-12. Sonotube® is a proprietary trademark for the most widely available cylindrical fiber form.

Figure 3-12. Fiber Forms Used for Forming Voided Slab Structure

3-3.05 Permanent Steel Deck Forms

Permanent Steel Deck Forms (PSDF), also referred to as stay-in-place forms (see Figure 3-13 and 3-14) may be used to form the underside of reinforced concrete bridge decks where specified for use in the contract documents, and as outlined in *Contract Specifications,* Section 51-1.03C(2)(c), *Concrete Structures – General – Construction – Preparation – Forms – Permanent Steel Deck Forms.* Unlike most forms, PSDF are left in place after the deck is cast and become permanent features of the bridge. The Contractor is obligated to submit PSDF shop drawings per *Contract Specifications*, Section 51-1.01C(2), *Concrete Structures – General – Submittals – Permanent Steel Deck Forms*. Review and authorize these shop drawings in accordance with *Contract Specifications*, Section 5-1.23, *Control of Work – Submittals.*

Figure 3-13. Permanent Steel Deck Forms (View Above Deck)

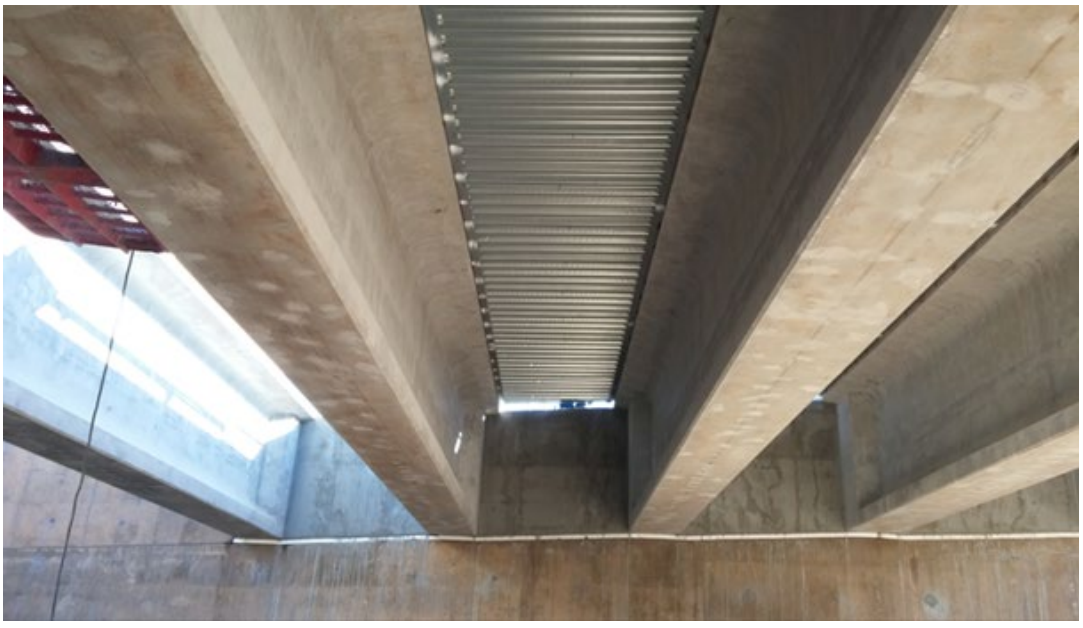

Figure 3-14. Permanent Steel Deck Forms (View Below Deck)

If PSDF are not specified in the contract but proposed for use by the Contractor, their use should be discussed with both Bridge Design (BD) and Structure Maintenance and Investigations (SM&I) to determine whether the proposal merits further discussion, and what design and/or maintenance considerations need to be addressed. Both the BD Project Engineer and SM&I must concur with the change order.

3-4 Form Workmanship

The actual size, shape, and alignment of abutments, columns, superstructure, and other concrete structural components and elements depend on the accurate construction of forms. The forms must be built to the correct dimensions, must be sufficiently rigid under the construction loads to maintain the desired shape of the concrete, must be stable and strong enough to maintain large members in alignment, and must withstand handling and reuse without losing their dimensional integrity.

The appearance of a finished concrete structure depends to a great extent on formwork quality, particularly the adequacy of the formwork to withstand the loads imposed by the concrete while it is in a plastic state without appreciable settlement or deflection. The behavior of formwork, as it is loaded, depends on the strength of the material supporting the form, the support system used, the quality of the form materials and workmanship, the forming method employed, and the rate and method of concrete placement. The formwork must remain in place until the concrete has hardened enough to maintain its cast shape.

The quality of the concrete surface finish is affected by the form panel material. For example, if a patterned or textured form liner is used, the liner must be properly supported so that it will not deflect and cause indentations in the concrete surface. The correct combination of quality form material and adequate releasing agent can contribute to eliminating air holes or other surface imperfections in the cast concrete.

Good workmanship in form construction should be as important to the Contractor as to the Department since the degree of care taken when building forms will determine the amount of subsequent work needed to obtain the required finished product. For example, grout leakage from forms that are not mortar tight will increase the surface finishing required (see Figure 3-15). Dirty form surfaces and form panels with worn or ragged edges will also increase surface finishing costs. Improperly braced forms will deflect, in which case remedial work may be necessary to obtain the required line, grade, and undulation limit specified in the contract documents.

Figure 3-15. Grout Leakage at Form Tie

The Contractor is not contractually forbidden to place new plywood next to old plywood; however, for exposed concrete surfaces or other locations where concrete surface appearance is important, doing so will likely produce an unacceptable, non-uniform concrete surface that will not meet finish requirements. Although not mandatory, contractors should consider “aging” new plywood if they plan to intermix them with older plywood. One method to accomplish this is to apply cement and water paste on the new material, then remove the paste after it dries. The dried cement paste absorbs the fresh wood sugar from the new plywood so that the finished concrete will have a color and texture similar to the color and texture of the seasoned plywood forms.

Additionally, the ability to produce a uniform appearance for exposed concrete surfaces will be affected by the placement of plywood used as form panels. Refer to *Contract Specifications,* Section 51-1.03C(2)(a), *Concrete Structures – General – Construction – Preparation – Forms – General,* for requirements for size uniformity, alignment, and symmetrical arrangement of form panels. Figure 3-16 shows form panels that have been properly sized and arranged.

Figure 3-16. Bridge Abutment Form Panels Properly Sized and Arranged

For exposed concrete surfaces, it is also essential to use the proper type of form tie or hanger that will not leave exposed metal at the concrete surface. If any moisture reaches the end of the tie, rust stains will appear on the surface of the concrete. A greater depth of break-back or threaded ends of internally disconnected tie units allows a better chance of bonding the patch that covers the tie, and less chance of the patch spalling or cracking. Although the patch remains in place, it may shrink and leave fine cracks through which moisture and rust gradually seep. Because it is non-corroding, a glass fiber-reinforced plastic tie, commonly referred to as a fiberglass tie, may be removed flush with the concrete surface, leaving no hole to patch.

As mentioned previously, forms must be mortar tight to prevent grout leakage. This requirement is particularly important for soffit forms located above traffic openings or forms near environmentally sensitive areas. The use of thin metal strips, plastic sheeting (Visqueen), spray foam, caulking, or other materials can reduce the risk of leakage. Although not contractually required, it is a highly recommended best practice to place plastic strips or similar material underneath the unsupported soffit plywood seams at these locations. See Figure 3-17 for an illustration of this proactive practice.

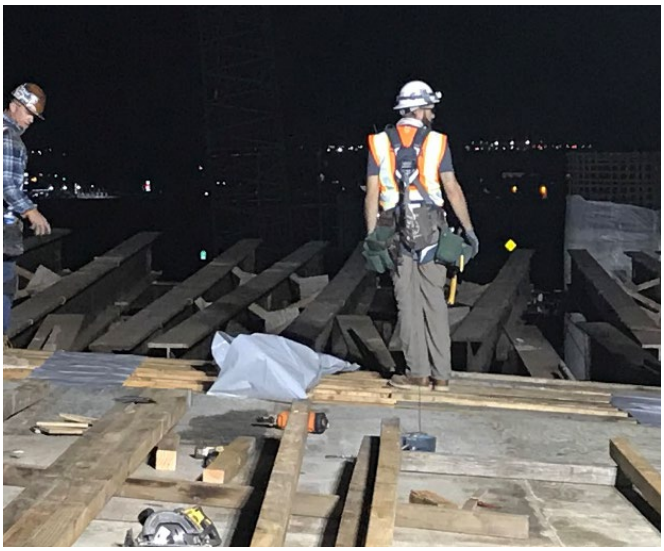

Figure 3-17. Plastic Placed Under Soffit Plywood Seams Over Traffic Opening

Inspect the forms sufficiently in advance of placing rebar and concrete to provide time for repairs without impacting the schedule. In addition to items discussed in this section, other common issues to look for include:

1. Loose form filler strips (e.g., form filler strips that are not firmly nailed to the joist).
2. Damaged and warped panels from overuse or exposure to weather.
3. Non-uniform filler strip widths.
4. Non-uniform form line patterns, particularly on skewed bridges.

Note in daily reports when the Contractor is notified of necessary corrective actions and when they are completed and accepted. Form panels that have minor damage or are damaged (damaged corners, holes, delamination, and scars) after installation and cannot reasonably be replaced may be repaired when using acceptable methods and materials, such as custom-cut wooden patches (referred to as “Dutchman”), wood fillers, resin products (Bondo), and wood or cork plugs. Building paper must not be used to patch cracks or holes in lost deck forms. Tin sheet metal or wood is acceptable, provided it does not infringe on the required deck thickness. Inspect forms again immediately before concrete placement to verify they remain in acceptable condition.

3-5 Formwork Design

Contract Specifications, Section 51-1.03C(2), *Concrete Structures – General – Construction – Preparation – Forms*, provides requirements for formwork. Although it is not required, *Contract Specifications*, Section 51-1.01C(1), *Concrete Structures – General – Submittals – General,* provides SC staff the right to request a concrete form design and materials data to be submitted for each forming system. It may be prudent to request that the Contractor provide details of the forming system for the Engineer’s review and meet to discuss any concerns about the adequacy of the formwork.

3-6 Formwork Design Review

3-6.01 Lateral Loading

Determining the appropriate lateral loading to be used in form design is a subjective exercise. This lack of precision is because the basic component of lateral loading and the fluid pressure of fresh concrete is governed by the unit weight of concrete and affected by several variables such as the type of cement, concrete temperature, concrete penetration (slump), consolidation method, and rate of concrete placement. ACI 347 *Guide to Formwork for Concrete*, published by American Concrete Institute (ACI), provides guidance for determining loads based on dimensions, placement rates, and other factors.

3-6.02 Unit Weight of Concrete

The basic component of the lateral loading on the forms is the unit weight of concrete. Freshly placed and vibrated concrete behaves temporarily like a fluid imparting lateral pressure on the vertical surfaces of the forms. If concrete is considered an idealized fluid, then the pressure on the form during concrete placement follows the standard fluid pressure formula:

$$\mathbf{P = wh} \qquad \text{3-6-1}$$

Where "**w"** is the unit weight of concrete in pounds per cubic foot (pcf) and "**h**" the height in feet of concrete over a given point. 150 pcf is a commonly assumed unit weight of concrete for the sake of convenience.

However, fresh concrete is a mixture of cementitious materials, aggregates, and water whose behavior only approximates that of a true fluid for a limited time. The effective lateral pressure used in form design is a modified hydrostatic pressure, where its basic component, the unit weight of concrete, is adjusted by concrete placement factors such as temperature of the concrete mix, rate of placement, the admixtures and cement blends used, and effects of vibration or other consolidation methods.

3-6.03 Rate of Placement

One of the most significant factors affecting the lateral pressure on concrete forms is the average rate of concrete placement. As soon as concrete is placed, it starts to become less fluid and lose its capacity to translate the weight of subsequent concrete layers as additional lateral pressure on the forms. This reduces the hydrostatic head to only those layers where concrete is still fluid, thereby decreasing the effective fluid pressure on the form. With slower rates of placement, concrete at the bottom of the form begins to harden, and the lateral pressure is reduced to less than the idealized fluid pressure by the time concrete is placed in the upper parts of the form.

3-6.04 Temperature

The temperature of the concrete during its placement also influences effective pressure on concrete forms because it affects the setting time of concrete. At low temperatures, the concrete generally stays fluid for a longer period, allowing for more concrete to be placed before the lower portion becomes firm enough to be self-supporting. The greater hydrostatic pressure head due to the lower concrete temperature results in higher lateral pressures. This must be considered when designing forms for concrete to be placed during cold weather.

3-6.05 Vibration

The method of consolidating concrete inside the forms is also a factor that affects the magnitude of the effective fluid pressure. Consolidating concrete using internal vibrators results in an increase in temporary lateral pressures, because it causes concrete to behave as a fluid for the full depth of vibration, generating approximately 10-20 percent greater pressure in the localized area of vibration. If external vibrators are used, the loads they exert on the forms must also be taken into consideration in form design. Essentially, the forms “hammer” against the concrete.

3-6.06 Admixtures

Chemical admixtures and supplementary cementitious materials have significant effects on lateral pressure. They may slow down or accelerate the rate at which the concrete hardens. The chemistry coefficient, $\mathbf{C_c}$, introduced in ACI 347, provides a way to quantify the effect of a number of these variables, on lateral pressure.

3-7 Formwork Removal

The contract requirements for form removal, also known as stripping, are found in *Contract Specifications*, Section 51-1.03C(2)(b), *Concrete Structures – General – Construction – Preparation – Forms – Removing Forms*. Be aware of the requirements of *Contract Specifications*, Section 90-1.03B, *Concrete – General – Construction – Curing Concrete*. Unless the concrete is cured using the “Forms-in-Place Method”, per *Contract Specifications,* Section 90-1.03B(5), *Concrete – General – Construction – Curing Concrete – Forms-In-Place Method,* the Contractor must be prepared to immediately apply one of the other approved curing methods provided in *Contract Specifications,* Section, 51-1.03H, *Concrete Structures – General – Construction – Curing Concrete Structures,* before starting form removal.

3-7.01 Form Release

The specifications require that forms to be removed must be thoroughly coated with oil before use. Form oil is applied to form sheathing to prevent concrete from bonding to

the form, permit its ready release, and keep the formwork clean. Form liners require application-specific form release agents. Follow the manufacturer's recommendation for form release agents or discuss with the Materials Engineering and Testing Services (METS) Representative. Ensure that the form release agent does not discolor the concrete. If in doubt about the efficacy of or potential discoloration caused by the product, have the Contractor cast a test sample.

Without form release agents, the forms will adhere to the surface of the concrete when the forms are stripped, creating rough, irregular, spalled surfaces. The resulting effect necessitates costly and lengthy refinishing of the exposed concrete surface. The form release agent must not contact the bar reinforcement. Otherwise, it may prevent or reduce the bonding between the concrete and steel necessary to develop the composite function of reinforced concrete. Accordingly, it is standard practice to apply form release agents to the formwork prior to the placement of bar reinforcement.

While the specifications only require a commercial quality form release agent that will permit the ready release of the forms, there are products that are specifically formulated as form release agents. In general, there are two broad categories of form release agents: barrier type and chemically active. Barrier types are water-insoluble materials that include neat oils, paraffin wax, and silicone oil. The Environmental Protection Agency prohibits the use of uncut or straight diesel oil as a release agent. Chemically active agents have fatty acids that chemically react with materials in portland cement paste and produce soap, a film that prevents the concrete from bonding to the form surface.

There has been increasing concern about the use of form release agents in applications over bodies of water; check with the Storm Water Pollution Prevention Plan or regulations of the local Regional Water Quality Control Boards on product limitations. Local and federal regulations on volatile organic compounds (VOCs) may need to be considered when selecting the appropriate release agent.

Chapter 4: Reinforcement

Table of Contents

Chapter 4: Reinforcement 1
Table of Contents 1
4-1 Introduction 2
4-2 Technical Resources 2
4-3 Contract Requirements and Preparation 3
4-4 Construction 5
4-4.01 Shipment 5
4-4.02 Material and Fabrication Verification 5
4-4.03 Placement 6
4-4.04 Safety 13
4-5 Corrosion Protection 15
4-5.01 Epoxy-Coated Reinforcement 16
4-5.02 Galvanized Reinforcement 21
4-5.03 Galvanic Anodes 21
4-6 Headed Bar Reinforcement 21
4-7 Splices 22
4-7.01 Splicing Methods 24
4-7.02 Service Splices and Ultimate Butt Splices 28
4-7.03 Sampling and Testing – Service and Ultimate Butt Splice 29
4-8 Drill and Grout Dowels/Drill and Bond Dowels 40

4-1 Introduction

Concrete is known for being strong in compression but weak in tension. To withstand tensile stresses, structural concrete members are typically designed with reinforcement. Reinforced structural concrete can incorporate various materials to provide a composite material with higher tensile and shear capacity compared to unreinforced concrete. Some specialized materials used for reinforcement include polymer microfibers and fiberglass rods. However, the term "reinforced concrete" generally refers to concrete incorporating bar reinforcement (also known as bar reinforcing steel or rebar). In some cases, welded steel wire reinforcement, placed in specific patterns and locations within a concrete structure, may be specified for concrete reinforcement.

This chapter primarily covers bar reinforcement and its installation, focusing on contract requirements and best practices for installation. It highlights the types of inspections Structure Construction (SC) staff are expected to conduct. Additional guidance can be found in *Construction Manual*, Section 4-52, *Construction Details – Reinforcement,* and SC's *Outline of Field Construction Practices*.

4-2 Technical Resources

Bridge Construction Memo (BCM) 52-1, *Reinforcement – General,* and its accompanying attachments provide supplemental information to the topics presented in this chapter. The attachments include rebar details such as radius, hook, and bend lengths, as well as bar reinforcement identifications. The radius and hook details in the BCM 52-1 attachments conform to the *Building Code Requirements for Structural Concrete* published by American Concrete Institute (ACI), otherwise known as *ACI 318*. Unless different details are shown on the project plans, *ACI 318* governs. The latest version of *ACI 318* can currently be downloaded by SC staff through the Engineering Workbench[1] by Accuris (account setup and login required). Instructions on using this resource can be found on the SC webpage under the "Field Resources"[1] tab.

The Concrete Reinforcing Steel Institute (CRSI) has issued various publications related to the design, fabrication, and installation of reinforcement that SC staff may find useful, including the *Manual of Standard Practice* and *Placing Reinforcing Bars*. CRSI also has a mobile application, *CRSI Rebar Reference*, that the Department currently has available to download for Department mobile devices.

These and similar resources provide best practices and valuable information. However, the *Contract Specifications* and contract documents govern if any contradictory information is presented.

[1] Caltrans internal use only

4-3 Contract Requirements and Preparation

The primary requirements for bar reinforcing steel incorporated into reinforced concrete are found in *Contract Specifications,* Section 52, *Reinforcement*, although other related specifications can be found throughout the *Contract Specifications*. The Contractor, or more specifically, the reinforcement subcontractor, is responsible for detailing, fabricating, and delivering rebar to the jobsite.

Source inspection and release by Materials Engineering and Testing Services (METS) is not usually required for typical rebar. For this reason, rebar delivered to the jobsite must be accompanied by a certificate of compliance (COC) in accordance with *Contract Specifications*, Section 52-1.01C(3), *Reinforcement – General – Submittals – Certificates*, and Section 6-2.03C, *Control of Materials – Quality Assurance – Department Acceptance – Certificates of Compliance*. File the COC in the job files as directed in the *Construction Manual,* Section 6-203D, *Sampling and Testing – Field Inspection and Release by the Resident Engineer*. Additionally, the Contractor must submit copies of the certified mill test reports (CMTR) and reinforcement lists. A CMTR, also known as a "mill cert", is a document from the mill providing information regarding the physical and chemical properties of the steel and traceability of the material's origin. A reinforcement list, also known as "bar list", is a bill of materials for delivered rebar. It lists, among other information, the rebar sizes, lengths, and quantities delivered. Remind the Contractor of their requirement to provide these documents before rebar is scheduled for shipment. This responsibility is often overlooked because rebar procurement is typically the responsibility of a subcontractor.

Rebar incorporating additional fabrication processes usually requires METS inspection and release at the fabrication facilities to ensure contract compliance, including the following items listed below:

- Epoxy-coated and galvanized bar reinforcing steel
- Headed bar reinforcement
- Butt spliced bar reinforcing steel.

Mechanical butt splices may be fabricated in the shop or in the field. The contract requirements are the same in either case, but the coordination between METS and SC is different, depending on where the splicing is performed. To ensure consistency, SC staff should discuss the field operations with the METS Representative (METS Rep) and coordinate their assistance as needed.

Contract Specifications, Section 6-1.06, *Control of Materials – General – Buy Clean California Act* (BCCA), identifies the types of projects that are subject to the Buy Clean California Act; for additional information, refer to Public Contract Code Sections 3500-3505. The BCCA came about to help control emissions related to the fabrication of

construction materials. For the types of projects identified in the aforementioned specification, carbon steel rebar must be sourced from a BCCA compliant mill that is on the Department's Authorized Material List (AML), Environmental Product Declarations (EPD). Verify that the rebar source is listed in the AML when reviewing the Form CEM-3101, *Notice of Materials to be Used,* submitted by the Contractor. Additionally, once rebar is delivered to the site, check that the Contractor has reported the material quantity delivered on the Data Interchange for Materials Engineering (DIME) webpage for the project within 5 business days. Refer to *Construction Manual*, Section 3-606, *General Provisions – Control of Materials – Buy Clean California Act*, for additional guidance.

Contract Specifications, Section 52-1.01C(2), *Reinforcement – General – Submittals – Shop Drawings,* requires the Contractor to submit temporary support system shop drawings with supporting design calculations for their proposed means of supporting any unsupported portion of reinforcing steel assembly that is greater than 20 feet. Typically, a column guying plan is used as a temporary support system plan. As part of its review, verify the guying plan addresses every stage of construction until the column is self-supporting. The guying system may be in one configuration for securing the column rebar cage itself, then be modified for placing and securing the formwork for the column, then modified yet again for access during concrete placement. Once the column concrete has gained enough strength to support itself without formwork, it is considered self-supporting. However, it is important to consider whether any unusual conditions, such as a very tall column pinned at its foundation or exposed to high winds, would require the guying system to remain in place. Refer to SC's upcoming *Temporary Structures Manual,* Chapter 5, *Guying Forms and Rebar Assemblies*, for specific guidance on reviewing and authorizing a column guying plan.

Unless specified otherwise, the Contractor is not required to submit any type of rebar shop drawing (sometimes known as placing drawings) or work plan for authorization. However, it may be a good idea to conduct a cursory review of rebar placing drawings generated by their rebar supplier or contractor to check that they align with the project plans, particularly for structures with complex rebar details.

Preparation for reinforcing steel fabrication and installation is not limited to just being familiar with applicable specifications, but also being aware of, and reducing the potential for, constructability issues. For instance, confirm that the rebar fabricator and detailer are mindful of features of the bridge that may affect rebar details. As mentioned in Chapter 2, *Preconstruction Planning*, some examples of features shown in the project plans that may cause errors in detailing and fabrication include varying girder spacing, varying section depths and girder heights, varying section thicknesses, skewed features at bents and abutments, and tightly curved or highly superelevated decks. Varying girder heights and section depths may require variations in rebar length. It is unlikely the Contractor will attempt to fabricate each stirrup to a specific length according to its exact

location along the girder length. Rather, they may propose a simplified alternative. The Structure Representative must review and authorize any such proposal. The Contractor may propose to fabricate in blocks of equal length for installation in specific locations along the girder length, or stirrups may be fabricated in pieces for assembly in the field with varying lengths of lap splices to make variation in the overall stirrup length.

4-4 Construction

4-4.01 Shipment

As mentioned previously, the Contractor is required to submit COCs, CMTRs, and a bar list for each rebar shipment. These documents are often accompanied with the actual shipment. Check that the field delivered rebar matches these submitted documents. The bar list can be used to assist SC staff with inspecting rebar placement and determining quantities for progress payments.

4-4.02 Material and Fabrication Verification

Verify the sizes, steel type (or ASTM designation), and grade (or yield strength) of rebar match those shown in the project plans and *Contract Specifications*. Bars are required to have marks identifying these characteristics. These marks are usually embossed, or rolled-in, along one side of the bar. Figure 4-1 shows identifying marks on a specific bar.

Figure 4-1. Bar Reinforcement Identifying Marks

In the United States, a mark of a single number indicates its size. For the bar shown in Figure 4-1, the number “11” indicates a #11 sized bar (this corresponds to approximately 1.41 inches in diameter, as U.S. sizes are identified in eighths of an inch). The type of steel is identified by another symbol or marking, based on instruction provided in the applicable ASTM Specification. For bars complying with ASTM A706, the ASTM instructs to use the letter “W” as a mark. Similarly, ASTM A615 instructs to use the letter “S”. The bar shown in Figure 4-1 is marked with “SW”, signifying that it complies with both ASTM specifications. A separate number identifies its grade, such as the marking of “60” shown in Figure 4-1. This indicates Grade 60 steel for a minimum yield strength of 60,000 psi (the absence of a grade mark identifies Grades 40 or 50 steel). A separate mark identifies the mill where the bar was fabricated. A legend of mill identification marks can be found in CRSI’s *Manual of Standard Practice.* For the bar in Figure 4-1, the check mark and “Z” marks identify that the bar was fabricated at CMC Steel in Arizona. BCM 52-1, Attachment 2, *Identification of Reinforcing Steel Bars,* provides further guidance for identifying bar reinforcement.

Additionally, verify that bar lengths and bends conform to the project plans. Bar reinforcement bends and hooks must conform to the provisions of the *Building Code Requirements for Structural Steel* published by the American Concrete Institute (ACI). BCM 52-1, Attachment 1, *Reinforcing Steel Hook Detail*, contains standard hook details that align with ACI guidelines. Most bars will arrive at the jobsite having already been bent or cut at the fabricator’s facility, although there may be some cases when these fabrication processes occur in the field.

Ironworkers commonly use a rebar bending hand tool, often called a “hickey”, to adjust the position of and bend bar reinforcement in the field. A hickey is typically made of a long-handled steel rod with a curved bending head at the end. Ironworkers can bend rebar by fitting the bending head around the bar, and then applying their leverage on the handle to force the bar to bend. If the Contractor chooses to field bend bar reinforcement for hooks, verify the hooks are bent to the minimum required bend diameter, which is a function of the rebar size. Per *ACI 318*, Section 26.6.3, *Bending*, preheating field-bent bars may be required. Regardless of where it occurs, reinforcing bars must not be damaged during bending or cutting. As mentioned later in this chapter, the only epoxy-coated reinforcement that is allowed to be field bent is reinforcement complying with ASTM A775/A775M.

4-4.03 Placement

To perform as intended, reinforcement must be placed in accordance with the contract documents. Bar reinforcement placement requirements are found in the project plans and *Contract Specification*s, Section 52-1.03D, *Reinforcement – General – Construction – Placing*.

The duration of rebar placement may vary based on the complexity and size of the component being constructed. It can range from a brief operation to an ongoing task of several weeks. Therefore, close coordination and cooperation with the Contractor and the ironworkers, especially the foreman, are crucial to ensure timely inspections and to verify that the work is completed correctly and efficiently, minimizing the need for rework.

Discuss the construction schedule with the Contractor to ensure benchmark[1] inspections are performed before moving to the next stage of construction. An example of a benchmark inspection of bar reinforcement is inspection of a lower mat of rebar before the Contractor begins installing the upper mat. Ironworkers often use their own rebar placing drawings, developed from the contract documents, to place rebar. As mentioned earlier, although it is not mandatory for rebar shop drawings to be submitted, it is good practice for the SC staff to request a courtesy copy.

Be mindful of potential conflicts between reinforcement and items that are to be embedded in the structure (e.g., prestress hardware, utilities, drainage systems, etc.). If significant adjustments or relocation of reinforcement are necessary to resolve the conflict, discuss the situation with the Bridge Design (BD) Project Engineer.

4-4.03A Spacing, Clear Distance, and Cover

Contract Specifications, Section 52-1.03D, *Reinforcement – General – Construction – Placing,* defines the standard required minimum center-to-center spacing as 2.5 times the diameter of the larger bar for parallel bars. Additionally, the contract documents may specify the minimum clear distance. Be aware of the difference between center-to-center spacing, which measures the distance between the centers of the bars, and clear distance, which refers to the distance between the outer surfaces of the bar and adjacent bar or object.

The clear distance requirement for bundled bars – individual bars tied together in a group – depends on several factors, including the size of the concrete aggregate, bar diameters, and number of bars in the bundle. The previously mentioned specification outlines the clear distance requirements for bundled bars based on the factors listed above. For example, Table 4-1 is a summary of the minimum clear distance requirements for bundled bars based on the contract requirements for concrete with a maximum aggregate size of 1.5 inches.

[1] Caltrans internal use only

Table 4-1. Bundled Bar Clear Distance for 1.5-inch Aggregate Concrete

Bar Size	Dia. (in.)	Clear Distance (in.)		
		Single	2-bar Bundle	3-bar Bundle
#3	0.375	2.25	2.25	2.25
#4	0.500	2.25	2.25	2.25
#5	0.625	2.25	2.25	2.25
#6	0.750	2.25	2.25	2.25
#7	0.875	2.25	2.25	2.25
#8	1.000	2.25	2.25	2.60
#9	1.128	2.25	2.39	2.93
#10	1.270	2.25	2.69	3.30
#11	1.410	2.25	2.99	3.66
#14	1.693	2.54	3.59	N/A
#18	2.257	3.39	4.79	N/A

Note: Assumed for 1.5-inch diameter maximum aggregate

The concrete clear cover, or the clear distance between the outermost rebar and its adjacent concrete surface, is typically 2 inches minimum, unless specified otherwise. For instance, cast-in-drilled-hole (CIDH) concrete piles require at least 3 inches of clear cover. Projects within marine environments and freeze-thaw areas may specify greater cover.

Oftentimes, ironworkers will mark where rebar will be placed on the forms, as shown in Figure 4-2. If possible, check these layout marks before rebar is placed, and resolve any concerns with the Contractor.

Figure 4-2. Bar Reinforcement Layout

Contractors use spacers to meet the various spacing and cover requirements. The most common type of spacer is the precast mortar block, often referred to as “dobies.” During fabrication, tie wire is cast into the dobies, which are used to secure dobies to rebar. The dobies shown in Figure 4-3 are being used to meet cover requirements for the bottom mat of reinforcement.

Figure 4-3. Concrete Dobies Under Approach Slab Bottom Mat

Less frequently used, but still acceptable, are ferrous metal chairs. They are typically used for supporting the bottom mat of rebar for footings and slabs. Unless exceptions are specified elsewhere in the contract documents, *Contract Specification*s, Section 52-1.03D does not allow the use of aluminum, plastic, or wood spacers and supports. One exception is plastic spacers for CIDH piles, which are allowed under *Contract Specifications*, Section 49-3.02B(8), *Piling – Cast-In-Place Concrete Piling – Cast-In-Drilled-Hole Concrete Piling – Materials – Spacers*. Refer to BCM 49-3, Attachment 6, *CIDH Concrete Piling – Materials,* for additional information regarding the use of plastic spacers for CIDH piles.

When verifying spacing and cover, also measure the size of the spacers to confirm they are correctly sized to provide the required space. Take into consideration that rebar may move out of its current position and even bend when it is loaded during concrete placement. Additional spacers may need to be installed if this is a concern.

4-4.03B Tying

A set of bar reinforcement tied together in a grid-like fashion is known as a rebar mat. Similarly, rebar tied to form a framework, in the shape of a box or cylinder, is known as a rebar cage. Rebar is typically tied together when bars are in final placement, although some rebar are delivered with bars tied at the fabricator. Rebar cages for CIDH piles are an example of the latter.

Rebar must be installed in a way that ensures it remains in its intended position and retains its planned configuration during concrete placement. Tying bars securely is crucial for achieving this goal. Ironworkers use tie wires, usually 16.5 gauge, to fasten rebar at their intersections. While not every intersection needs to be tied, the frequency of ties should be sufficient to keep the rebar stable as intended. The *Contract Specifications* may define the frequency of tying. For example, column and pile rebar cages that are at least 4 feet in diameter have minimum tying frequencies specified in *Contract Specifications*, Section 52-1.03D, *Reinforcement – General – Construction – Placing*. Also, the ties for bundled bars must be spaced not more than 6 feet apart. There are also extra requirements for tying epoxy-coated rebar, including requirements for the tying material, as discussed in Section 4-5.01, *Epoxy-Coated Reinforcement*, of this chapter. The column reinforcement shown in Figure 4-4 is tied so that the vertical and hoop bars are secured together.

Figure 4-4. Column Reinforcement Ties

Check that rebar is held firmly in position by attempting to move it out of position by hand. Rebar in areas subject to heavy foot traffic may require additional tie wiring and more focused inspection to ensure it remains in place. Tack welding crossing bars is not recommended, as the properties of the bar reinforcement can be negatively affected.

4-4.03C Surface Cleanliness

To function as a true composite material, the bond between reinforcement and concrete must be secure and continuous such that the steel cannot slip relative to the concrete. For this reason, the rebar must be incorporated into the concrete free of surface contaminants or defects that could degrade the efficacy of the bond between the two materials. *Contract Specifications*, Section 52-1.03B, *Reinforcement – General – Construction - Cleaning*, states that “reinforcement…must be free of mortar, oil, dirt, excessive mill scale and scabby rust, and other coatings that would destroy or reduce the bond.” Some of these items are clear, while others require some judgment and interpretation. It is always better to prevent contamination than attempting to address it later.

For rebar storage, it is good practice (although not contractual) for the Contractor to store rebar away from mud, grease, water, and other deleterious material that may attach to the rebar. If storing rebar on site, contractors typically keep the bundles elevated off the ground by placing them on wooden pallets and lumber. Epoxy-coated rebar has its own storage requirements, which will be discussed later in this chapter.

If form oil is present on the rebar surface, it can be removed by wiping with rags and solvent. Dirt, of course, is everywhere on a construction site where workers may be walking across or standing on rebars. Proper access must be provided to prevent tracking mud onto the rebar. The tracking of dirt can even take place during a concrete pour. Dirt is relatively easy to remove but be sure it isn't knocked or washed into another location where it can cause contamination with the concrete pour, such as into nearby forms.

Curing compound on rebar is another concern. Rebar can unintentionally be sprayed with curing compound because of over spraying from an adjacent concrete pour. This oftentimes occurs when rebar protrudes from a construction joint. That curing compound must be removed from both the concrete and the rebar before the subsequent pour. This can be done by abrasive blasting the affected area. However, if the rebar is epoxy-coated, abrasive blast cleaning is not recommended due to potential damage to the coating. The bar should instead be wiped clean immediately when the cure is applied. The better practice is to protect the rebar from overspray.

Rebar that is protruding from or adjacent to a pour can also accumulate concrete that has splashed onto or has been poured through the rebar. This too can be considered deleterious material. It should be removed during the pour while the contaminating paste is still wet. If the concrete cures on the rebar, it becomes difficult to remove. In addition to forming a weak bond, it can also reduce the required clearance between adjacent bars. This situation can lead to issues such as aggregate segregation, voids, or rock pockets in future pours.

4-4.03D Mill Scale and Rust

The removal of mill scale and rust is often a matter of judgment. Some mill scale and rust are inherent in the processes of manufacturing, handling, and storing rebar. They are generally considered non-detrimental to the bond between rebar and concrete. The specifications state that mill scale should not be "excessive" and rust not "scabby". Although there are no established standards for these terms, "scabby" suggests that there are flakes of rust or scale that can be peeled off the bar like a scab off a wound. In general, rust and mill scale are not excessive if the weight, dimensions, or cross section are not significantly compromised when removed by hand using wire brushes, and bars remain compliant with the applicable ASTM specifications. This is not to imply the remaining bars should then be cleaned, but rather that the bars are acceptable in their current condition. Figure 4-5 shows light rust on bar reinforcement that does not appear

to have affected the weight or cross section dimension. Loose rust and other material that may affect concrete bond to rebar can be removed by lightly striking the bar with a hammer. They may also be removed during handling by the Contractor.

Figure 4-5. Light Rust on Bar Reinforcement

4-4.04 Safety

In addition to verifying the acceptability of reinforcement material and placement, verify that required safety measures are in place. The California Code of Regulations (CCR) Title 8, Chapter 4, subchapter 4, contains the Construction Safety Orders (CSO). Within the Construction Safety Orders, § 1712, *Requirements for Impalement Protection*, requires workers to be protected from potential impalement from projecting objects. For steel reinforcement, the CSO specifies the "guarding all exposed ends… with protective covers, or troughs." This applies when workers are at grade and rebar extends up to 6 feet above grade or working surface.

Contractors commonly use Cal/OSHA approved manufactured caps and covers, such as plastic caps or steel troughs, for this purpose. Square protective covers must measure at least 4-inch by 4-inch, while round covers must have a diameter of 4 ½ inches. Square protective covers have been installed on the end of the bars shown in Figure 4-6 for impalement protection. Note that some of the caps have likely fallen off from the tops of the bars, which is common with these types of covers, especially if used on smaller sized bars.

Figure 4-6. Plastic Caps

Contractors may also use “job-built” protective covers constructed of “Standard Grade” Douglas Fir or stronger material. Within the Construction Safety Orders, Appendix C, Plate C-25, *Protective Troughs for Protruding Reinforcing Steel*, provides details for acceptable trough designs to be used for rebar that extends up to 6 feet. For taller rebar or troughs not conforming to *Appendix C,* Plate C-25, troughs must be designed by a California licensed engineer and may be subject to a drop test as specified in the CSO.

Personal fall protection or guardrails must be used where applicable, including where there is potential for falls of more than 6 feet. They may be used in conjunction with protective covers or troughs.

Circular bar reinforcement cages, such as those for CIDH piles and columns, have a potential to roll if laid on their sides, as the reinforcement shown in Figure 4-7. These cages should be wedged to prevent them from rolling.

Figure 4-7. Bar Reinforcement Cage Laid on its Side

4-5 Corrosion Protection

Corrosion is the deterioration of materials caused by chemical reactions between the material and the environment it is exposed to. Rebar is susceptible to corrosion if it is exposed to the environment long term. For this reason, rebar must be protected from water and salts in the environment. As mentioned earlier, at least 2 inches of concrete cover is typically required. Project plans may show a larger concrete cover for projects in harsh environments. The consequences of insufficient cover include rebar corrosion and concrete spalling, as illustrated in Figure 4-8.

Figure 4-8. Bar Reinforcement Rusting and Concrete Spalling on Barrier

In some harsher environments, supplemental protective coatings on the rebar may be required to aid in resisting rebar corrosion. Epoxy-coated reinforcement and galvanized bar reinforcement are two types of coated bars typically incorporated in Caltrans projects. Attaching galvanic anodes to rebar is another preventative measure that may be utilized. Refer to the Caltrans METS *Corrosion Guidelines* for further information regarding the corrosive process and various corrosion protection methods for reinforcing steel and other materials.

4-5.01 Epoxy-Coated Reinforcement

Epoxy-coated reinforcing bars are the most common corrosion-resistant bar reinforcement used in reinforced concrete. Protection is provided by the application of an epoxy resin layer, or coat, all around the bars. The contract requirements for epoxy-coated rebar are covered in *Contract Specifications*, Section 52-2, *Reinforcement – Epoxy-Coated Reinforcement and Epoxy-Coated Prefabricated Reinforcement.*

Epoxy coating is typically specified for barrier reinforcement on projects that are within 1000 feet of marine environments in accordance with *Memo to Designers (MTD)*, 10-6, *Use of Pre-Fabricated Epoxy Coated Reinforcement in Marine Environment*. If a project in such an environment does not contain this requirement, the issue should be discussed with the BD Project Engineer, as a change order may be necessary to

include epoxy coating. Additionally, *Contract Specifications*, Section 52-2.02A(1), *Reinforcement – Epoxy-Coated Reinforcement and Epoxy-Coated Prefabricated Reinforcement – Epoxy-Coated Reinforcement – General – Summary,* calls for specific reinforcement to be epoxy coated for projects in freeze-thaw areas.

Epoxy-coated rebar requires additional time for processing, as it must be fabricated, shipped to a coating facility, and then coated before shipping to the jobsite. The Contractor should account for the additional time required for procuring coated rebar. Epoxy-coated reinforcement is usually inspected, tagged, and released for delivery to the jobsite by METS. A TL-0624, *Inspection Release Tag* ("orange tag") produced by METS should be attached to the released material along with COCs when delivered. The one instance when epoxy-coated reinforcement does not require the typical source inspection process is when the fabricator is included in METS Authorization to Deliver (AD)[1] program for the applicable epoxy-coated reinforcement specification. Discuss with the METS Rep if there is any question regarding source inspection.

There are two types of epoxy-coated rebar specified in the *Contract Specifications*:

1. Epoxy-Coated Reinforcement
    a. Complies with ASTM A775/A775M.
    b. May be cut and bent in the field as needed.
    c. Coating must be light green.
2. Epoxy-Coated Prefabricated Reinforcement
    a. Complies with ASTM A934/A934M.
    b. Bar is cut and bent to specified lengths and shape before being coated.
    c. Cannot be bent after coated.
    d. Coating must be gray or purple.

Figure 4-9 shows an approach slab being constructed with epoxy-coated reinforcement (green) complying with ASTM A775/A775M.

[1] Caltrans Structure Construction

Figure 4-9. Epoxy-Coated Reinforcement (Green)

Epoxy-coated prefabricated reinforcement (purple), with coating complying with ASTM A934/A934M, is being used for the concrete barrier shown in Figure 4-10.

Figure 4-10. Epoxy Coated Prefabricated Reinforcement (Purple)

Contract Specifications, Section 52-2.02, *Reinforcement – Epoxy-Coated Reinforcement and Epoxy-Coated Prefabricated Reinforcement – Epoxy-Coated Reinforcement,* and Section 52-2.03*, Reinforcement – Epoxy-Coated Reinforcement*

and Epoxy-Coated Prefabricated Reinforcement – Epoxy-Coated Prefabricated Reinforcement, addresses the contract requirements for these two coating types. The former specification also addresses epoxy-coated wire reinforcing, which will not be discussed in this manual.

To provide the required long-term protection against corrosion, epoxy coating must have a uniform minimum thickness, be protected against damage in the field, and be free of skips and holidays. The Contractor must protect the coating at every stage of fabrication, shipping, storage, and placing (including concrete placement) until it is incorporated into the work.

The *Contract Specifications* reference ASTM A775/A775M and A934/A934M standards for epoxy-coated rebar. These standards include requirements for handling, inspection, and repair of the coating. The "Field Resources" tab on the SC Intranet Webpage contains a link to instructions[1] for accessing ASTM standards. SC staff should pay particular attention to the *Guidelines for Jobsite Practices* found in the Appendices to the referenced ASTM standards. *Contract Specifications*, Section 52-2.03C, *Reinforcement – Epoxy-Coated Reinforcement and Epoxy-Coated Prefabricated Reinforcement – Epoxy-Coated Prefabricated Reinforcement – Construction,* requires the Contractor to comply with these practices. It is important to discuss these practices with the Contractor before fabrication and delivery to ensure they are taking the necessary precautions with the material. The goal is to reduce the potential of extensive damage, which would either require extensive repairs or rejection of the material.

The following are examples of jobsite practices that the Contractor must follow as specified in ASTM A775/A775M and A934/A934M:

1. Handle with care to avoid abrasion. This includes padding contact areas of handling equipment and not dropping or dragging bars.
2. Store so that there is no contact with the ground. Support with wooden or padded supports, spaced to minimize sagging. Separate coated and uncoated steel reinforcing bars.
3. Minimize rehandling by either off-loading as close as possible to final placement or by placing under the crane so bars can be hoisted to final placement.
4. Avoid long-term storage onsite, including after installation and prior to fully incorporating into concrete. If stored outdoors for more than two months, take measures, such as providing an adequate cover, to protect the material from the effects of direct sunshine, salt spray, or any other contaminants.
5. Do not flame cut.
6. Tie with non-conductive tie wire, such as epoxy-coated or plastic-coated tie wire.

[1] Caltrans internal use only

7. During concrete placement, use vibrators with plastic or rubberized coatings. Do not permit vibrators to rattle on coated rebar. This may damage the rebar coating. Coated rebar will not be visible for inspection after concrete placement, so consolidation must be done correctly.
8. Provide walkways where necessary to prevent damage from foot traffic on installed rebar.

Be sure to inspect epoxy-coated rebar for damage to its coating during delivery and installation. Bars with more than 2 percent surface area damage to its coating must be replaced. Otherwise, damage can be repaired with patching material that is compatible with the existing coating. Figure 4-11 shows an example of damaged coating. Follow the manufacturer's recommendation for surface preparation, including removal of rust, and application of the patching material.

Figure 4-11. Damaged Epoxy Coating

Contract Specifications, Section 51-1.03D(4), *Concrete Structures – General – Construction – Placing Concrete – Construction Joints,* requires construction joints to be abrasive blast clean before placing the adjoining concrete. However, this may be an issue if the joint contains exposed epoxy-coated reinforcement, such as when epoxy-coated reinforcement is required for concrete barriers on bridge decks. As mentioned earlier, abrasive blast cleaning can potentially damage the coating. In such cases, discuss alternative methods for preparing the construction joint.

4-5.02 Galvanized Reinforcement

Galvanizing is another means of providing a protective coating around reinforcement. In this case, rebar is coated with a zinc layer. Galvanized reinforcement must be identified in the contract documents when required. Requirements for galvanized rebar are detailed in *Contract Specifications*, Section 52-3, *Reinforcement – Galvanized Bar Reinforcement.* Galvanized bar reinforcement has its own standards, ASTM A767/A767M, Class 1, that the Contractor must comply with.

4-5.03 Galvanic Anodes

Galvanic anodes protect against corrosion, mainly for reinforcement in existing structures. As such, they are typically specified for concrete repair and rehabilitation projects. Galvanic anodes function by taking on the corrosive process instead of the reinforcement, which is why they are sometimes called “sacrificial anodes”. Anodes typically have tie wires that allow them to be secured to reinforcement. They are installed at regular intervals, following spacing provided by the project plans or manufacturer’s recommendation.

4-6 Headed Bar Reinforcement

To function as designed, rebar must be securely bonded into concrete and anchored such that it can sustain loading to yield without pulling out of the concrete. This can be achieved by providing a hook on the terminal end of a bar or by continuing the bar into an adjacent component. However, there may be situations where these design considerations are not be feasible. For instance, in the former scenario, the additional length or terminal hook may create unacceptable rebar congestion. For the latter, an adjacent member may not be available. A commonly used solution for these issues is to utilize headed rebar, sometimes referred to as T-heads. The head secures the bar in place by bearing against the concrete as an alternative to a length of bar or bar hook.

Headed rebar is fabricated so that the end of the bar is larger than the diameter of the actual bar. This is frequently achieved by attaching a cap or plate to the end of the bar. Common methods for attaching the plate include welding and threading. Heads can also be forged onto the bar end itself.

Headed bar reinforcement manufacturers and products that are authorized to be used are listed in the AML. If headed rebar is required for the project, check that the products noted in the Contractor’s submitted Form CEM-3101, *Notice of Materials to be Used,* are on the AML. METS typically inspects headed rebar at the source, attaching a TL-0624, *Inspection Release Tag,* to the lot of headed rebar authorized for release and delivery to the jobsite. During installation, pay particular attention to the clearance and cover of the rebar heads. Even though they are usually incorporated to reduce rebar congestion, this issue may still be a concern (although to a lesser degree).

Figure 4-12 shows headed bar reinforcement installed at a hinge of a CIP (cast-in-place) concrete bridge.

Figure 4-12. Headed Bar Reinforcement

4-7 Splices

Project plans may detail reinforced concrete structure components and elements that require rebar longer than what can be fabricated or delivered at full length. In such cases, shorter lengths of rebar would need to be provided and installed in segments. Constraints such as limited access, tight formwork, or construction joints may also make the installation of full-length rebar impractical, thus requiring this approach. Regardless of the reason for installing rebar in segments, segments must be installed so that they act as single, continuous units. This can be achieved by splicing the rebar.

Splices can be divided into three functional categories: lap splice, service splice, and ultimate butt splice. These categories are based on the design criteria and location of rebar within the structure. *Contract Specifications*, Section 52-6, *Reinforcement – Splicing,* and subsequent subsections outline the contract requirements for splicing, including applicable testing and acceptance criteria.

All splices of adjacent rebar must be staggered. If installed within the same vicinity, splices may create a weak zone in the group of rebar. The required stagger length is dependent on the type of splice and bar diameter. The minimum staggered distance for

all lap splices is the same length specified for the lap length. For butt splices, including those butt spliced per welding or mechanical means, the staggered distance is at least 2 feet between splice midpoints. Project plans may identify “No Splice Zones”, which are locations within the structure where splices are not allowed. Remember to document in the as-built project plans all ultimate butt splices (except for bar reinforcing hoops) and splices not placed per the project plans under BCM C-6, Attachment 3, *Guidance for Completing As-Built Project Plans*. Figure 4-13 shows staggered adjacent mechanical splices that are staggered approximately 2 feet.

Figure 4-13. Staggered Splices with Couplers

4-7.01 Splicing Methods

The typical methods of splicing rebar are lap splice, mechanical splice, and welded splice. The method used must conform to the contract requirements and depends on factors such as application and functional category.

4-7.01A Lap Splice

A lap splice is the most common means of splicing bar reinforcement. It involves overlapping, or lapping, the end portions of separate rebar segments to create a longer continuous line of rebar. The lapped sections must be in contact and securely tied with each other, with a clear distance of at least 2 inches between the spliced section and adjacent reinforcement or splices. As a category, lap splice does not have specified testing and acceptance requirements as opposed to service and ultimate splices.

For the splice to be considered continuous, the lap splice length for installed bars must meet the minimum length of lap specified in *Contract Specifications*, Section 52-6.03B, *Reinforcement – Splicing – Construction – Lap Splicing*. Lap length varies, depending on bar diameter, grade, and if rebar is coated and/or bundled. For instance, uncoated reinforcement complying with ASTM A615, Grade 60, requires a lap length of at least 45 times the diameter of the bar for no. 8 size bars or smaller. For nos. 9, 10, and 11 sized bars, the lap length is 60 times the diameter of the bar. If two different bar diameter sizes are lapped, the minimum length of lap for the smaller diameter bar governs. Table 4-2 summarizes the minimum lap splice length required for each type of non-epoxy-coated or galvanized reinforcement bar.

Table 4-2. Minimum Lap Splice Length

Inch-Pound Smaller Bar Size	Dia. (in.)	Minimum Lap Splice Length (in.)		
		ASTM (Grade): A615 (G60), A706, A1036	ASTM (Grade): A775, A934, A1055	ASTM (Grade): A615 (G40)
#3	0.375	16.88	24.38	11.25
#4	0.500	22.50	32.50	15.00
#5	0.625	28.13	40.63	18.75
#6	0.750	33.75	48.75	22.50
#7	0.875	39.38	56.88	26.25
#8	1.000	45.00	65.00	30.00
#9	1.128	67.68	95.88	50.76
#10	1.270	76.20	107.95	57.15
#11	1.410	84.60	119.85	63.45

Lap splicing is not allowed for no. 14 and no. 18 sized bars, as well as for all hoops.

Lap splicing can also be achieved using mechanical lap splice couplers. Mechanical lap splicing is similar to traditional lap splicing, where continuous bars are provided by lapping segment ends. The difference is that the lapping segments are attached mechanically using couplers. The manufacturer's recommendation may require less overlap than traditional lap splicing. Mechanical lap splice couplers are subject to the requirements of mechanical splices.

Contract Specifications, Section 52-1.03D, *Reinforcement – General – Construction – Placing*, addresses the splicing of spiral reinforcement. Project plans sometimes include discontinuities in spiral column reinforcement at the column/soffit interface or the column/footing interface. This is to facilitate placing the main horizontal rebar for the footing or bent cap. Check the project plans for details at these types of discontinuities. They usually require spiral lap splices and either terminal hooks or mechanical lap splices.

4-7.01B Mechanical Splice (Coupler)

A mechanical splice uses a mechanical coupler, or coupler, to join two pieces of rebar. Couplers act by "gripping" the end of the two rebar mechanically, producing what would be considered a continuous bar.

The AML contains an assortment of commercially available couplers that are allowed to be used on Caltrans projects. Their means of mechanically connecting one bar to the other vary. Verify that couplers to be used are on the AML for steel reinforcing couplers. Witness that the Contractor's operator, who must be prequalified and listed in the Contractor's authorized splice prequalification report, installs couplers per the manufacturer's recommendation. Figure 4-14 shows the installation of sleeve-lock shear bolts type mechanical couplers, and Figure 4-15 shows the installation of two-piece sleeve/forged end type mechanical couplers. Sampling and acceptance testing requirements depend on if the splice is considered a service splice or an ultimate splice and is discussed later in this section.

Figure 4-14. Sleeve-Lock Shear Bolt Mechanical Coupler Installation

Figure 4-15. Two Piece Sleeve/Forged End Mechanical Coupler Installation

Mechanical splices add an additional thickness to the original bar size. This must be considered when placing mechanically spliced rebar in its final location. For example, the clear spacing of the couplers shown in Figure 4-16 is questionable, as concrete may not be able to adequately surround the bars and couplers. This situation should raise concern and immediately be brought to the attention of the Structure Representative and Contractor; elevating it to the BD Project Engineer may be appropriate, to investigate an appropriate solution.

Figure 4-16. Congestion of Mechanical Couplers

The outer surface of the coupler must have at least 1-3/4 inches clearance from the concrete surface.

4-7.01C Welded Splice

A welded splice uses a welding process to splice rebar, typically connecting the butt-ends of rebar. The two butt-weld splicing methods discussed in the *Contract Specifications* are described below*:*

1. Resistance-Butt-Weld: A machine holds both ends of the hoop together and passes a large electrical current through the bar which creates enough heat to fuse the two ends together completing the process. This type of welding is not

covered by the American Welding Society (AWS) code and therefore does not require any of the Non-Destructive Testing (NDT) or Certified Welding Inspector (CWI) requirements. The *Contract Specifications*, Section 52-6.02B(1), *Reinforcement – Splicing – Materials – Service Splices and Ultimate Butt Splices – General*, requires the fabricator performing this splice be on the AML for resistance welding fabricators. This welding method is commonly used for rebar hoops, especially for cast-in-drilled-hole (CIDH) pile rebar and column cages.

2. Complete-Joint-Penetration (CJP) Butt-Weld: This type of weld uses a CJP groove weld complying with AWS D1.4 to join two butt ends together. The groove weld extends completely through the thickness of components joined. The primary purpose for using CJP groove welds is to transmit the full load-carrying capacity of the structural components they join. This welding method is commonly used for field splicing straight bars.

4-7.02 Service Splices and Ultimate Butt Splices

Service splices and ultimate butt splices are designed to higher standards than lap splices. As a result, there are specific testing and acceptance criteria for both service and ultimate butt splices (lap splices do not have such requirements). The key difference is that ultimate butt splices include additional testing criteria beyond those of service splices to ensure ductile behavior.

During the design phase, the BD Project Engineer must identify structural members that are supposed to be ductile and deform inelastically through several cycles during a seismic event, dissipate seismic energy, and sustain damage without significantly losing strength. These members are referred to as seismic critical members (SCMs). SCMs may be designed to force damage to occur at locations most accessible for inspection and damage assessment. Additionally, the BD Project Engineer must identify capacity protected members (CPMs). The forces transmitted from SCMs to adjoining CPMs are limited during a seismic event. CPMs stay mostly elastic with minimal damage to the member. Columns, shafts, and piles in soft or liquefiable soils are members that are commonly identified as SCMs. Common CPMs include footings, bent caps, abutment diaphragms, and girders.

For splicing rebar within SCMs, project plans will note that splices are not allowed, limit splice locations by noting a “No Splice Zone” at plastic hinge regions, or allow only ultimate butt splices. For splicing rebar within CPMs, project plans may identify a “No Splice Zone” within a critical zone and/or designate locations where service splices are acceptable. For any bridge member, if there is no such designation, then splices may be either service splices or lap splices. The exception is that if a butt-weld or mechanical splice is shown on the project plans without a designation, that splice must comply with service splice requirements.

4-7.03 Sampling and Testing – Service and Ultimate Butt Splice

The inspection, sampling, and testing of service splices and ultimate butt splices are very rigorous processes that require coordination among SC staff, METS, and the Contractor. The requirements for these processes are located in *Contract Specifications,* Section 52-6.01C, *Submittals*; Section 52-6.01D, *Quality Assurance*; Section 52-6.02B, *Service Splices and Ultimate Butt Splices*. The following sections detail as to what is involved with these processes and elaborate on these contract specifications.

4-7.03A Prior to the Start of Any Splice Work

4-7.03A(1) Preconstruction Meeting

Although not required by the contract, it's advisable to hold a preconstruction meeting with the Contractor to discuss the service and ultimate butt splice requirements. The sampling and acceptance criteria vary between these types of splices.

The Contractor should have their splicing Quality Control Manager (QCM), rebar subcontractor, and the representative for the Authorized Laboratory attend such a meeting. If possible, a representative from METS should also attend the preconstruction meeting. A suggested partial list of items to discuss at the preconstruction meeting includes:

1. Splicing QCM's responsibility to inspect the lots of splices for conformance with the specifications and manufacturer's recommendations prior to sampling.
2. Splice Prequalification Reports, production, and quality assurance (QA) sampling and testing requirements.
3. How samples of ultimate butt splices will be selected from a completed lot of splices that have been assembled for the final time.
4. The Contractor's method of designating and making the lots available for sampling.
5. The Department's method of random sample selection.
6. Labeling and shipping of the samples.
7. Result reporting, time allowed, and Department approval.

4-7.03A(2) Splice System Prequalification

Contract Specifications, Section 52-6.02B(1), *Reinforcement – Splicing – Materials – Service Splices and Ultimate Butt Splices – General,* requires that the material and,

if applicable, welding fabricator for both service and ultimate splice systems be prequalified prior to use. The Contractor must select a splice system from the AML, specifically the *Caltrans Authorized List of Couplers for Reinforcing Steel*. If the proposed system is not on the prequalification list, contact the METS Rep to verify the latest approved splice systems.

4-7.03A(3) Splice Prequalification Report

The Contractor must submit a splice prequalification report for service splices and ultimate butt splices in accordance with *Contract Specifications*, Section 52-6.01C(6)(c), *Reinforcement – Splicing – General – Submittals – Qualification Statements – Splice Prequalification Report*. This report must include:

1. A copy of the coupler manufacturer's product literature giving complete data on the splice material and installation procedures.
2. Names of the prequalified operators who will be performing the splicing.
3. Descriptions of the positions, locations, equipment, and procedures that will be used in the work.
4. Certifications from the fabricator for operator and procedure prequalification including the certified test results from the authorized laboratory for the prequalification splice test samples. For each bar size of each splice type to be used, each operator must prepare two (2) prequalification splice test samples and two (2) additional prequalification splice test samples if using splices dependent on bar deformations.
5. Splice test samples that must have been prepared and tested no more than two (2) years before the submittal of the splice prequalification report. Splice test samples and testing must comply with the production testing requirements.

Forward a copy of the splice prequalification report to the METS Rep so that they can assist with its review.

4-7.03B Sampling and Testing Splices During Production

The sampling and testing of service splices and ultimate butt splices are somewhat similar. However, ultimate butt splices are critical to the structure's seismic performance. Hence, the sampling and testing requirements for ultimate butt splices are more stringent compared to service splice requirements.

4-7.03B(1) Ultimate Splice Sampling Procedures

The Contractor's splicing QCM must notify the Department when a designated lot of splices is complete and has been inspected. SC staff must collect four samples of production splices from each lot for testing.

Production sample splices are required to be randomly selected from a completed lot. Selecting from a completed lot means that samples will be removed after final splicing has been made. Splices that are unassembled for transportation or other reasons are not considered completed and would require resampling when assembled for the final time.

The intent of the ultimate butt splice specification is to sample splices as close as possible to the in-place completed work, which may or may not entail removing splices from bars after they have been tied in their final location. For example, if the main longitudinal reinforcement of a column rebar cage was spliced together and assembled on the ground prior to full height erection, the straight bar sample production splices could be selected prior to cage assembly. If splices are made vertically at the job site in or above their final positions for bar reinforcement of columns or CIP concrete piles, instead of removing the splice test samples from the completed column rebar cage, it is acceptable to prepare the samples as specified for service splice test samples, mimicking the field conditions, provided testing as specified for ultimate butt splices is performed.

Similarly, in most cases, the selection of production samples for welded hoops can be done prior to cage assembly.

All production sample splices removed from the work must be repaired or replaced. The Department does not require ultimate butt splice testing on repaired splices from a lot unless an additional ultimate butt splice test is required on the same lot of splices. If this additional test is required, the Department may select any repaired splice for the additional test.

Each sample must be at least 4 feet long for #9 and smaller rebar, and at least 6-1/2 feet long for #10 and larger rebar in accordance with California Test (CT) 670, *Method of Tests for Mechanical and Welded Reinforcing Steel Splices*.

4-7.03B(2) Service Splice Sampling Procedures

The *Contract Specifications* require the Contractor to prepare four splice test samples from each lot of completed splices. The service splice samples must be prepared in the same conditions as the production service splices. The same splice material, operator, location, equipment, position, and procedures must be used when preparing service splice samples. The sample length must be at least 4 feet long for #9 and smaller rebar, and at least 6-1/2 feet long for #10 and larger rebar in accordance with CT 670. Figure 4-17 shows splice test samples being prepared.

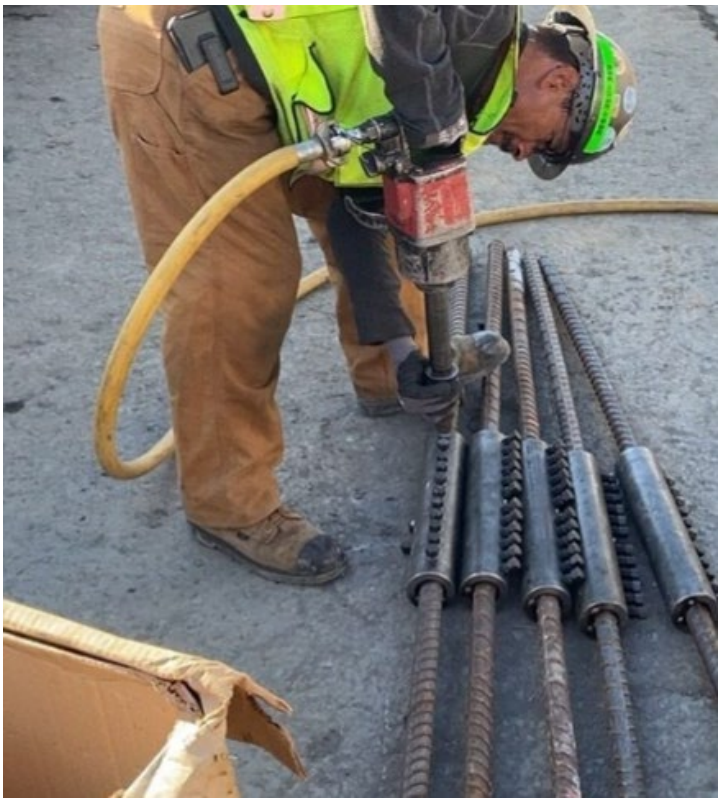

Figure 4-17. Splice Test Sample Preparation

4-7.03B(3) Quality Assurance Testing

Quality assurance (QA) testing is a requirement of the ultimate butt and service splice specifications. QA tests are always performed concurrently with the first production test. After the first QA test, at least one out of every five additional production tests (or portion of) thereafter will be accompanied by an additional QA test. Use a random selection method to designate both QA lots and QA sample splices. Table 4-3 illustrates the number of QA tests required for a given amount of splice lots.

Table 4-3. QA Test Requirement for Lots

Number of Lots	Number of Accumulative QA Tests Required
1	1
2-6	2
7-11	3
12-16	4
17-21	5
22-26	6

To obtain samples for the QA test, four (4) sample splices will be made concurrently with the production test samples. These sample splices do not have to be removed from a completed lot of splices.

The Contractor may encase splices in concrete before receiving notification of the QA test results from the Department. However, the Contractor will not be relieved of the responsibility for incorporating material into the work that complies with the contract.

4-7.03B(4) Tamper Proof Markings and Sample Shipping

To ensure that the sample splices are not tampered with, all ultimate butt-splice samples (i.e., pre-job, production, and quality assurance) must have a tamper proof marking applied to them as required per *Contract Specifications*, Section 52-6.01D(3)(b), *Reinforcement – Splicing – General – Quality Assurance – Test Samples – Ultimate Butt Splice*. SC staff should apply the marking. Examples of tamper proof markings include:

1. Rubberized paint. This will show any re-gripping or disassembly of the splices. (See Figure 4-18).
2. A digital photo of the splice sent to the lab for comparison.
3. Alternative marking systems which can be considered with METS concurrence.

Figure 4-18. Tamper Proof Marking on Production Sample Splices

All samples must be identified pre-job, production, or job QA and be accompanied with Form TL-0101, *Sample Identification Card*. Create a sample record, generate the Form TL-0101, and assign testing using the Data Interchange for Materials Engineering (DIME) webpage. Figure 4-19 shows a Form TL-0101 that was generated on DIME for sample splices to be tested by METS. Coordinate the delivery of test specimens to the METS Laboratory or other authorized Department laboratory assigned to perform testing of mechanical and welded splices per CT 670. Discuss the method of shipment and other testing related questions with the METS Rep.

STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION
SAMPLE IDENTIFICATION CARD DIME Sample ID: 2023-11-06-9
TL-0101 (REV. 02/17)

SAMPLE SENT TO:
- ☐ HDQRS. LAB
- ☐ BRANCH LAB
- ☐ DIST. LAB
- ☑ TRANS. LAB

TEST TYPE:

SHIPMENT NO.

AUTHORIZATION NO.

FIELD NO.

DIST LAB NO.

LOT NO. L123-099-23

P.O. OR REQ. NO.

SAMPLE OF: #8 bar HRC 500-510 Couplers

FOR USE IN:

SAMPLE FROM: Fabricator

DEPTH:

LOCATION OF SOURCE: Integrity Rebar Placers

THIS SAMPLE IS SHIPPED IN(NO. CONTAINERS)

AND IS ONE OF A GROUP OF

SAMPLES REPRESENTING (TONS, GALS, BBLS, STA, ETC.)

OWNER OR MANUFACTURER: Integrity Rebar Placers

TOTAL QUANTITY AVAILABLE: 4 Couplers

TEST RESULTS DESIRED ☐ NORMAL ☐ PRIORITY

DATE NEEDED

REMARKS:

DATE SAMPLED: 11/06/2023 BY: Osiell Ramirez

TITLE: Quality Assurance Inspector ((916) 767-3535)

DIST, CO, RTE, PM: 05-SB-217-0.9/1.4

CONT. NO.: DEA: 051C3604 FED. NO.: ACNH-P217(003)E

LIMITS: SANTA BARBARA COUNTY NEAR GOLETA FROM 0.2 MILE EAS

RECIPIENT(S): (to be selected by data publishing engineer)

CONTRACTOR:

Figure 4-19. Form TL-0101, Sample Identification Card

When completing Form TL-0101, ensure that all items are completed. If incomplete, it could delay METS' ability to issue test results. Specific items to consider are:

1. Contact information for the person that did the sampling is needed to answer potential questions.
2. Include an email address in the remarks section; this is used by METS to expedite sending the test results.
3. Include with the couplers:
   a. A copy of the Material Test Report (MTR) for the heat number of the bar reinforcing steel
   b. The MTR for the lot number of couplers represented by the samples. METS cannot issue test results without this information.
   c. A copy of the certificate of compliance for the bar reinforcing steel represented by the samples.

METS cannot issue test results without this information.

4-7.03C Splice Acceptance Requirements

4-7.03C(1) Slip Test Requirement

Except for mechanical lap, welded, or hoop splices, one (1) of the four (4) splice test samples is tested for total slip. If the slip test result complies with the total slip value requirement specified in the aforementioned *Contract Specifications*, Section 52-6.02B(1), proceed to perform the tensile and/or rupture tests.

If the splice test sample exceeds the total slip value specified in the *Contract Specifications*, the three (3) remaining test samples are tested for total slip. If any of the three (3) remaining test samples exceed the specified total slip value, the Department rejects all splices in the lot.

4-7.03C(2) Other Requirements for Service Splice

Service splices must develop a minimum tensile strength of 80,000 psi. The acceptance criteria are described below:

1. If only one (1) splice test sample complies with the requirements, the Department rejects all splices in the lot.
2. If only two (2) splice test samples comply with the requirements, perform one (1) additional service splice test consisting of four new splice test samples on the same lot of splices. This additional test must consist of tensile testing four (4) splice test samples, randomly selected by the Department, and removed from the lot of completed splices. If any of the four (4) splice test samples from this additional test do not attain the specified minimum tensile strength, the Department rejects all splices in the lot.

3. If three (3) or more splice test samples comply with the requirements, the Department accepts all splices in the lot.

4-7.03C(3) Other Requirements for Ultimate Butt Splice

Ultimate butt splices must meet one of the following requirements:

- Rupture in the reinforcing bar outside of the affected zone and show visible necking as specified in CT 670, Necking (Option I).
- Rupture anywhere and neck as specified in CT 670, Necking (Option II).

The acceptance criteria are described below:

1. If only one (1) splice test sample complies with the requirements, the Department rejects all splices in the lot.
2. If only two (2) splice test samples comply with the requirements, perform one (1) additional ultimate butt splice test consisting of four new splice test samples on the same lot of splices. If any of these four (4) new splice test samples do not comply with the specified requirements, the Department rejects all splices in the lot.
3. If three (3) or more splice test samples comply with the requirements, the Department accepts all splices in the lot.

Figure 4-20 depicts terms used in CT 670. The bar shown in this figure would pass the tensile test for an ultimate coupler because the visible necking is outside the affected zone.

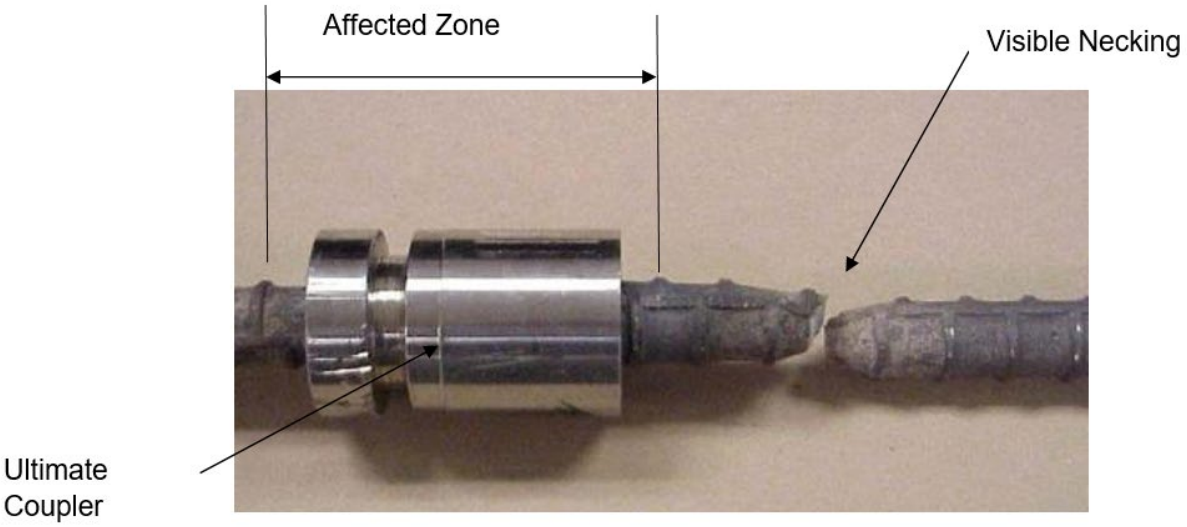

Figure 4-20. Passing Tensile Tested Ultimate Coupler

Figure 4-21 illustrates the mechanical splice acceptance procedure for QC and QA testing in a flow chart.

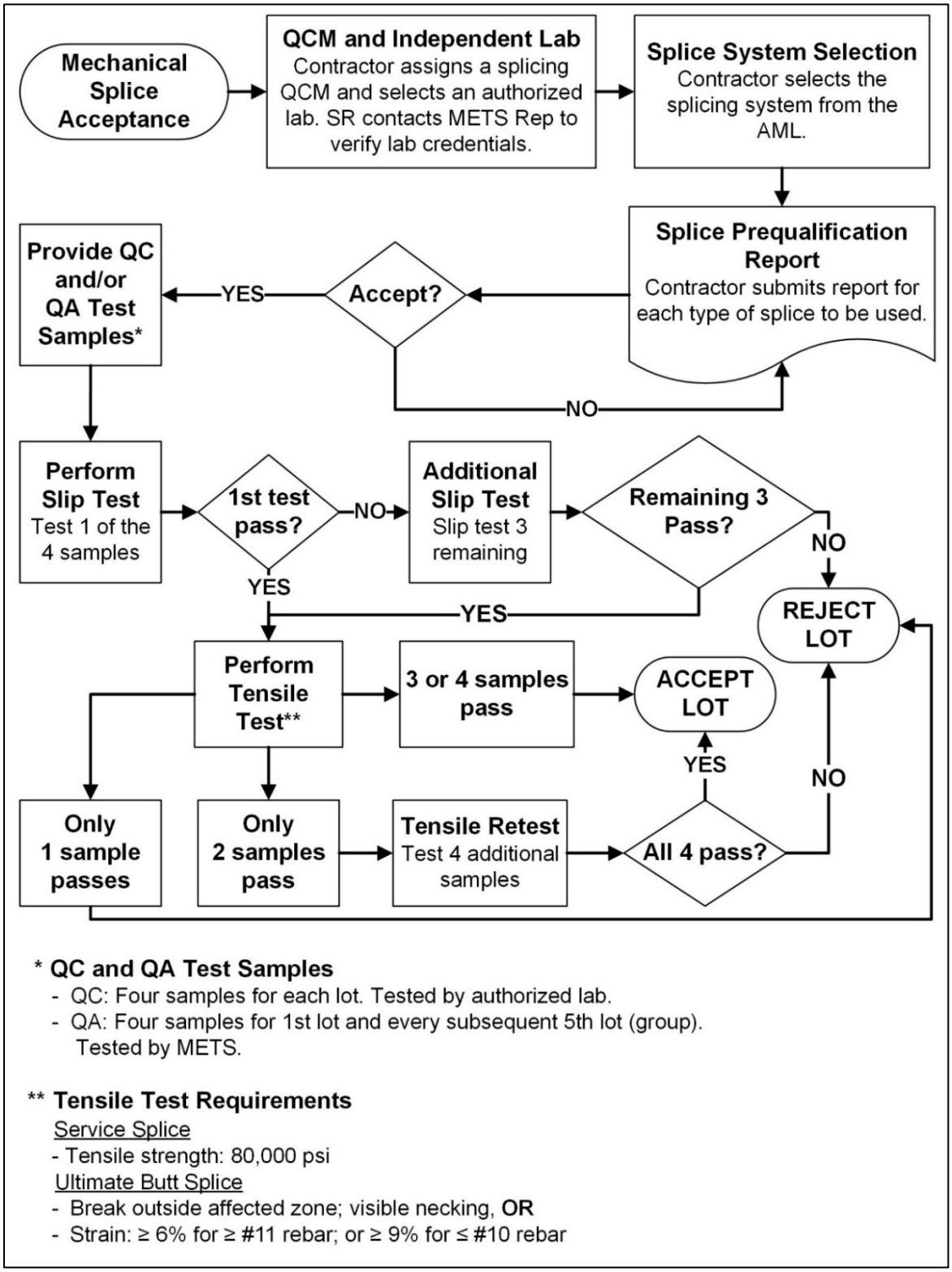

Figure 4-21. Mechanical Splice Acceptance Procedure Flow Chart

4-7.03D Review Time

The *Contract Specifications* include a review time for production and quality assurance tests. To avoid costly delays, it is important to respond to the Contractor in writing within the time allotted per the *Contract Specifications* as shown in Table 4-4.

Table 4-4. Review Time for Sample Tests

Sample Type	Review Time
Production Sample Tests	Three business days to review each production test report submitted by the QCM.
Quality Assurance	Three business days upon receipt of the samples by METS. Two extra business days per each simultaneous submittal.

4-7.03E After Completion of Splice Production Work

The Contractor provides the following submittals for Department's review:

1. Splice Quality Control Test Report
2. Splice Rejection Mitigation Report
3. Radiographic Film Developing Process Records (when welding is involved).

After completion and acceptance of the bar splices, ensure that the locations of the splices are noted in the as-built plans per BCM C-6, *Required Documents to be Submitted During Construction,* and that all the submittals and test reports are filed in the project records.

4-7.03F Testing Requirement Clarifications for Welded Butt Splices

The following clarifies test requirements for welded butt splices:

1. For Resistance-Butt-Welded splices (welded hoops):
   a. Slip test is not required.
   b. Destructive testing is required.
   c. Radiographic testing is not required.
2. For Complete Joint Penetration (CJP) butt-welded splices (except welded hoops):
   a. Slip test is not required.
   b. Destructive testing is required for both service and ultimate butt splices.
   c. Radiographic testing is not required whenever butt-welded splices are removed from a lot of completed splices (i.e., whenever they require replacement).

d. Radiographic testing is required whenever samples are prepared as described in the *Contract Specifications* (i.e., whenever they do not require replacement due to removal from a completed lot).

3. Refer to CT 670 regarding tensile test (destructive testing) requirements.

4-7.03G Items to Be Recorded in the Job Files

During the progress of the work, all splice documentation must be filed in Category 37, *Initial Tests and Acceptance Tests*, under the appropriate sub-category headings. Table 4-5 is an example of a summary record of production tests that SC staff can adopt for this purpose.

Table 4-5. Sample Summary of Record Production Tests

Model	Size	Sample Date	Description	Location	Number Used		Lot No.	QA Test	QC Test	Note
					This time	To date				
HRC 500XL/ 510XL	#9	10/1/24	Two Piece Sleeve/ Forged Ends	Bent 19 Column HOV	14	14	1	Pass	Pass	
				Bent 16 Column HOV	18	32	1			
HRC 500XL/ 510XL	#14	10/1/24	Two Piece Sleeve/ Forged Ends	Bent 19 Column HOV	92	92	1	Pass	Pass	
				Bent 16 Column HOV	100	192	1, 2	N/A	Pass	
HRC 410/420	#18	1/7/25	Sleeve-tapered thread	Bent 17 HOV	108	108	1	Pass	Pass	
Bar Grip XL	#14	1/19/25	Sleeve-tapered thread	Bent 3R middle CIDH pile extension	60	60	1			

4-8 Drill and Grout Dowels/Drill and Bond Dowels

"Drill and Grout Dowels", "Drill and Bond Dowels", and "Drill and Bond Dowel – Chemical Adhesive" are post-installed, non-mechanical methods used for embedding anchors, or dowels, into an existing structure. These techniques are often specified for projects that require a new concrete structure to either connect to an existing one or to a recently constructed concrete structure that lacks protruding reinforcement. Dowels are typically not specified for supporting sustained tension loads (*Structure Technical Policy*, 5.50, *Post-Installed Adhesive Anchors in Concrete*).

These methods typically involve drilling holes into the existing structure, cleaning the holes, filling those holes with a bonding material, and inserting dowels into the holes to a minimum specified depth. The tail ends of the dowels, which are not bonded to the existing structure, are then cast into the new structure. The post-installed dowels act to enhance the bond between the two separate structures. The required dowel material is specified in the contract documents and usually consists of reinforcing bars or threaded rods. The primary difference between the three methods is the bonding material required to fill the hole.

Contract Specifications, Section 51-1.03E(4), *Concrete Structures – General – Construction – Miscellaneous Construction – Drill and Grout Dowels,* specifies that grout be used as the bonding agent for the "Drill and Grout Dowels" method. Grout, as defined in *Contract Specifications*, Section 51-1.02G, *Concrete Structures – General – Materials – Grout,* is made of 4 gallons of water, at most, for every 94 pounds of cement (portland or portland limestone).

For the "Drill and Bond Dowels" method, the requirements for the bonding material to be used are specified in *Contract Specifications*, Section 51-1.02C, *Concrete Structures – General – Materials – Bonding Materials*. These include the same materials specified for rapid setting concrete.

Chemical adhesives are to be used for the "Drill and Bond Dowel – Chemical Adhesive" method. The AML lists chemical adhesive products that are authorized for use. It also notes the types and sizes of dowels that each product is intended to be used with. Additionally, refer to the AML for the permissible concrete temperature range for each adhesive product. Using a chemical adhesive outside its specified temperature range can negatively impact the performance. For instructions on product usage and installation, refer to the manufacturer's recommendations and the product's International Code Council Evaluation Service (ICC-ES) report, which documents the product's compliance with various building codes. The ICC-ES report number for each authorized chemical adhesive product can be found in the AML, and the reports are readily available online. Figure 4-22 shows reinforcement installed to an existing structure using a chemical adhesive.

Figure 4-22. Drill and Bond Dowel – Chemical Adhesive

SC staff must perform the following during inspection:

1. Verify that any loose, chipped, or spalled concrete has been removed and the holes are drilled into sound concrete.
2. Verify that the holes are drilled at the locations specified in the project plans. This is essential for maintaining proper edge distance and center-to-center spacing.
3. Check that the diameter of the drilled holes is correct by checking the drill bit size marked on the shank (see Figure 4-23). The required hole diameter is specific to the bonding material being used. Refer to the relevant specifications or, if applicable, the manufacturer's recommendations.

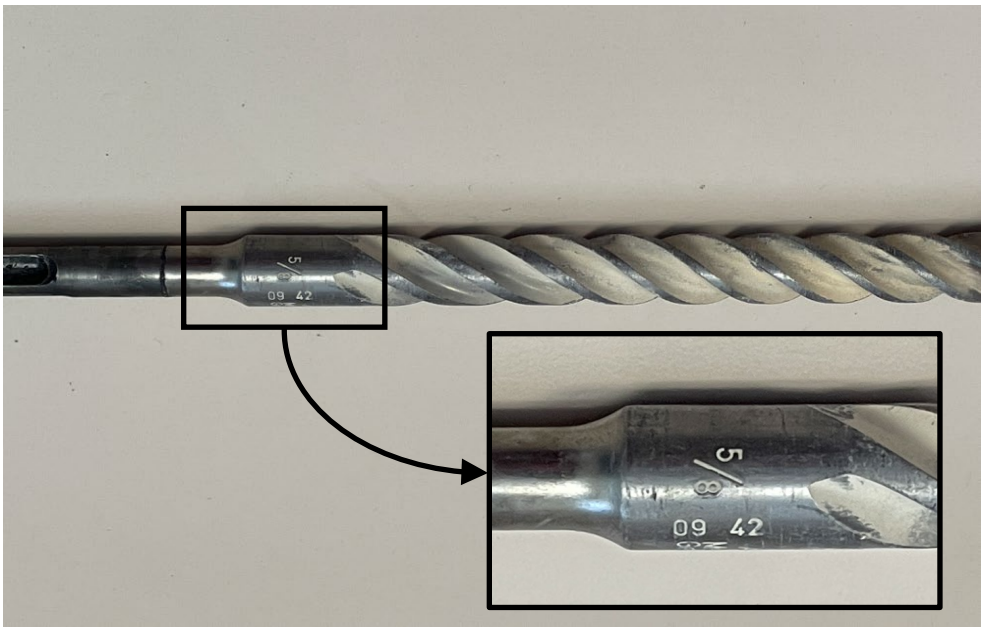

Figure 4-23. Diameter Size on Drill Bit Shank

4. Confirm that the holes are drilled to the depth indicated in the project plans. Over-drilling can create a through hole, which may allow the bonding material to drain away. Contractors often use tape on the drill bit to mark the desired depth (see Figure 4-24) or employ drill stops to limit the drill depth (see Figure 4-25).

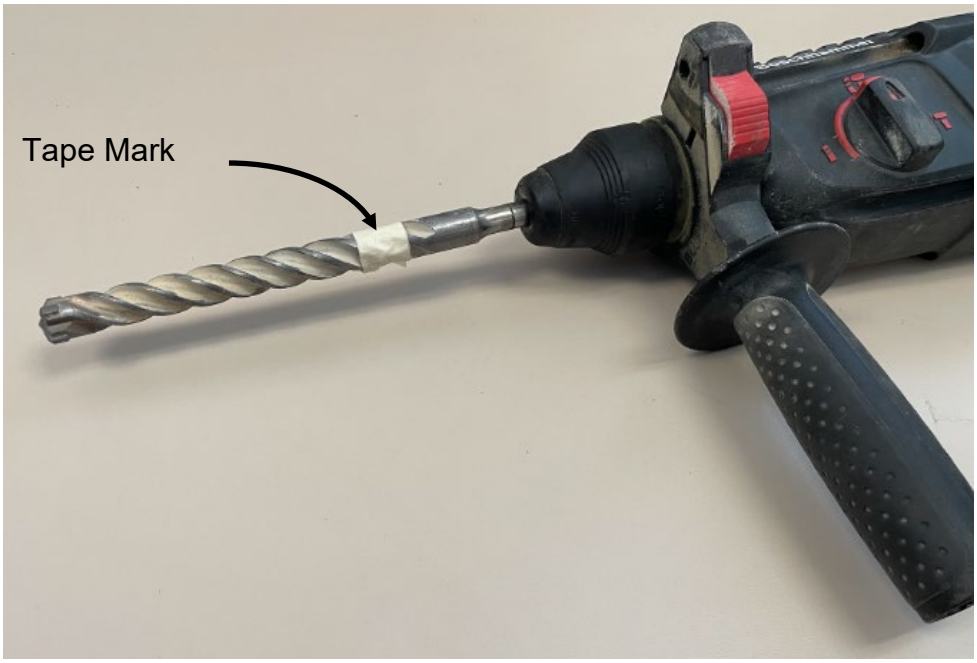

Figure 4-24. Drill Bit with Tape Mark

Figure 4-25. Drill with Drill Stop Attachment

5. After they are drilled, confirm that the holes are dry and clean. A clean hole is typically achieved by blowing compressed air into the hole, brushing the hole with a wire or nylon brush, and blowing compressed air a second time. Verify that the manufacturer's instructions for the specific adhesive are followed. Additionally, inspect the dowels to ensure they are clean and free of any oil or residue that might interfere with proper bonding.
6. After the bonding material is placed and the dowel inserted into the hole, verify that the hole is filled completely and that the level of the bonding material remains consistent over time. A stable level of bonding material indicates that the drilled hole is a blind hole and not a through hole. Through holes may be present due to over-drilled holes, voids in the concrete (such as in a voided slab), or utilities in the structure. Any changes in the level of bonding material should be investigated, with corrective action taken.

The various requirements for each method, including those not discussed above (e.g., hole size, curing method, etc.), are summarized in Table 4-6:

Table 4-6. Drill & Grout and Drill & Bond Requirements

	Drill and Grout Dowels	Drill and Bond Dowel	Drill and Bond Dowel-Chemical Adhesive
Contract Specifications (CS)	51-1.02G 51-1.03E(3) (drilling) 51-1.03E(4)	51-1.01C(3) 51-1.02C 51-1.03E(3)	51-1.01C(5) 51-1.01D(3)(c) 51-1.02H 51-1.03E(5)
Material Type	Portland Cement or Portland Limestone Cement	Rapid Setting Concrete: 1. Magnesium phosphate concrete 2. Modified high-alumina-based concrete 3. Portland-cement-based concrete	Chemical Adhesive
Material / Product Requirement	Grout (CS 51-1.02G)	Table in CS 51-1.02C	Authorized Materials List (AML)
Drilled Hole Size	Dowel Diameter + ¼ inches	Dowel Diameter + ½ inches	Per Manufacturer's Recommendation
Slope Limit for Horizontally Drilled Hole (Vertical/Horizontal)	1:3	1:3	No slope
Curing Method	Curing Compound Method or Kept Continuously Wet	1. Curing Compound Method: Modified High-Alumina-Based concrete, Portland-Cement-Based concrete 2. None: Magnesium Phosphate	Per Manufacturer's recommendation
Cure/Immobilization Time	3 days	3 hours	Per Manufacturer's Recommendation

Grout can only be used where specified. Do not allow the Contractor to substitute grout as the bonding material when “Drill and Bond Dowels” or “Drill and Bond Dowel – Chemical Adhesive” is specified. Grout does not provide as strong a bond as a rapid-setting material or chemical adhesive would provide.

Chapter 5: Concrete

Table of Contents

Chapter 5: Concrete 1
Table of Contents 1
5-1 Introduction 3
5-2 Technical Resources 3
5-3 Quality Assurance 3
5-4 Planning Concrete Pours 5
5-5 Concrete Batching and Delivery 7
5-5.01 Truck Mixers 8
5-5.02 Concrete Tickets 8
5-5.03 Adding Water to Concrete 8
5-5.04 Transit Mixer Time and Drum Revolution 9
5-5.05 Concrete Temperature 10
5-5.06 Certificates of Compliance 10
5-5.07 Weight Limits and Overloads 12
5-5.08 Delivery Rate 12
5-6 Concrete Conveyance 12
5-6.01 Delivery Chutes 13
5-6.02 Concrete Buckets 13
5-6.03 Drop Chutes 16
5-6.04 Belt Conveyors 17
5-6.05 Concrete Pumps 18
5-6.06 Slick Line 19
5-7 Placing Concrete 21
5-7.01 Depositing Concrete 21
5-7.02 Segregation 23
5-7.03 Consolidating Concrete 24
5-8 Construction Joints 27
5-8.01 Planned Construction Joints 27
5-8.02 Emergency Construction Joints 28

5-9 Concrete Placement Protection 29
5-10 Finishing Plastic Concrete 30
5-10.01 Strike Off / Screed 30
5-10.02 Finishing 31
5-10.03 Finishing Air-Entrained Concrete 33
5-11 Curing Concrete 34
5-11.01 Plastic Shrinkage Cracking 34
5-11.02 Specified Concrete Curing Methods 36
5-12 Common Concrete Defects 45
5-12.01 Rock Pockets and Honeycombing 46
5-12.02 Cold Joint 50
5-12.03 Bug Holes 51
5-12.04 Plastic Settlement Cracking 51
5-12.05 Sand Streaking 51
5-12.06 Laitance 51
5-12.07 Dusting 51
5-13 Concrete Surface Finish 52
5-13.01 Ordinary Surface Finish 52
5-13.02 Class 1 Surface Finish 54
5-13.03 Class 2 Surface Finish 58
5-14 Concrete Architectural Features 58
5-14.01 Concrete Surface Textures 59
5-14.02 Concrete Coloring 60
5-14.03 Concrete Placement for Structures with Architectural Features 62
5-15 Concrete Placement During Extreme Temperatures 63
5-15.01 Hot Weather Construction 63
5-15.02 Cold Weather Construction 68
5-16 Mass Concrete 71
5-17 Placing Concrete Under Water 72
5-17.01 Seal Course Concrete 73
5-17.02 Water and Slurry Displacement Method 74
5-18 Environmental Stewardship 75
5-19 Public Safety for Bridge Construction Over Traffic 80

5-1 Introduction

This chapter focuses on concrete placement, emphasizing methods and procedures that will likely result in a high-quality finished product. It is intended to guide Structure Construction (SC) staff on the various aspects of concrete construction, covering fundamental construction operations like transporting, handling, depositing, consolidating, and curing concrete. Many topics introduced here will be discussed in greater detail in subsequent chapters, particularly in relation to how they apply to the construction of various bridge components and elements. Refer also to *Construction Manual,* Section 4-5103, *Construction Details – Concrete Structures – During the Course of Work,* and Section 4-5104, *Quality Control,* for items to address when inspecting concrete.

5-2 Technical Resources

The Department has issued various technical publications regarding concrete construction to guide SC staff. *Concrete Technology Manual (CTM)*, Chapter 3, *Review of Concrete Mix Designs*, provides information for the review of concrete mix designs. Concrete construction materials – aggregates, cementitious materials, water cement ratio, admixtures, and strength requirements – are discussed in Chapter 2, *Concrete Construction Materials*, of the CTM. Refer to Bridge Construction Memo (BCM) 90-1, *Concrete – General*, for guidance on reviewing concrete mix designs and supplemental information to the topics presented in this chapter.

SC staff may also find the below resources useful in furthering their knowledge and expertise in concrete materials and placement.

- Portland Cement Association (PCA)
- American Concrete Institute (ACI)
- The Engineered Wood Association (APA)

If any information found in these external sources contradicts *Contract Specifications*, policies, or standing practices and procedures, the contract documents govern, especially for any issues related to contract administration.

5-3 Quality Assurance

To help ensure a quality concrete structure, the Contractor must employ rigorous quality control (QC) processes, and SC staff responsible for the concrete work must diligently observe established quality assurance standards. Thorough preparation on the part of both parties is also a key factor. Chapter 2, *Preconstruction Planning*, discusses the Contractor's responsibility for implementing a formal concrete quality

control (QC) program for cast-in-place (CIP) structural members, per *Contract Specifications*, Section 90-1.01D(10)(b), *Concrete – General – Quality Assurance – Quality Control – Cast-In-Place Structural Concrete Members*.

The Department performs quality assurance testing, or acceptance testing, for both individual components of the concrete mix and the concrete mix itself. *Construction Manual*, Table 6-1.17, *Materials Acceptance Sampling and Testing Requirements: Concrete (Standard Specifications Section 90) (1 of 9),* outlines the type of acceptance tests required and the frequency they are to be performed.

The local district materials lab is typically responsible for sampling and testing concrete components, with the sampling occurring at the batch plant. Follow the established protocol for notifying the materials lab before scheduled concrete pours.

SC staff is responsible for sampling and performing various acceptance testing of fresh concrete onsite. For testing compressive strength, they are responsible for making test specimens, in the form of 4-by-8-inch or 6-by-12-inch cylinders, per California Test (CT) 540, *Method of Test for Making, Handling, and Storing Concrete Compressive Test Specimens in the Field* (ASTM C31/C31M). CT 540 also outlines how SC staff are to cure specimens before they are delivered to the testing laboratory. Coordinate the delivery of test specimens to the Caltrans Concrete Materials Testing Laboratory[1] or other authorized Department laboratory assigned to perform compressive testing.

Before performing any sampling and testing, SC staff must be trained and certified per American Concrete Institute (ACI) Concrete Field Testing through the Joint Training and Certification Program (JTCP). For recording sample and test data of concrete material, *Construction Procedure Directive,* CPD 22-12, *DIME Statewide Implementation*, mandates all Caltrans construction staff to input the information into the Data Interchange for Materials Engineering (DIME) database for the following test methods:

1. ASTM C143/C143M, *Standard Test Method for Slump of Hydraulic-Cement Concrete*
2. CT 504, *Method of Test for Determining Air Content of Freshly Mixed Concrete by the Pressure Method (ASTM C231/C231M)*
3. CT 557, *Method of Test for Temperature of Freshly Mixed Portland Cement Concrete (ASTM C1064/C1064M)*
4. CT 518, *Method of Test for Unit Weight of Fresh Concrete (ASTM C138)*
5. CT 521, *Method of Test for Compressive Strength of Molded Concrete Cylinders (ASTM C39/C39M).*

[1] Caltrans internal use only

Figure 5-1 shows the slump test being performed per ASTM C143/C143M on a sample of fresh concrete.

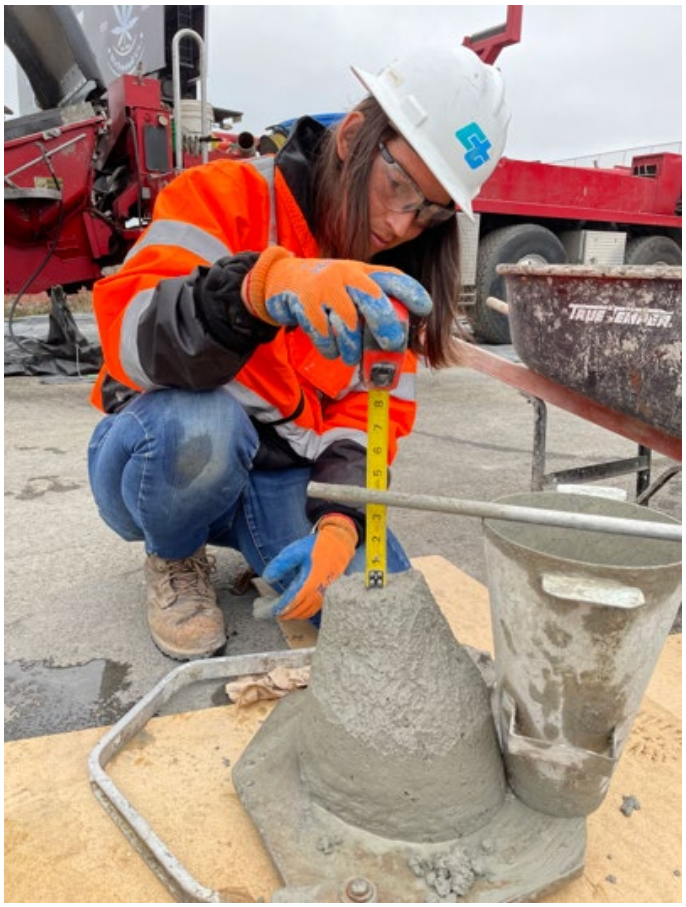

Figure 5-1. Slump Test

DIME can also be used for scheduling and assigning compressive strength testing of samples delivered to the testing laboratory.

5-4 Planning Concrete Pours

Planning is essential when placing concrete because of the short working time that concrete remains fluid, or in the plastic state. Once started, concrete placement must continue uninterrupted until the application of concrete cure, as required by *Contract Specifications*, Section 51-1.03D(1), *Concrete Structures – General – Placing Concrete – General.*

Before work begins, review the Contractor's proposed concrete construction methods. Even though not contractual for all operations, as suggested in Chapter 2, SC staff and the Contractor should hold a pre-operation, or "pre-pour", meeting to ensure that all

parties have a common understanding of the activities related to the concrete pour. Below are suggested items to discuss, review, and confirm during this meeting:

1. Concrete mix design to be used (contractors often submit multiple mix designs to be used for various purposes on the same project) and quantity of concrete to be poured.
2. Delivery truck staging and delivery rate (how many trucks per hour are scheduled).
3. Location for sampling concrete and creating test cylinders.
4. Effects of traffic.
5. Staging of concrete conveyances (pumps, buckets, etc.)
6. Location and details of concrete washout areas.
7. Safety hazards, e.g., work near electrical lines, no boom over live traffic, fall hazards, etc.
8. Weather contingencies, e.g., rain, temperature extremes, wind events, etc.
9. Labor, equipment, and material planned for the pour including finishing and curing.
10. Access to the work for crew and SC staff, e.g., walkways, ladders, platforms, etc.
11. Availability of backup equipment to complete the work in case of breakdown, e.g., standby concrete pump (required for concrete placed under slurry for cast-in-drilled-hole (CIDH) piles per *Contract Specifications*, Section 49-3.02C(9)(a), *Piling – Cast-In-Place Concrete Piling – Cast-In-Drilled-Hole Concrete Piing – Construction – Placing Concrete Under Slurry – General*) or generator on site or on call.
12. Inspections, such as below, that must be scheduled and completed before the start of the pour:
    a. Rebar placement is complete and has been inspected and accepted by the engineer.
    b. All embedded items (e.g., barrier rebar, conduit, drainage, etc.) have been installed, inspected, and accepted by the SC staff.
    c. Formwork installation is complete and has been cleaned of any dirt, ponded water, wood, including wood chips and sawdust, metal scraps of any kind, or any other foreign or deleterious material.
    d. Falsework installation is complete and has been inspected and accepted by SC staff, and the Contractor's temporary-structure engineer has performed a final inspection. The latter includes submission of the temporary-structure inspection report and certification per *Contract Specifications*, Section 48-1.01C(2), *Temporary Structures – General – Submittals – Temporary-*

Structure Inspection Report, and Section 48-1.01D(2), *Temporary Structures – General – Quality Assurance – Temporary-Structure Engineer*. Refer to the *Falsework Manual* for additional guidance.

e. All planned staging is complete as agreed to.

f. Temporary access is securely installed.

g. All equipment, labor, and material discussed in the pre-pour meeting are on site and in good working order:

   i. If using coated rebar, vibrators are properly coated.

   ii. Material and equipment for providing concrete cure (e.g., curing compound, appropriate spray equipment, curing blankets, water supply, etc.) are on-site and ready to be applied.

After the concrete has been mixed and delivered to the jobsite, it must be conveyed to the proper location, placed, consolidated, and finished, all within a relatively short period of time. Even if the delivered concrete may be of excellent quality, the quality of the finished concrete still depends on the handling, placing, finishing, and curing methods employed.

5-5 Concrete Batching and Delivery

Contract Specifications, Section 90-1.02G(1), *Concrete – General – Materials – Mixing and Transporting Concrete – General,* requires that all concrete be homogeneous and thoroughly mixed, with no lumps or evidence of undispersed cement. Monitor the concrete stream as it is discharged from transit mixers or deposited into the work, looking for evidence of deleterious materials, such as debris, broken bricks, or recycled concrete.

Variations in mix consistency outside of acceptable tolerances should be avoided. Changes to concrete properties between concrete batches, such as penetration and grading, could have a cumulative effect on the ease of finishing and are reflected in the finished surface. Variations in the consistency of the concrete may indicate improper mixing or the use of deleterious materials. This may warrant rejection of the material or investigation of the entire concrete production activity.

Contract Specifications, Section 90-1.02G(3), *Concrete – General – Materials – Mixing and Transporting Concrete – Transporting Mixed Concrete,* and Section 90-1.02G(2), *Concrete – General – Materials – Mixing and Transporting Concrete – Machine Mixing,* addresses allowable means for transporting concrete. *Concrete Technology Manual*, Chapter 4, *Proportioning, Mixing and Transporting,* contains additional discussion on concrete batching and delivery.

5-5.01 Truck Mixers

Concrete trucks, or truck mixers, are the most common means used by contractors for transporting concrete to the job site. The sections below discuss requirements for truck mixers to be equipped with systems for controlling and monitoring drum revolutions and the addition of water. *Concrete Technology Manual*, Chapter 4, details additional truck mixer requirements and items for inspection.

5-5.02 Concrete Tickets

Each load of ready-mixed concrete delivered to the jobsite must be accompanied by a weighmaster certificate, commonly known as a "concrete ticket." Check that each concrete ticket provides the required information listed in *Contract Specifications,* Section 90-1.01C(7), *Concrete – General – Submittals – Concrete Delivery,* for the delivered concrete it represents.

Compare the quantities on the ticket to the mix design. Note the quantity of water that has been introduced during initial batching and held back from the mix by the batch plant. If authorized, this water may be available in the field to adjust the workability of the mix, as discussed below. In addition to *Concrete Technology Manual*, Chapter 4, BCM 90-1, *Concrete – General*, outlines the procedure to be used for checking concrete tickets.

5-5.03 Adding Water to Concrete

Arbitrarily adding water to batched concrete to make it more workable and fluid is not allowed. Doing so increases the risk of lowering the quality of concrete. However, adding water at the jobsite is acceptable within the requirements of *Contract Specifications,* Section 90-1.02G(3), *Concrete – General – Materials – Mixing and Transporting Concrete – Transporting Mixed Concrete*, all other requirements in Section 90-1.02G, *Concrete – General – Materials – Mixing and Transporting Concrete*, and if the mix otherwise complies with the contract including *Contract Specifications*, Section 90-1.01D(4), *Concrete – General – Quality Assurance – Concrete Uniformity*.

As mentioned earlier, use information noted on the concrete ticket to determine the amount of water SC staff may authorize to be added in the field. Verify the amount of additional water added to the concrete mix inside the truck mixer does not cause the total amount of water introduced to the mix to exceed the water-cement ratio from the authorized mix design. This can be done by monitoring the truck mixer's water gauge or meter. Some trucks may have a control system, such as the one shown in Figure 5-2, that the driver uses to control the amount of water to add. Added water may be introduced only once and mixed into the concrete load for at least 30 drum revolutions before more than ¼ cubic yard of the load has already been discharged. Make a note of

how much water was added on the concrete ticket. Be aware that inspecting the concrete as it comes down the chute to verify that it is not too wet is often our last line of defense. Any added water in the field should not produce a mix which does not conform with our slump and/or penetration requirements.

Figure 5-2. Concrete Truck Control System

Concrete must be placed while fresh and before it has taken an initial set. Re-tempering any partially hardened concrete with additional water is expressly prohibited. The later addition of water and remixing to re-temper the mixture can result in marked strength reduction. If early setting becomes a persistent problem, a retarder may be used to control early hydration, especially in mixes containing high cement-content.

5-5.04 Transit Mixer Time and Drum Revolution

Concrete begins to harden as soon as the cementitious materials and water are mixed. It must be placed completely from a truck mixer or agitator before 250 revolutions of the drum or within 90 minutes, whichever occurs first, after cementitious materials are added to the aggregates. The allowable number of revolutions and time limit increases to 300 revolutions and 120 minutes, respectively, if a retarding admixture is included in the concrete mix. During hot weather conditions, *Contract Specifications*, Section 90-1.02G(3), *Concrete – General – Materials – Mixing and Transporting Concrete – Transporting Mixed Concrete,* gives SC staff the authority to reduce the standard 90-minute time allowed for delivery, standby, and concrete placement, if such reduction is necessary, to ensure an acceptable product.

The truck mixer manufacturer recommends the minimum number of drum revolutions for truck mixers and the speed of the drum during mixing. Truck mixers must be equipped with electrically or mechanically actuated revolution counters, so that the number of revolutions of the drum or blades may readily be verified. Truck mixers may also have a control system, similar to the one in Figure 5-2, for the driver to use to control drum speed and monitor the number of revolutions.

5-5.05 Concrete Temperature

Verify that the temperature of mixed concrete, immediately before placing, is not less than 50 °F or more than 90 °F. If the concrete mix includes a retarding admixture, the maximum allowable temperature is reduced to 85 °F. Aggregates and/or water may be heated or cooled as necessary to produce concrete within these temperature limits; however, neither is permitted to be heated to more than 150 °F. If ice is used to cool the concrete, do not permit discharge of the mixer until all ice is melted. Cooling and heating methods for concrete are further discussed later in this chapter, as well as temperature control for mass concrete.

5-5.06 Certificates of Compliance

Contract Specifications, Section 90-1.01C, Concrete – General – Submittals, requires the Contractor to furnish a certificate of compliance (COC) for each lot of material delivered to the work, including the delivery of concrete. The COC must clearly identify the concrete being certified (including mix design number, date batched, materials incorporated, and applicable concrete tags), state that the materials involved comply in all respects with the requirements and specifications, and be signed by the concrete supplier. SC staff usually receives the COC with the concrete ticket for the last delivery of concrete. Figure 5-3 is an excerpt from a concrete COC.

We certify that the Portland cement, chemical & mineral admixtures contained in the material described below are brands stated and comply with the specifications for:

Contract Number: 408-404-1000

Mix Design Number: DDJ118K3

Cementitious Materials

Brand: Cement		Mill Location:	Cal portland
Type: II/V			Stockton Terminal
Brand: Slag		Mill Location:	Pan Pacific
Type:			Stockton Terminal
Brand:		Mill Location:	
Type:			

Chemical Admixtures

Brand: XUT12/MASTER SET/ DELVO		Manufacturer:	Master Builders
Type:			
Brand: XUH82/MASTER GLENIUM 7920		Manufacturer:	Master Builders
Type: Lampblack			
Brand: SILVERSMOKE- DAVIS EQUIVALENT		Manufacturer:	SIKA
Type:			
Brand:		Manufacturer:	
Type:			
Brand:		Manufacturer:	
Type:			

Delivery Date: 07/02/2024

Tag Numbers: 636537, 636584, 636655, 636723

For Right Away Redy Mix: Alecia Carrillo

By (authorized representative):

Figure 5-3. Concrete Certificate of Compliance

SC staff may still sample and test materials used and released based on a COC at any time. The fact that material is used and released based on a COC does not relieve the Contractor of the responsibility for incorporating material in the work that complies with the requirements of the project plans and *Contract Specifications*. Any material not complying with the contract requirements will be subject to rejection, even if a COC accompanies the material.

5-5.07 Weight Limits and Overloads

When outside the project limits, concrete truck mixers traveling on the highway with full loads generally need to use booster axles to meet the axle weight requirements of the California Vehicle Code. The booster wheels of a truck mixer need to be raised when it discharges concrete. This increases the loads on the remaining axles, resulting in axle loads that exceed the legal load allowed by the California Department of Transportation Permit Policy. When traveling within the project limits, *Contract Specifications,* Section 5-1.37B, *Control of Work – Maintenance and Protection – Load Limits*, provides the allowable construction loads for equipment operating on bridges and other facilities. This will likely restrict most truck mixers to hauling less than a full 10-cubic-yard load if they are discharging from a bridge deck. Refer to Attachment 2, *SC Staff Responsibilities for Performing Standard Construction Activities,* of BCM A-1 for further discussion on monitoring overloads for contractor equipment, including concrete truck mixers.

5-5.08 Delivery Rate

Although not specified, SC staff must pay attention to the Contractor's expected concrete delivery rate. Concrete delivery rate can have an impact not only on the productivity of concrete placement, but potentially on concrete quality. For example, delays may result in cold joints or unplanned construction joints. If the concrete placement is too slow relative to the delivery rate, the truck mixers arriving at the jobsite will begin to accumulate. This may cause a delay in discharging their load, which can cause the concrete to exceed the maximum 90-minutes mixing time. A reasonable starting estimate of delivery rate is that the interval between concrete deliveries should not exceed 20 minutes.

The key to a successful pour is getting a good start and maintaining a constant delivery rate. Also, if the delivery rate is too slow to assure a continuous supply of fresh concrete, the resulting delivery interruptions may result in cold joints and extend the anticipated placement schedule. Therefore, the delivery rate must be adequate to prevent cold joints from forming.

5-6 Concrete Conveyance

The Contractor's chosen method (or methods) of conveying concrete from delivery point to final location depends on factors such as the size of the pour, location, and accessibility of the concrete pour. To a certain extent, the availability of equipment to do the work may also be a factor. The methods used should facilitate concrete placement with a minimum of handling or re-handling and without damaging the concrete or structure.

5-6.01 Delivery Chutes

Concrete truck mixers are equipped with delivery chutes that can be conveniently used for conveying concrete to a second delivery system, such as the hopper of a pump. They can be also used for tailgating concrete directly into footings, abutments, or other locations where the truck can be positioned above the placement location as seen in Figure 5-4. Multiple chutes can be added to extend the reach of delivery, although the number of chutes that may be added depends on the concrete weight and reach. The Contractor must not add water to concrete in a chute or use a vibrator to promote the free flow of concrete.

Figure 5-4. Concrete Truck Mixer with Built-In Delivery Chute

5-6.02 Concrete Buckets

Concrete buckets are still used in concrete bridge construction to aid in conveying concrete. They may be used where the pour volume is small or at remote locations where concrete pumps are not readily available. Concrete placement involves discharging concrete into the concrete bucket (see Figure 5-5), lifting the bucket with suitable lifting equipment (e.g., crane, forklift, etc.), moving it to position over its final location or secondary discharge point (see Figure 5-6), and then opening the bucket's gate or chute to deposit the concrete.

Figure 5-5. Concrete Bucket

Figure 5-6. Concrete Placement with Bucket and Forklift

Buckets can also be used with cableways and even with a helicopter to convey concrete directly from a central discharge point to where the concrete will be deposited.

A typical crane-and-bucket operation will consist of one or more cranes, with each crane handling one or two concrete buckets. The placing rate will vary depending on the location of the crane with respect to the point of concrete placement and the type of work involved. A typical placing rate for a crane and bucket operation is about 20 to 30 cubic yards per hour per crane, although higher rates of 50 cubic yards per hour or more are possible with heavier equipment under ideal conditions.

Concrete buckets come in various shapes and sizes. Large buckets with capacities of 8 cubic yards and higher have rectangular cross-sections, such as the one shown in Figure 5-7. The lower part of the bucket has sides that slope toward a small gate at the center. Concrete is released by opening this gate. For bridge construction, bucket capacity usually varies between 1/2 and 2 cubic yards, with 3/4 and 1 cubic yard buckets being the most common; these are usually circular.

Figure 5-7. High-Capacity Bucket

SC staff must be aware of some disadvantages of the crane-and-bucket method. When the crane-and-bucket method is used, contractors should be careful that while the bucket is being filled with concrete it is positioned on a sheet of plywood or other containment in order to catch the spills. This would also keep the bottom of the bucket frame and boot from coming in contact with dirt. The crane's operating radius must encompass the pour front. Often, there are areas that are inaccessible. High pour rates require the use of additional cranes, which leads to a safety concern with swinging booms. Overhead wires are a serious hazard. Impact due to a large volume of concrete being released at once or concrete dropping from too far above the forms, can cause form failure.

5-6.03 Drop Chutes

Drop chutes, also known as “elephant trunks”, are lengths of pipe or tubing that are used to facilitate the placing of concrete, typically as a way for contractors to direct the flow of the concrete inside forms and control the height of its fall. Some drop chutes are one-piece tubes made of flexible rubberized canvas or rubber; others are assembled from individual segments of metal cylinders that are fastened together in a manner that permits the lower segments to be removed as concrete is placed.

Contractors typically attach drop chutes to a funnel or small hopper so that concrete can be introduced without spilling. The size of the drop chute should match the size of the form opening so that it can be inserted without interfering with reinforcing steel. They should be long enough to make certain that concrete does not fall freely more than the specified drop limit of 8 feet, per *Contract Specifications,* Section 51-1.03D(1), *Concrete Structures – General – Construction – Placing Concrete – General*, or strike the reinforcing steel inside the forms. Figure 5-8 shows a drop chute that is attached to a hopper in use.

Figure 5-8. Depositing Concrete Using a Drop Chute Attached to a Hopper

Their use is a means for the Contractor to provide a controlled and consistent flow of concrete with even distribution. An advantage of using a drop chute is that it aids in minimizing segregation of the concrete.

5-6.04 Belt Conveyors

As the name implies, a conveyor belt system used in concrete placement consists of a series of portable, motor-driven, continuous belts that carry the concrete horizontally from the jobsite delivery point to the point where the concrete is to be placed, which may be a few hundred yards away. The belts are supported by light steel framing which is set on the forms.

Belt conveyors can be used for concrete placement activities where it is impractical to use concrete pumps or buckets. Conveyor belt systems offer the advantage of rapid delivery of concrete to relatively inaccessible locations. Belts are utilized in areas that have impaired vertical clearances, traffic restrictions, and obstructions. Belts can produce pour rates of 65 cubic yards per hour.

There are truck mixers equipped with belt conveyors, which can be advantageous because the truck mixer arrives complete with concrete conveying equipment. These mixer-mounted belt conveyors have adjustable reach and variable speeds. End discharge arrangements are necessary to prevent segregation and leave no mortar on the return belt.

A major disadvantage of belt conveyors is a tendency for concrete to segregate at intermediate transfer points and at the discharge point. If segregation occurs, it may be necessary for the Contractor to install hoppers or drop-chutes at transfer points and then add some type of baffle or hopper, so that the concrete will recombine at the discharge point before it is deposited into the forms.

Concrete belt conveyors often require special supports. They may have to be located along girder stems for concrete bridge construction. Cleanup due to spillage is often a problem. It is advisable for the Contractor to place rugs or plastic sheathing at terminal points to minimize cleanup. Since the concrete on the belt is uncovered, it is exposed to the risk of rain or drying conditions, such as high temperature and high winds.

Because conveyor belts deliver concrete rapidly, there must be adequate labor and sufficient equipment available to handle the concrete as it is delivered. Failure to correlate the capacity of a conveyor belt system with the size of the concrete placing and finishing crew will result in a reduced placement rate, and much of the inherent advantage of the conveyor belt will be lost.

5-6.05 Concrete Pumps

The use of concrete pumps is the most popular method for placing concrete. Truck-mounted pumps are more versatile and have higher pour rates than other equipment. They also have a low risk of major breakdowns or malfunctions compared with other concrete placement equipment.

The typical mobile pumping system being used consists of a pump mounted on a truck equipped with an adjustable boom. The concrete is deposited from the transit mixer into the pump hopper, as shown in Figure 5-9.

Figure 5-9. Concrete Pump Hopper

Concrete is then pumped through a system of pipes and hoses mounted on the boom to a delivery hose, typically 5 inches in diameter, attached to the boom. The boom is usually capable of depositing the concrete at the exact location desired. Pumping rates of 100 cubic yards per hour are easily attainable. Typical concrete pumps can reach about 130 feet horizontally and 120 feet vertically, although pumps can be equipped with longer booms that can reach more than 200 feet. Figure 5-10 shows a pump, with its boom extended, delivering concrete to a column that required a significant reach.

Figure 5-10. Concrete Pump with Extended Boom

Concrete pumps are very mobile and can change locations quickly. This is important in maintaining a continuous pour and is particularly useful in placing concrete decks. Pumps normally require less headroom (overhead clearance) than a crane and bucket. Pumps also eliminate repeatedly moving and positioning crane booms and heavy swinging concrete buckets over the heads of work crews. Pumps present a less disruptive and less ominous presence on the jobsite.

Standard Specifications, Section 90-1.02G(1), *Concrete – General – Materials – Mixing and Transporting – General,* prohibits the use of aluminum components, such as aluminum pipe, in a concrete pumping system. There have been reported instances where pumping concrete through an aluminum pipe resulted in a significant reduction in concrete strength. The strength reduction has been attributed to voids in the cement paste, which are thought to be the result of hydrogen gas produced by a chemical reaction between abraded aluminum particles and certain constituents in portland cement.

Spot-check that all pump hose and pipe sections are properly connected together with collars, and that the locking safety devices for the collars are being used.

5-6.06 Slick Line

A slick line is a pumping system consisting of a stationary portable concrete pump with a rigid conduit delivery system that can move concrete horizontally over a long distance where access limitations or other considerations preclude the use of mobile pumping equipment. Figure 5-11 shows a typical slick line set up, while Figure 5-12 shows a moveable slick line a contractor devised using a combination of a long beam and crane.

Figure 5-11. Slick Line Used to Deliver Concrete

Figure 5-12. Moveable Slick Line

In a typical slick line setup, the concrete is pumped through sections of steel pipe, typically 6-inch diameter, joined together to make a single conduit. A flexible delivery hose is connected to the outlet end of the conduit. Portable pumps are capable of moving concrete up to 1500 feet horizontally and 200 feet vertically, at pumping rates in excess of 100 cubic yards per hour.

For several reasons, there is a high potential for clogging to occur in slick lines:

1. Deficient concrete mix: The mix may not adequately retain water, affecting how well it flows.
2. Early concrete setting: This can occur if there is a delay in concrete delivery to the jobsite or during high temperature weather conditions. Concrete containing a high early strength admixture is susceptible to early setting as well.
3. Slick line issues: Pipe diameters may be too small or lengths too long to adequately handle concrete flow. The pump used may be underpowered. Slick lines with bends are vulnerable to trapping concrete. Pipelines may contain residue from previous concrete pours.

The use of authorized admixtures in the concrete mix to improve its flowability and extend working and set time, along with proper equipment cleaning and maintenance, can reduce the risk of slick line clogging.

5-7 Placing Concrete

Proper concrete placing techniques will help prevent segregation, eliminate voids, and provide adequate bond strength between successive layers, or lifts, as the concrete is placed. These techniques help achieve the "dense homogeneous concrete" required by the *Contract Specifications*.

5-7.01 Depositing Concrete

The Contractor must not place, or cast, concrete in forms until the work connected with constructing the forms has been completed, all materials to be embedded in the concrete have been securely placed, and SC staff has inspected the forms and materials. Verify all dirt, chips, sawdust, water, and other foreign materials have been removed from the forms. As required per *Contract Specifications*, Section 51-1.03D(1), *Concrete Structures – General – Construction – Placing Concrete – General*, immediately before placing the concrete, the Contractor must thoroughly moisten the subgrade and the inside surface of the wood forms with water to prevent unwanted water absorption from the concrete. Form release agent applied to wood forms may reduce the amount of water absorption.

The Contractor must also deposit concrete continuously and as near as possible to its final position without segregation. Concrete should not be deposited in large piles and moved horizontally into final position. Neither should concrete be dumped into separate piles and then worked together into its final location. Such practices result in segregation, as mortar tends to flow ahead of the coarser material. Note that the specifications expressly prohibit the use of vibrators for extensive shifting of concrete. In most bridge applications, such as the bridge deck or footings, concrete is placed starting along the perimeter at one end of the work, with each batch discharged against

previously placed concrete. When it is necessary to place concrete on a slope, placement should begin at the lower end of the slope and progress upward.

For concrete placement in retaining walls, abutments, footings, bridge stems, columns or bents, and for thick slabs, it is good practice to place the concrete in uniformly thick horizontal lifts, with each lift thoroughly consolidated before the next is placed. The rate of placement should be rapid enough so that previously placed concrete has not yet set when the next lift of concrete is placed and vibrated into the lower lift. Lifts should be about 6 to 20 inches thick for reinforced members and 15 to 20 inches thick for “mass concrete”. Lift thickness can also depend on concrete fluidity and set time, and the placement rate that the crew can support.

Where standing water is present, such as at the bottom of footing excavations or drilled piles, excessive water must be removed. This is typically done by using a sump pump. If water is expected at the bottom of the excavation, one practice is to slope the bottom of the excavation to a corner where the pump can be installed. For the minimal amount of water left in the excavation, the concrete should be placed in a manner that displaces the water ahead of the concrete but does not allow water to be mixed in with the concrete which can dilute the concrete paste and segregate the aggregate. In all cases, water should be prevented from collecting at the ends, in corners, and along faces of forms.

For spread footings or toes and keys of retaining walls without piles, the Contractor should avoid disturbing subgrade soil so that they can maintain sufficient bearing capacity for supporting structural loads. During concrete placement, check the clearances of reinforcing steel throughout the pour. Have the Contractor reposition displaced reinforcing steel and replace broken dobies. Also, check the position of waterstops, deck drains, conduit, and prestressing hardware and appurtenances, and reposition them if displaced.

Natural consolidation takes place as the heavier materials slowly settle through the mixture, even after concrete has been vibrated as specified. In this process, free water rises to the surface as it is displaced by the heavier particles. Free water appearing on the surface of the concrete is called “bleed water”. When concrete is placed in tall forms at a rapid rate, some bleed water may collect on the top surface, especially with non-air-entrained concrete. Bleeding can be reduced by placing concrete more slowly and by using concrete with a stiffer consistency, particularly in the lower portion of the forms. In addition, the slower rate of placement reduces the hydrostatic pressure on the forms, as explained in Chapter 3, *Forms*.

Concrete is sometimes placed through openings, referred to as “pour windows”, in the sides of tall, narrow forms, or through forms that do not have openings easily accessible at the top. Pour windows have been constructed through the wall form shown in Figure 5-13.

Figure 5-13. Pour Windows on Form

When a chute discharges directly through the opening without controlling concrete flow at the end of the chute, there is potential for the concrete to segregate. A collecting hopper outside the opening will permit the concrete to flow more smoothly through the opening; this will decrease the tendency for the concrete to segregate.

5-7.02 Segregation

Segregation is the non-uniform separation of the coarse-aggregate particles from the sand-cement components of the concrete mixture. Preventing segregation is the major consideration and goal in the handling, placing, and consolidation of concrete. Concrete is not a naturally homogeneous material; in its fluid state it may be sensitive to external forces that tend to separate the heavier coarse aggregate particles from the sand-cement mortar. When segregation occurs, the concrete mixture becomes unbalanced, portions of the concrete will have an excess of coarse aggregate, and the resulting concrete will have air voids. The portion of segregated concrete with less coarse aggregate tends to shrink and crack more. It also tends to have poorer resistance to abrasion due to its higher water and mortar content. The portion of the segregated concrete with more coarse aggregate tends to be difficult to consolidate and finish, resulting in concrete defects such as honeycombing and rock pockets.

Placing the concrete as closely as possible to its intended final location is an important factor in preventing segregation. Doing so minimizes or eliminates the need for concrete to be moved horizontally. In some work, such as placing concrete in sloping wingwalls or beneath window openings in walls, it is necessary to move the concrete horizontally

within the forms. This should be kept to a minimum as vibrators are not allowed to be used to move the concrete laterally.

Another key factor is keeping the drop of the concrete in a vertical direction to a minimum per *Contract Specifications,* Section 51-1.03D(1), *Concrete Structures – General – Construction – Placing Concrete – General*. Although the free fall distance is limited by the specifications to 8 feet, it should be minimized to the extent possible.

5-7.03 Consolidating Concrete

Consolidation is the process of compacting fresh concrete, molding it within the forms around the reinforcement and embedded items, and eliminating voids such as rock pockets, honeycomb, and entrapped air. Consolidation can be accomplished by hand or by mechanical methods. *Contract Specifications*, Section 51-1.03D(1), *Concrete Structures – General – Construction – Placing Concrete – General,* requires that concrete be placed and consolidated by methods that will not cause segregation of aggregates and will result in a dense homogeneous concrete that is free of voids and rock pockets.

5-7.03A Vibrating Concrete

Vibration is the most common method of consolidating concrete. When done correctly, vibration ensures maximum consolidation of the concrete without causing segregation, and without resulting in an excessive flow of water and fine particles to the surface.

Before vibration, concrete has an irregular surface due to the presence of aggregate on top. When concrete is vibrated, the internal friction between the aggregate particles is temporarily reduced and the concrete behaves like a liquid; it settles in the forms under the action of gravity. The large, entrapped air voids rise more easily to the surface. Vibrated concrete takes on a moist appearance as fines and water move to the top and the aggregates settle. Internal friction is re-established when vibration stops.

Excessive vibration may cause segregation as concrete continues to settle and fines and paste float to the top. This increases the amount of surface water and may leave a layer of mortar at the surface. Excessive vibration can also result in unacceptable deflection of forms, or even failure, due to unanticipated high lateral pressure from the fluid concrete in the forms. Insufficient vibration of concrete can cause concrete defects such as honeycombs, rock pockets, excessive entrapped air voids, cold joints, placement lines, and subsidence cracking.

Unsatisfactory concrete is much more likely to occur as the result of too little vibration than from too much. Keep this in mind when the Contractor is vibrating heavily reinforced sections where additional effort may be warranted to achieve proper consolidation.

5-7.03B Internal Vibrators

Contract Specifications, Section 51-1.03D(1), *Concrete Structures – General – Construction – Placing Concrete – General,* requires structural concrete to be consolidated with high-frequency internal vibrators within 15 minutes after it is placed in the form. Concrete for certain minor structures and concrete placed under slurry or water are exempted from this requirement.

The vibrator type required by the *Contract Specifications* is known in the construction industry as an immersion or internal vibrator, since it is "immersed" into the concrete when used. Flexible-shaft vibrators consist of a vibrating head connected to a driving motor by a flexible shaft. Inside the head, an unbalanced weight connected to the shaft rotates at high speed, causing the head to revolve in a circular orbit. The vibrating head is usually cylindrical with a diameter ranging from 3/4 to 7 inches. The smaller diameter heads have higher vibration rates but lower amplitude and will vibrate a smaller volume of concrete. Conversely, larger diameter vibrators vibrate more slowly at greater amplitude and affect a larger volume of concrete for each vibration. The consolidation of a 2-inch vibrator typically affects an area 6 inches in radius while a 3-inch vibrator could have an effective radius of 14 inches.

Where possible, the vibrator should be inserted vertically and allowed to descend through the concrete naturally, as shown in Figure 5-14. It should penetrate the lift being placed and at least 6 inches into any previously placed lift to ensure a thorough combining of the two lifts and to prevent cold joints. The distance between insertions should be approximately one to one and one-half times the radius of action, so that the area visibly affected by the vibrator overlaps the adjacent previously vibrated area by a few inches.

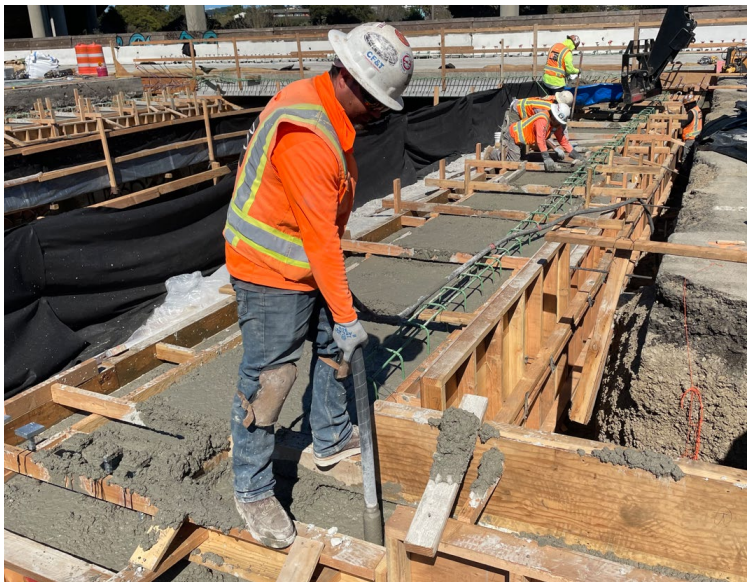

Figure 5-14. Vibrating Using Internal Vibrator

Once the vibrator has been inserted, it must be held steady as consolidation occurs and then withdrawn slowly. The vibrator allows aggregate to settle into the concrete mix, resulting in the accumulation of cement paste around the vibrator, usually within 5 to 15 seconds. When the paste first appears near the top of the vibrator head, the vibrator should be withdrawn vertically at about the same rate that it descended.

Skilled operators using vibrators will know the depth of the recently poured lift of concrete. One practice to ensure vibrators are inserted the proper depth is to mark a point along the vibrator hose, with the mark measured from the vibrator tip the same distance as the depth of the recent lift plus 1 foot. By dipping the hose into the fresh concrete up to the marked point, the vibrator will consolidate the two lifts, minimizing the potential of cold joints. The height of each lift should be about the length of the vibrator head, or generally a maximum of 20 inches in regular formwork.

In thin slabs, where vertical insertion is not feasible, insert the vibrator at an angle or horizontally to immerse the vibrator. For slabs on grade, the vibrator should not contact the subgrade; otherwise, subgrade material would be disturbed and incorporated into the concrete.

For a given consistency of concrete, there is an optimum amount of vibration that will result in maximum consolidation without appreciable segregation. The time that a vibrator should be left in the concrete will depend on the workability or slump of the concrete, the power of the vibrator, and the nature of the section being consolidated. An insertion time of 5 to 15 seconds will usually provide adequate consolidation. The concrete should move to fill the hole left by the vibrator when it is withdrawn. If the hole does not refill, reinserting the vibrator at a nearby point should solve the problem. To obtain the same degree of consolidation, low-slump concrete requires more vibration than concrete having a higher slump.

It is best practice to always have a standby vibrator and generator on hand, in the event of a mechanical breakdown.

Where epoxy-coated rebar or epoxy-coated prestressing steel is used, vibrators must be coated with plastic or hard rubber to prevent damaging the epoxy coating.

5-7.03C External Vibrators

At locations where the concrete placement configuration precludes the use of internal vibrators such as narrow and congested spaces, *Contract Specifications*, Section 51-1.03D(1), *Concrete Structures – General – Construction – Placing Concrete – General,* allows the use of external vibrators. In most cases, these are proprietary motors attached to the forms and operated according to the manufacturer's instructions, which will vary depending on the structural section, forming material, and concrete mix. Refer to the vibrator manufacturer's instructions to be familiar with its best practices.

5-7.03D Footing Reconsolidation

After initially being consolidated and screeded, *Contract Specifications*, Section 51-1.03D(1), *Concrete Structures – General – Construction – Placing Concrete – General,* requires footings that are deeper than 2.5 feet and have a top layer of reinforcement to be reconsolidated. The most practical way for contractors to achieve this is by penetrating an internal vibrator into approximately the top 1 foot of the footing. This must be performed within 15 minutes after the footing has been initially screeded but before the concrete has set to the point that it no longer reconsolidates adequately. Footing reconsolidation is discussed further in Chapter 6, *Bridge Construction Practices for Cast-In-Place Bridges*.

Revibrating previously consolidated concrete consolidates fresh concrete into a previous lift, improves the bond between concrete and reinforcing steel, releases water trapped under horizontal reinforcing, removes additional entrapped air voids, and prevents the formation of voids from forming under rebar due to the concrete consolidating under its own weight.

5-8 Construction Joints

Many structures are designed to be monolithic. However, for large structures or those containing different components or elements, concrete placement for the entire structure is typically not done all at once. Instead, concrete placement is divided into stages. This approach involves using construction joints, which are breaks in the continuity of the structure. Construction joints allow one section of a structure to be poured separately and, if constructed and prepared properly, provide a sufficient bond for the subsequent adjoining concrete pour.

5-8.01 Planned Construction Joints

Planned construction joints are either shown on the project plans or proposed by the Contractor. Locations and configurations of planned construction joints would be shown in the project plans. They may be identified as mandatory or optional joints. The *Standard Plans* include construction joint details for various types of structures. Chapter 6 discusses construction joints for bridge girder stems and for soffit.

Proposed construction joints must be authorized according to *Contract Specifications*, Section 51-1.03D(4), *Concrete Structures – General – Construction – Placing Concrete – Construction Joints.* The locations of construction joints impact the performance of the structure. Therefore, it is important to include the Bridge Design (BD) Project Engineer in reviewing proposed construction joints. They may require proposed construction joints to include a key to enhance bonding.

All construction joints must be prepared as outlined in the aforementioned specification. It is crucial that the Contractor thoroughly abrasive blast clean construction joint surfaces to remove laitance and other materials that could hinder concrete bonding. Likewise, cleaning the surface with water afterward will remove foreign material that remains. As discussed in Chapter 4, *Reinforcement,* abrasive blast cleaning could potentially damage the coating of epoxy-coated reinforcement. Discuss alternative means of construction joint preparation with the Contractor if this situation applies.

Although not required for all construction joints, request that the Contractor provide a rough surface finish, similar to the 1/4-inch amplitude roughened surface required at the joint between girder stems and deck. This roughened surface will promote additional bonding at the construction joint.

5-8.02 Emergency Construction Joints

There is always the possibility that unanticipated circumstances will make it necessary for the Contractor to halt concrete placement unexpectedly. This will require a construction joint at a location where none was intended. Examples of such situations include form failures, usually caused by broken form ties; equipment breakdowns, either at the site of the work or at the concrete plant; and adverse weather, such as a heavy rainstorm after work begins. Prepare to take whatever action is needed and anticipate the best locations for an emergency construction joint, the configuration required, and whether keys and/or additional reinforcing steel will be needed.

Contract Specifications, Section 51-1.03D(4), *Concrete Structures – General – Construction – Placing Concrete – Construction Joints,* requires that when a construction joint is necessary, it must be constructed as directed by the Engineer. If proper care is taken, an emergency construction joint can be installed at virtually any location in a reinforced concrete structure. For girder stems in CIP concrete bridges, the best practice for an emergency construction joint is to form the joint with step keys, similar to the one illustrated in Detail J-3 of *Standard Plans,* B7-1, *Box Girder Details,* and add additional reinforcing steel in the manner shown on the project plans detailed for that particular girder type. If the joint is located within the center third of the span, additional stirrup reinforcing should be added as well. For slabs, the joint may be located at any convenient location, and be constructed as shown in the deck construction joint details of *Standard Plans,* B0-5, *Bridge Details.*

When installing an emergency joint, it may be necessary to remove some of the fresh concrete that is already in place. This can be accomplished by cutting a hole in the forms and washing out the fresh concrete, by removing the fresh concrete by hand, or by removing hardened concrete with jackhammers or similar equipment. Reinforcing steel should continue through the emergency bulkhead or formwork of the construction joint. If this is not possible, another method of providing rebar continuity through the bulkhead must be in place before SC staff allows rebar to be cut. Emergency bulkheads

may be made of any available material, keeping in mind that they must be removed later, with joint preparation to follow before the subsequent pour. The use of expanded metal lath, which may be left in place if the joint surface is sound, is an alternative material for thin slabs.

While the location of an emergency joint in a girder stem is dictated by the location of the concrete when the concrete placement stoppage arises, review its location with respect to the supporting falsework before work continues. If the joint is located near the center of a falsework span, additional beam deflection that will occur when concrete placement resumes may remove the support under the previously placed stem. To prevent loss of beam support and corresponding stress on the previously placed stem, a supplemental falsework bent may be needed at the joint location. Discuss the possible need for additional falsework support with the Contractor and their temporary-structure engineer.

5-9 Concrete Placement Protection

Adverse weather conditions before, during, and immediately after concrete placement can contribute to undesirable properties in the finished product. *Contract Specifications*, Section 90-1.03C, *Concrete – General – Construction – Protecting Concrete,* requires the Contractor to protect concrete from anything that can potentially cause damage. This requirement includes protection from potential damage due to undesirable weather conditions, such as rain, heat, cold, and wind. *Contract Specifications,* Section 90-1.01C(10), *Concrete – General – Submittals – Protecting Concrete,* authorizes SC staff to request a plan for protecting concrete from the Contractor.

Do not allow the Contractor to place concrete that may interact with frozen or ice-coated elements. *Contract Specifications*, Section 90-1.03C, explicitly prohibits concrete placement on frozen or ice-coated ground or subgrade. Similarly, this requirement prohibits placement that may cause concrete to be in contact with forms, reinforcing steel, structural steel, conduits, precast members, or construction joints that are in this condition. The Contractor will have to rectify these conditions or wait until they are improved before being allowed to place concrete. This issue is further discussed later in this chapter.

Concrete should not be exposed to heavy rain during placement. Rain will dilute the mortar at the concrete surface and may increase the water-cement ratio, enough to decrease both strength and durability at the surface. If concrete placement is scheduled when there is potential for rainfall, the Contractor must have plans in place in the event of rain during the concrete placing activity. This is especially important for placing activities involving significant areas of concrete. If placement is for a concrete deck, and if a protection plan was not submitted, verify that protection measures are addressed in the Contractor's deck placement work plan, which they must submit per *Contract Specifications*, Section 51-1.01C(1), *Concrete Structures – General – Submittals –*

General. Protective coverings such as polyethylene sheets or tarpaulins may be acceptable to use, provided they are applied appropriately to perform as intended.

Concrete protection measures should consider how to protect recently poured concrete, and, if the Contractor is contemplating continuing the pour during rainfall, how to protect the ongoing concrete placement. Unless they provide adequate protection against rain damage, the Contractor should halt concrete placement under rainy conditions before surface water damages surface mortar or causes a flow of the concrete surface. Directing the Contractor to do this requires subjective judgment. However, if more than a light rainfall occurs during concrete placement, consider ordering a suspension until the rain stops. Remind the Contractor that it is their responsibility to mitigate issues that may occur with the concrete if they choose to continue the pour.

During and after concrete placement, *Contract Specifications*, Section 51-1.03I, *Concrete Structures – General – Construction – Protecting Concrete Structures*, requires structural concrete and shotcrete to maintain a minimum internal temperature of 45 °F for 72 hours after placing and at a minimum of 40 °F for an additional 4 days. Monitor structural concrete temperature during these periods after placement, verifying that the concrete continues to comply with these temperature requirements. If temperature is out of compliance, or trending towards non-compliance, discuss with the Contractor means to resolve. Heating methods, such as heating mats or enclosures, may be appropriate if the concrete temperature becomes too low during the periods specified above.

5-10 Finishing Plastic Concrete

Unless otherwise specified, after concrete has been consolidated but before application of the curing medium, surfaces of structural concrete that are not in contact with forms receive an initial concrete finish. This consists of striking off the top of the concrete to the planned level, grade, or slope, followed by finishing the surface by floating to seal the concrete surface. This process must be completed while the concrete is still in a workable state.

5-10.01 Strike Off / Screed

After concrete is vibrated, the exposed concrete surface is brought to the final line and grade. This process is called strike off or screeding. The most common device used to manually strike off concrete is a straight edge, typically a piece of lumber such as a 2-by-4-inch nominal size lumber cut to a convenient length, as seen in Figure 5-15, which brings the concrete surface to the proper level. The proper strike off level can be indicated by grade strips, screed rails, or by the top of forms set by the Contractor. The straight edge is moved across the concrete with a sawing motion to remove excess material from high points and fill low points. If rails are used for the screed to ride along,

any interior supports are removed after the grade is established, and any voids left by the removal of the support are filled with concrete and finished.

Figure 5-15. Striking Off Concrete

5-10.02 Finishing

For most concrete construction, initial finishing is usually accomplished using hand floats. For bridge decks, mechanical bridge deck finishing machines are the industry standard. Finishing concrete bridge decks is discussed in depth in Chapter 7, *Bridge Deck Construction*. The floating action performed by moving the slightly angled float back and forth across the surface of the concrete pushes aggregate down to surface level as the float is extended. It pulls mortar to the surface as the float is pulled back. Floating removes high points and fills low points, while leaving the surface unsealed. An unsealed surface allows bleed water to rise through the concrete. Figure 5-16 shows a worker floating a concrete surface by hand.

Figure 5-16. Hand Floating

Floats can be made from wood, metal, or fiberglass. A wood float would leave the roughest finish, allowing the most bleed water to rise to the surface. Fiberglass also produces a rough surface but resists the abrasive forces of aggregate and sand that cause wooden float finishes to become rougher. Air-entrained concrete typically arrives with less water in the mix design, producing less bleed water than concrete without air entrainment. A metal float would be more durable than either a wooden or fiberglass float and produces a smoother finish. Bull floats are larger floating devices used to finish large and hard to reach areas. Figure 5-17 shows metal bull floats being used to smooth a large surface.

Figure 5-17. Bull Floats

When floating concrete, a hand float is held flat on the concrete surface, moving with a slight sawing motion in a sweeping arc to fill in holes, cut off lumps, and smooth ridges. When finishing large slabs, such as building slabs, power floats can be used to reduce finishing time. Floating produces a relatively even (but not smooth) texture that has good slip resistance and is often used as a final finish for many bridge concrete surfaces.

Further finishing is not required for most bridge construction finishing operations. For floor slabs within buildings or structures that require additional finishing work, floating can be followed by one or more of the following finishing activities, as required by the contract documents:

1. Edging – Shaping concrete edges, usually along the perimeter of the slab, using an edging hand tool. This produces smooth rounded or beveled edges.
2. Jointing – Scoring grooves into the concrete surface to create contraction or control joints, using a scoring tool. This is typically required to control the amount of potential cracking on the surface of sidewalks. Saw cutting into hardened concrete may be an acceptable alternative.
3. Additional floating or troweling – Further smoothing the concrete by bringing a thin layer of mortar to the surface, using a metal float or trowel after the concrete has partially hardened. This is typically performed if a smooth finish is required.
4. Brooming – Gently dragging the bristles of a wide broom along the mostly hardened concrete surface. This is performed when a broom finish is required, typically for sidewalks and pedestrian overcrossings, as discussed in Chapter 7.

The Contractor must complete finishing before bleed water begins to collect on the surface. The concrete surface should then remain undisturbed until the bleed water has evaporated, and the surface takes on a dull appearance.

5-10.03 Finishing Air-Entrained Concrete

Air entrainment gives concrete a somewhat altered consistency that permits the start of surface finishing at an earlier stage than is the case with normal (no entrained air) concrete.

Air-entrained concrete contains microscopic air bubbles that tend to hold all the materials in the concrete, including water, in suspension. Concrete without air entrainment would tend to have more water in the concrete. Since air-entrained concrete contains less water and the water is held in suspension for a longer time, little or no bleed water reaches the surface. With reduced bleeding, finishing should not be delayed while waiting for free water to evaporate from the surface.

5-11 Curing Concrete

Proper concrete curing prevents or substantially reduces the rate of evaporation of water from within the concrete mass by keeping an optimum level of moisture and temperature as it hardens. Properly cured concrete has higher compressive strength, is less permeable, and can be more resistant to stress, abrasion, freezing, and thawing.

The strength and durability of freshly placed concrete will continue to improve over time if conditions remain favorable for the continued hydration of the cement. The most critical time of the curing period is immediately after concrete placement, as it is during this initial period that rapid improvement in strength and durability is possible under favorable conditions. If curing conditions are unfavorable, concrete strength improvement will be slow, and the intended properties may never be attained.

For CIP concrete construction, curing methods can be divided into two categories depending on how moisture loss is prevented:

1. Methods that supply additional moisture to the surface of the concrete. The continuous application of water, often combined with the use of a moisture-retaining fabric or blanket, is one method. Applying water must be done without diluting or washing away the cement paste at the surface.
2. Methods that prevent moisture loss by sealing exposed surfaces of the concrete. One example is the application of a membrane curing compound.

In cases of curing in hot or cold weather, it may be necessary to employ special measures to counter the effects of extreme temperatures. Hydration proceeds at a much slower rate when the concrete temperature is low. For example, temperatures below 50 °F are unfavorable for the development of early strength. Below 40 °F, the development of early strength is greatly retarded; at or below freezing temperatures, little or no strength develops.

5-11.01 Plastic Shrinkage Cracking

The term "plastic shrinkage cracking" is used to describe the formation of cracks in the surface of fresh concrete. Plastic shrinkage cracking occurs when concrete has been placed and finished while it is still in the plastic state. It is caused by the rapid evaporation of moisture from the concrete surface, as the rate of evaporation exceeds the rate at which bleed water rises to the surface.

Although plastic shrinkage cracking is frequently associated with hot weather conditions, it can occur at any time when ambient conditions are conducive to a rapid evaporation rate. Loss of water will also cause the concrete to shrink, thus creating tensile stresses within the concrete. The rate of evaporation is a function of four interrelated factors: concrete temperature, air temperature, wind velocity, and humidity.

Evaporation rates are illustrated in a nomograph shown in Figure 5-18 which provides a graphic method of estimating the loss of surface moisture for various weather conditions.

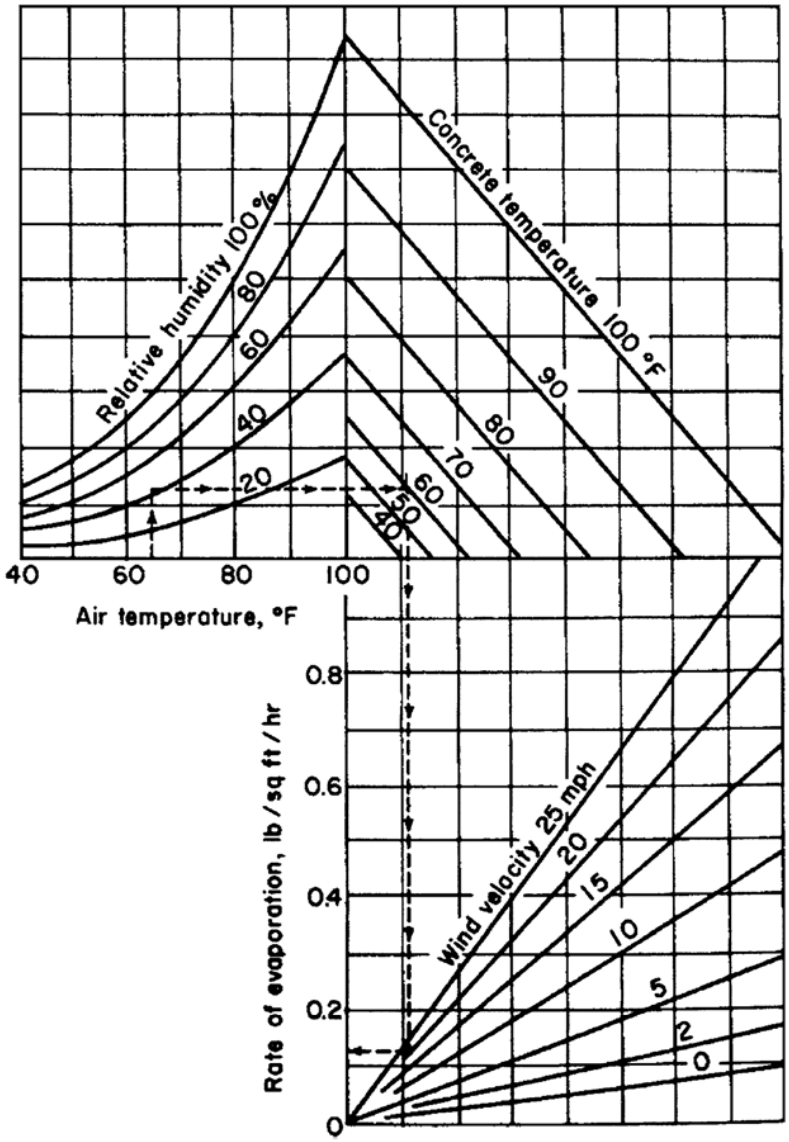

Figure 5-18. Evaporation Rate Nomograph (ACI 308, Standard Practice for Curing Concrete)

While it is not possible to determine the exact evaporation rate at which cracking will occur under all circumstances, cracking may occur when the rate is as low as 0.1 lb per square foot per hour. When the evaporation rate reaches about 0.2 lb per square foot per hour, cracking is likely if mitigating measures are not employed.

The most important factor in reducing the risk of shrinkage cracking is keeping the concrete surface moist during the initial curing period, as this reduces the evaporation rate. This becomes increasingly important as the rate of evaporation increases due to

adverse ambient conditions. Employing proper curing methods is the best and most practical means to maintain moisture on the concrete surface. Using supplementary cementitious materials and admixtures, such as high-range water reducers and shrinkage reducing admixtures, to extend concrete set time and reduce rate of hydration, can further reduce the risk of shrinkage cracking in cured concrete.

5-11.02 Specified Concrete Curing Methods

Contract Specifications, Section 90-1.03B, *Concrete – General – Construction – Curing Concrete*, permits four methods of curing concrete: water, forms-in-place, curing compound, and waterproof membrane. However, for CIP structures other than bridge decks, *Contract Specifications*, Section 51-1.03H, *Concrete Structures – General – Construction – Curing Concrete Structures*, allows only the water or forms-in-place methods to cure concrete. This same section permits the use of curing compound for construction joints and surfaces not visible to the public.

Bridge decks have their own specified curing method within this specification, using both the water method followed by the application of curing compound. The bridge deck curing method is explained further in Chapter 7.

Approach slabs are cured by the application of curing compound per *Contract Specifications*, Section 51-5.03A, *Concrete Structures – Approach Slabs – Construction – General*. To cure minor structures, *Contract Specifications*, Section 51-7.03, *Concrete Structures – Minor Structures – Construction* specifies the use of the water method, forms-in-place method, or curing compound application. Concrete barriers have several curing requirements, with the applicable requirement depending on the barrier type. These requirements are detailed in the *Contract Specifications*, Section 83-3.03A(8), *Railings and Barriers – Concrete Barriers – Construction – General – Curing,* and discussed further in Chapter 6.

The waterproof membrane method is used for concrete pavement, not concrete structures. As such, details for its use are not included in this manual. Do not confuse the waterproof membrane method with the curing media used for the water curing method.

5-11.02A Water Method

For the water method, concrete surfaces are kept continuously wet by applying water for at least 7 days after the concrete placement. It should be applied on exposed surfaces of newly placed concrete almost immediately after placement and finishing. Until the concrete has hardened sufficiently to prevent any washing away of the cement or damage to the finish, water is applied with an atomizing nozzle that forms a mist. This way, water gently settles onto the concrete surface. It should not be applied under pressure directly onto the concrete. If formed surfaces are going to be cured by the

water method, water must be applied to the formed surfaces immediately after form removal, with the surfaces kept continuously wet for the entire curing period.

With the water method, an additional material, referred to in the *Contract Specifications*, Section 90-1.03B(2), *Concrete – General – Construction – Curing Concrete – Water Method*, as a "curing medium", may be used as a barrier to retain moisture on the concrete and reduce the need to continuously mist the concrete with fresh water. The specification explicitly cites mats, rugs, blankets, earth or sand blankets, and sheeting materials as acceptable materials to use as curing media. Regardless of what material is used, the medium must be properly installed and sealed so that the cure is uniform with no gaps or seams that can allow drying of exposed areas.

Sheeting used as a curing medium must be secured close to the concrete and not allowed to flap in the wind or be otherwise displaced. Inspect the curing medium regularly to ensure that it is maintaining the concrete in a wet condition. Remind the Contractor to monitor and reapply water as often as necessary to keep the curing medium and the concrete uniformly and constantly wet for the entire curing period so that it does not dry out. The Contractor must develop a system to apply water to the concrete, either through or within the curing media. For example, columns are generally subjected to the most drying and hot conditions due to having a large surface area subject to wind and direct sun. Columns are commonly water cured using white polyethylene sheeting extruded onto burlap as a curing medium. The white plastic reflects the sun and provides a wind and moisture barrier, and the burlap helps retain moisture within the plastic sheet. This setup is demonstrated in Figure 5-19.

Figure 5-19. Curing Concrete Columns Using Polyethylene Sheets

A soaker hose installed at the top of the column, and under the curing medium, is the most common way of applying water within the curing medium to ensure that the water cure is maintained.

“Burlene”, also known as curing blankets, is the proprietary name for white polyethylene sheeting extruded onto burlap. It is the most common curing medium used in bridge construction due to its many advantages. It is lightweight and easy to install. The burlap is installed facing the concrete and retains water to keep the concrete wet. This curing method is shown in Figure 5-20. The polyethylene is an opaque waterproof barrier that protects the concrete and burlap from the drying effects of wind and sun. The white color reflects sunlight and helps to cool the burlap and concrete. However, like other curing media, it can dry out and must be inspected and maintained to ensure that the concrete stays wet during the curing period. Burlap used as a curing media must be free of any substance that is harmful to concrete or causes discoloration. The Contractor should rinse new burlap thoroughly with water to remove soluble substances and to make the burlap more absorbent.

Figure 5-20. Curing with Burlene Curing Blankets

Earth or sand blankets may be less effective than other specified curing media due to the tendency of the curing water to wash or spread the material, creating skips or thin spots. Water must be carefully applied to sand or earth so that it does not wash or spread. Also, sand may be too coarse to retain enough moisture to ensure that the concrete surface remains damp. Earth or sand as a curing medium requires frequent, regular inspection to ensure that it keeps the entire concrete surface uniformly and constantly wet during the cure period.

Check the concrete surface temperature during the water cure period, especially during hot weather. If the concrete surface temperature cannot be maintained at or below 140 °F, the Contractor must determine the reason and either revise or develop a new curing

method to be authorized as required per *Standard Specifications*, Section 90-1.03B(2) *Concrete – General – Construction – Curing Concrete – Water Method*.

5-11.02B Forms-In-Place Method

Although forms are usually removed as soon as possible so that they can be reused, occasionally contractors will choose to leave them in place for the required curing period for the forms-in-place method. Leaving the forms in place, as shown in Figure 5-21, is an effective curing method, provided the forms do not dry out, and concrete surfaces exposed outside the forms are cured by another method. *Contract Specifications*, Section 90-1.03B(5), *Concrete – General – Construction – Curing Concrete – Forms-In-Place Method,* requires forms to be left in place for at least 5 days if the structure is over 20 inches in the least dimension. For smaller structures, forms must be left for at least 7 days. When deemed necessary during periods of hot weather, water may be applied to forms and the concrete being cured by the forms-in-place method, until a cooling effect is no longer required.

Figure 5-21. Forms-In-Place Curing Method

During the curing period, periodically check that the joints between form panels and areas between forms and concrete surfaces continue to be moisture tight. Additionally, any cracks in the forms or between the forms and the concrete that develop during the curing period must be sealed by methods authorized by SC staff. Inspect the forms regularly during the curing period and enforce this specification.

5-11.02C Curing Compound Method

The curing compound method is the most practical and widely used method for curing concrete. While not as effective as a well-applied and maintained water cure, curing compounds can maintain the relative humidity of the concrete surface above 80 percent for 7 days to sustain the hydration of the concrete. Curing compound may also be used for continuing the curing process if forms are removed before the completion of the forms-in-place timeframe.

This method consists of applying one of the membrane-forming curing compounds listed in the table in *Contract Specifications*, Section 90-1.03B(3)(b), *Concrete – General – Construction – Curing Concrete – Curing Compound Method – Materials,* to the surface of freshly placed concrete. Liquid membrane-forming curing compounds consist of waxes, resins, chlorinated rubber, and other materials that are designed to reduce the evaporation of moisture from concrete. Curing compounds, which are furnished and applied in liquid form, contain volatile substances that evaporate within a short time after application, leaving a thin waterproof membrane that seals the concrete surface. For maximum effectiveness, curing compounds should be applied following the completion of initial surface finishing, and after the bleed water has evaporated. At the optimum application time, the surface will have a slight moisture sheen and will be damp to the touch.

Unlike the water and forms-in-place curing methods, which are easy to understand and use, the curing compound method is a sophisticated procedure. The requirements, including requirements for the material, its preparation, and its application, are detailed and explicit. Unless followed precisely, curing compound will not perform as intended. SC staff should review and be familiar with applicable contract requirements and discuss them with the Contractor before work involving curing compounds has started.

Pigmented and nonpigmented are the two general types of curing compounds that can be used. The table in *Contract Specifications*, Section 90-1.03B(3)(b) assigns a curing compound number based on their ASTM C309 classifications. Curing compounds no. 1 through no. 3 are pigmented Type 2, while no. 4 through no. 6 are nonpigmented Type 1.

Pigmented is advantageous for several reasons. The white pigment makes it easy to determine if curing compound has been adequately sprayed over newly placed concrete surface. It also reduces the rise of temperature by reflecting radiation from the sun. Unless otherwise stated, *Contract Specifications*, Section 51-1.03H, *Concrete Structures – General – Construction – Curing Concrete Structures,* lists the type of structures that are allowed to receive pigmented curing compound. Generally, pigmented curing compound can be used on surfaces that will not be seen or exposed at project completion.

Nonpigmented curing compound is clear when applied, with some exceptions, and is clear when dry. It is typically specified for colored concrete. An option for a clear curing compound is the inclusion of a fugitive dye that gives a red tint to the newly applied curing compound but fades to clear as the compound dries. This type of curing compound is identified as Type 1-D, Class A. The fugitive dye allows SC staff to verify complete curing compound coverage immediately after application.

Per *Contract Specifications*, Section 83-3.03A(8), *Railings and Barriers – Concrete Barriers – Construction – General – Curing*, concrete barrier rails, other than Type 80 and 85, may be cured using a non-pigmented curing compound or by the forms-in-place method. For curing barrier rail by the forms-in-place method, the forms must remain in place a minimum of 12 hours if the barrier does not support soundwalls. Afterward, no further curing is required when the forms are removed.

At the time of use, curing compound must be mixed well, regardless of type. This is particularly important for pigmented curing compound, as the pigments would have likely settled. It must also be kept agitated in the container to prevent pigment from settling out. The Contractor should be aware to not introduce air or other foreign substances into the curing compound. *Contract Specifications*, Section 90-1.03B(3)(c), *Concrete – General – Construction – Curing Compound Method – Mixing,* provides further direction for loosening and dispersing pigment during mixing.

Curing compound must be applied uniformly, without skips, sags, or holidays, as the intent for using curing compound is to form a moisture-retaining membrane on the concrete surface. The exposed surface must be completely covered, otherwise discontinuities in the membrane, regardless of size, will increase the evaporation of moisture from the concrete. Additionally, curing compound must be applied to the concrete surface after the finishing activity, immediately after bleed water evaporates and before the moisture sheen disappears from the surface, but before any drying shrinkage cracks begin to appear. The concrete surface should be kept damp until the curing compound is applied. If cracks begin to appear on the surface of a recently cast structure before curing compound has been applied, notify the Contractor to apply atomized water immediately until the surface receives curing compound. If necessary, such as extremely hot weather, atomized water should be applied to concrete surfaces where the recently applied curing compound has dried until the cooling effect is no longer required.

Normally, one smooth, even coat of curing compound is applied at the recommended application rate. However, if a second coat is necessary to ensure complete coverage, the second coat should be applied perpendicularly to the direction that the first coat was applied to ensure effective coverage.

Contract Specifications Section 90-1.03B(3)(d), *Concrete – General – Construction – Curing Concrete – Curing Compound Method – Application,* requires that curing compounds be applied using power-operated spray equipment, as shown in Figure 5-22. The power-driven spray equipment must have the capability to apply the curing compound as a uniform membrane on the surface of the concrete, similar in appearance to the uniform application found on painted surfaces. The power-operated spraying equipment must be equipped with an operational pressure gauge and a means of controlling the pressure. The Contractor should arrange spray nozzles and windshields on such equipment to prevent wind-blown loss of the curing compound.

Figure 5-22. Applying Curing Compound Using Power-Operated Spray Equipment

If permitted by SC staff, hand-operated spray cans may be used for spraying small and irregular areas that are not reasonably accessible to mechanical spraying equipment. Spraying by hand must meet the same quality standard as achieved by mechanical spray equipment. Since hand-operated sprayers do not disperse the curing compound in a fine spray that is conducive to a uniform application of the cure and is prone to clogging, the amount of curing compound needed to achieve the required uniform coverage is considerably higher.

Curing compound applied to a deck surface texture or broomed surface should not run off peaks or collect in grooves. It should form a tough film to withstand early construction traffic without damage.

After it has been applied, periodically check that the applied curing compound has not been damaged or removed before the 7-day cure period. If the curing compound has been damaged or removed, have the Contractor reapply curing compound to the affected area.

If left in place, curing compound acts as a bond breaker between successive layers of concrete. It must be completely removed from construction joint surfaces to ensure proper continuity of concrete structures. For example, the exposed surfaces of soffit and girder stem pours for CIP box girders are usually cured with curing compound. This material must be removed to enable the top of stems to bond properly to the deck. This is typically accomplished by abrasive blasting.

Curing compound is effective only if the material itself remains true to its intended composition throughout its use. These membrane-forming curing compounds are made up of volatile chemical compounds that need attention during their use to ensure the maximum benefit of these curing products. For material acceptance purposes, the manufacturer batches a large load of curing compound, sending QC samples to an independent lab for testing the criteria specified in *Contract Specifications*, Section 90-1.01D(6), *Concrete – General – Quality Assurance – Curing Compound.* The samples and tests can represent no more than a 10,000-gallon-sized batch of curing compound. If the samples pass, the manufacturer produces a COC with the QC test results attached. They then ship samples of the same batch with the COC to the Caltrans Chemical Testing Laboratory[1] for quality assurance testing.

Curing compound is typically delivered to the jobsite in 5-gallon buckets, as the one shown in Figure 5-23, in drums, or in 250-gallon totes. SC staff may accept the shipped curing compound on the basis of the COC. They may also sample curing compound, delivering their own samples to be tested at the Caltrans Chemical Testing Laboratory. Sampling and testing must be performed per the *Construction Manual*, Section 6-1, *Sampling and Testing – Sample Types and Frequencies* and Table 6-1.17, *Materials Acceptance Sampling and Testing Requirements: Concrete (Standard Specifications Section 90) (7 of 9)*. Curing compounds are not to be used until the required evidence or certificate of inspection has been received. Upon final inspection, SC staff may release the curing compound batch at the jobsite using Form CEM-4102[1], *Material Inspected and Released on Job*. Acceptance of this material does not relieve the vendor and Contractor from incorporating materials meeting the specific project documents.

[1] Caltrans internal use only

Figure 5-23. Curing Compound in 5-Gallon Bucket

Curing compounds must remain sprayable at temperatures above 40 °F and must not be diluted or altered after manufacture. It is formulated to maintain its specified properties for 1 to 2 years. SC staff may require retesting whenever there is reason to believe the compound is no longer satisfactory or if testing was performed more than 1 year from its intended use. Curing compound manufacturers typically do not extend the warranty of their product past its shelf life.

It is necessary to be cautious when using curing compounds containing solvents of high volatility, especially in confined spaces or near sensitive occupied spaces such as hospitals, because evaporating volatiles may cause respiratory problems. Follow the applicable local environmental laws concerning volatile organic compound (VOC) emissions.

Precautions concerning the handling and the application of curing compound must be shown on the label of the curing compound containers in conformance with the Construction Safety Orders and General Industry Safety Orders of the State of California. When the curing compound is shipped in tanks or tank trucks, a shipping invoice must accompany each load. The invoice must contain the same information as required for container labels.

Curing compound can be an environmental hazard if accidentally discharged to the surroundings, including overspray during application. Environmental protective measures for curing compound storage and application are discussed later in this chapter.

5-12 Common Concrete Defects

Although concrete defects are occasionally attributable to improper batching or mixing, most concrete defects are the result of improper placing activities of concrete. Proper placing methods and procedures along with continuous inspection as the work progresses are the keys to obtaining a defect-free concrete structure. SC staff must verify that the Contractor is following acceptable construction practices and that the resulting structure is free of unacceptable defects. Investigation and repair of concrete defects are discussed in this section and in *Concrete Technology Manual*, Chapter 6, *Structure Concrete Repair and Rehabilitation*. Note that this chapter is slated for incorporation into the *Structure Rehabilitation and Repair Manual*, pending publication.

Visually inspect the exposed concrete surfaces immediately after the Contractor removes forms. Timely inspection is important where access to the concrete surfaces may soon become difficult, such as when lost deck forms are erected, which results in limited access to girder stems.

Look for imperfections and defects that may be deemed unacceptable. Pay close attention to locations where the Contractor may have paused concrete placement, locations where there is high congestion of reinforcing steel and other embedded items, and locations where there could be difficulty inserting vibrators, such as below post-tensioned ducts. “Sound” suspect locations by tapping the surface with a light hammer or dragging a chain apparatus along the surface. Areas with voids will produce a dull or hollow sound. Mark questionable areas for further investigation or repair. Figure 5-24 shows a questionable area on the top of a newly placed soffit, found using a chain apparatus.

Figure 5-24. Questionable Area Found with Chain

Materials Engineering and Testing Services (METS) can perform more in-depth investigations to confirm if concrete defects are not structurally sound, as shown in Figure 5-25. Contact the project's assigned METS Representative to discuss and schedule potential testing.

Figure 5-25. In-Depth Concrete Investigation

5-12.01 Rock Pockets and Honeycombing

Rock pockets are areas of the hardened concrete in which the materials have segregated, resulting in spaces, or voids, between coarse aggregate that are not filled with mortar. In extreme cases, the aggregate is not even bonded to the surrounding matrix and is essentially a gravel-filled void within the concrete. These do not constitute a homogeneous material and are areas of reduced strength. Figure 5-26 is an example of a rock pocket.

Figure 5-26. Rock Pocket

Honeycombing, sometimes known as “popcorn”, is very similar to rock pockets, in that it leaves voids in the concrete. Their voids, though, are usually smaller and imitate the look of a honeycomb. They occur at the surface of the concrete, whereas rock pockets can be much deeper. Figure 5-27 is an example of honeycombing.

Figure 5-27. Honeycombing

5-12.01A Causes and Prevention

When deposited into the forms, low-slump or stiff concrete has a pronounced tendency to "hang up" on the reinforcing steel. This tendency is particularly troublesome in wall forms, where placing too much concrete in a single lift often results in rock pockets at the bottom of the lift.

To avoid such rock pockets, the lift should be shallow with the vibrator penetrating through the fresh concrete and into the concrete from the previously placed lift, as discussed previously. The more reinforcing steel there is in the forms, and the narrower the forms, the more care is required to ensure adequate vibration and avoid the formation of rock pockets (e.g., area around post-tensioned ducts in girder stem).

Voids occasionally occur beneath hinges and expansion joint armor. These voids are caused by entrapped air and are usually the result of following an improper placing sequence that prevents adequate and/or timely vibration.

Rock pockets may occur when mortar is lost through open joints in improperly constructed forms. Forms that are not mortar-tight permit the fines and mortar to leak out, causing a rock pocket. This usually results in the formation of honeycombing. Mortar-tight forms will prevent this occurrence. Occasionally, a rock pocket will be formed simply because there is an excessive amount of rock in the mix, but such occurrences are usually attributable to a batching error rather than to an improperly designed mix or improper placing technique.

5-12.01B Repair

The appropriate repair procedure for rock pockets depends on the depth and extent of the voids. For example, if the honeycombed area is shallow (i.e., there is a deficiency in the sand-cement paste that has left the coarse aggregate exposed, but the concrete substrate is sound), a simple dry-pack mortar patch may be suitable. *Contract Specifications,* Section 51-1.02F, *Concrete Structures – General – Materials – Mortar,* states that mortar is produced by mixing 1 part cement to 2 parts sand. Only the minimum amount of water needed to moisten the mortar is to be used to obtain a dry-pack mortar. For best results, verify the steps presented in *Contract Specifications,* Section 51-1.03E(2), *Concrete Structures – General – Miscellaneous Construction – Placing Mortar,* are followed:

1. The area to be patched is cleaned with a stiff brush, free of loose and nonconcrete materials.
2. The brushed surface is flushed with water and is surface dry before applying mortar.
3. Area is mortar-tight.

4. Mortar is tightly packed in half-inch increments, using a suitable tamping device, until the recess is filled.
5. Resulting mortar patch is cured using the water method for 72 hours.

If a more in-depth repair is needed, the exposed aggregate may have to be removed and replaced with a bonded patch.

When the rock pockets are widespread, deeper, and/or a significant amount of reinforcing steel is exposed, a complete structural repair may be necessary. At this point, involve the BD Project Engineer in the review and authorization of the Contractor's proposed repair. When rock pockets are present, selecting an appropriate repair method will involve subjective judgment. If SC staff determines that the defect may affect the strength of the structure or the service life of the steel reinforcement, SC staff may direct that affected portions of the structure must be removed and replaced. Figure 5-28 shows the removal of defective concrete caused by the formation of rock pockets. Any repair that includes the repair of the concrete surface must comply with the applicable concrete surface finish requirements.

Figure 5-28. Concrete Removal for Repair

5-12.02 Cold Joint

A cold joint is a discontinuity resulting from a delay in placement between concrete lifts. This allows one concrete lift to harden before the subsequent lift is placed. Cold joints are often accompanied by rock pockets. Figure 5-29 shows a cold joint that resulted from a long delay between placement which was caused by the Contractor relocating the concrete pump.

Figure 5-29. Cold Joint

When fresh concrete is placed on the old lift, the vibrator head should penetrate the older lift sufficiently to ensure adequate blending of the new and old concrete. Cold joints are apparent in the presence of placement lines or “pour” lines. These are dark lines between adjacent placements of concrete batches.

The discontinuity can reduce the structural integrity of a concrete member if the successive lifts do not properly bond together. The concrete can be kept alive by re-vibrating every 15 minutes or less depending on job conditions. However, once the time of initial setting approaches, discontinue the vibration and prepare the surface, per the requirements of the *Contract Specifications*, Section 51-1.03D(4), *Concrete Structures – General – Construction – Placing Concrete - Construction Joints*.

As with all concrete defects, the repair method depends on the extent of damage. Repairing cold joints follows a similar process to repairing rock pockets and honeycombing.

5-12.03 Bug Holes

Bug holes are small or irregular cavities found on the surface of hardened concrete. They occur due to the entrapment of air bubbles against the forms, especially impervious forms such as steel or plastic form liners. Bug holes are usually less than a half inch in diameter. They can best be prevented by proper vibration or by re-vibrating the concrete prior to initial set. Bug holes usually do not affect the structural integrity. They are typically repaired during the finishing process.

5-12.04 Plastic Settlement Cracking

Plastic settlement cracking may occur at or near the initial setting time, as concrete settles over reinforcing steel in relatively deep elements. It occurs particularly for concrete that has not been adequately vibrated. *Contract Specifications*, Section 51-1.03D(1), *Concrete Structures – General – Construction – Placing Concrete - General*, requires reconsolidation of the concrete to a depth of 1 foot after placing, consolidating, and initial screeding for footings over 2.5 feet deep with a top layer of reinforcement. Reconsolidation at the latest time that the vibrator will sink into the concrete under its own weight may eliminate these cracks.

5-12.05 Sand Streaking

Sand streaking is the exposure of sand on a concrete surface. It is usually caused by wet mixes that result in excessive bleeding. The use of a stiffer mix and/or air-entrained concrete will greatly reduce bleeding and thereby reduce sand streaking as well. Sand streaking is not usually associated with the type of concrete mixes used for SC projects. This surface defect is very difficult to repair.

5-12.06 Laitance

Laitance is a soupy mixture of cement, fine sand, and water that accumulates on a horizontal concrete surface. Any laitance on a construction joint will be removed when the joint is cleaned as required. Laitance occurs on finished surfaces, such as the top of a retaining wall, and will produce a soft surface that is vulnerable to deterioration from the effects of weathering. Laitance is caused by bleed water accumulating on the surface of an excessively wet concrete mix. It is less likely to occur in air-entrained mixes since air entrainment reduces bleeding significantly.

5-12.07 Dusting

Dusting, or soft and powdery surfaces, may result from inadequate curing. Over-finishing or exposure to high temperatures or strong winds can also result in dusting. Dusting is usually caused by excessive water being drawn to the surface, thereby creating a weak surface layer. The concrete surface drying too quickly can also be a cause. Timely curing is essential to increase the likelihood of a sound, powder-free surface.

5-13 Concrete Surface Finish

Although structural concrete may possess the requisite strength, durability, and other desired qualities as a structural material, a poor appearance can be an indication of poor workmanship. That is why the *Contract Specifications* emphasizes both the surface finish of concrete as well as the strength and material quality of concrete. It particularly emphasizes portions of the structure that are visible from the traveled way, which require a surface finish that is uniform in appearance.

Requirements for the final finishing of concrete surfaces are found in the *Contract Specifications*, Section 51-1.03F, *Concrete Structures – General – Construction – Finishing Concrete*. This section describes the work involved and the results required for three classes of surface finish:

- Ordinary Surface Finish
- Class 1 Surface Finish
- Class 2 Surface Finish

In a broad sense, the specified finishing requirements have two objectives. The first is to remove surface discoloration and repair surface defects, while the second is to obtain a smooth surface having a uniform texture and appearance at locations where the surface is visible.

In general, the amount of surface finishing that will be necessary to meet the contract requirements is a function of the quality of the formwork. The degree of care in building forms and the character of materials used in formwork will be a contributing factor in the amount of additional finishing required to produce smooth, even surfaces of uniform texture and appearance, free of unsightly bulges, depressions, and other imperfections.

5-13.01 Ordinary Surface Finish

An ordinary surface finish is the required final finish where specified in the contract documents, including locations noted in *Contract Specifications*, Section 51-1.03F(2), *Concrete Structures – General – Construction – Finishing Concrete – Ordinary Surface Finish*. However, it is also a preparatory finish to be completed before applying either a Class 1 or a Class 2 surface finish. Ordinary surface finish is applied after forms have been removed, the structure has had adequate time to set, and any required in-depth repairs complete.

Ordinary surface finish consists of filling holes and surface depressions; patching minor rock pockets; removing fins; and, on surfaces that are visible from a traveled way, removing stains or discolorations. Fins that are on buried or enclosed surfaces do not have to be removed. Deleterious materials on the surface of the concrete, such as nails, tie wires, debris, etc., must be removed to sound concrete and the voids patched

properly. When patching voids, including plugging form bolt holes or filling voids where form ties were removed, the only consideration for enclosed or buried surfaces is to obtain a sound patch. However, if the surface is visible from the traveled way, appearance is also a factor. The color of the patch must match the surrounding concrete, which may be achieved by adding a small amount of white cement to the mortar patching material. To achieve the best color match, it is considered best practice to make sample patches, using different proportions of white cement, at inconspicuous locations. Figure 5-30 shows a typical ordinary surface finish.

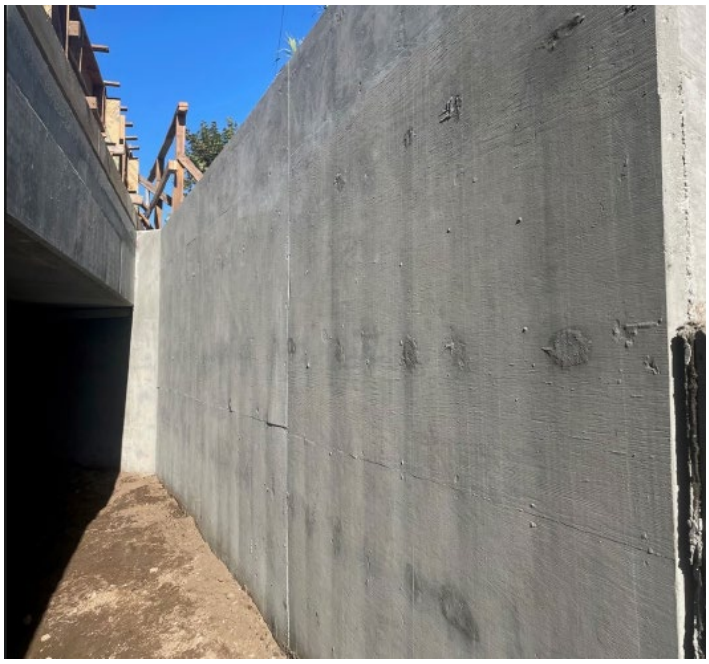

Figure 5-30. Ordinary Surface Finish

All form bolts and any metal placed for the convenience of the Contractor, such as snap ties, must be removed to a depth of at least 1 inch below the surface of the concrete. The resulting holes or depressions must be cleaned and filled with mortar. A sound patch for snap tie holes that is well bonded to the surrounding concrete is essential in attaining the long-term surface quality of concrete. If any moisture gets to the tie, corrosion will occur, resulting in expansive rust which could cause surface spalls and rust staining.

Snap-tie holes, bolt holes, and other cavities on the concrete surface that are small in area but relatively deep are typically patched with dry-pack mortar. Dry-pack mortar is a stiff mix of cement and sand (usually, one part cement to two- and one-half parts No. 16 sand), mixed with just enough water to produce a mortar that can be formed into a ball when squeezed gently by hand. Before patching, the cavity must be cleaned and moistened. Dry-pack mortar is typically applied by forcibly ramming it into place. For bigger cavities, it is recommended that the mortar be packed into place in lifts of about 1/2-inch thick, with each lift given a scratch finish to improve the bond with subsequent lifts of mortar. The vigorous packing of the dry-pack mortar is the primary means of

achieving a good bond with the surrounding concrete with minimum patch shrinkage. It is also important that the color of the dry-pack patch matches the surrounding concrete. Metal tools should not be used in dry packing, as they tend to discolor the mortar. Patches are part of the structural concrete and, as such, the requirements for curing the patch are the same as the concrete element being patched. If a patch is not properly cured, it is likely to fail and be ineffective.

Admixtures may be used in the patching mix to improve moisture resistance and adhesion of the patch. Non-shrink grouts are also viable options.

5-13.02 Class 1 Surface Finish

A Class 1 surface provides a higher level of appearance than an ordinary surface finish. It consists of finishing the surfaces of the structure as necessary to produce smooth, even surfaces of uniform texture and appearance, free of unsightly bulges, depressions, and other imperfections.

Contract Specifications, Section 51-1.03F(3), *Concrete Structures – General – Construction – Finishing Concrete – Class 1 Surface Finish*, contains the requirements of a Class 1 finish and at which locations it is required. Class 1 surface finish is applied to certain specified surfaces that do not exhibit a smooth, even surface of uniform texture and appearance after the ordinary surface finish is applied. In other words, Class 1 surface finish consists of performing only the "additional" finishing necessary to obtain the "smooth even surfaces of uniform texture and appearance" required by the specifications. The use of grinders to smooth surfaces is acceptable. The Contractor, though, must keep in mind that excessive grinding can result in an unwanted appearance, leaving grind marks and exposing aggregate, as illustrated in Figure 5-31.

Figure 5-31. Excessive Grinding Exposing Aggregate

If the forms are carefully constructed and an ordinary surface finish is thoroughly applied, little work will be necessary to achieve a Class 1 surface finish.

5-13.02A Whip Blasting

The *Contract Specifications* allows the Contractor to use authorized abrasive means to achieve a Class 1 surface finish. One method typically used is light sandblasting or light abrasive blasting, as shown in Figure 5-32. This is commonly known as whip blasting. The abrasive medium used for whip blasting may be silica sand, aluminum carbide, black slag particles, or even walnut shells. The type and grading of the abrasive material used in whip blasting significantly affect the surface finish. Therefore, the abrasive material used should remain the same throughout.

Figure 5-32. Whip Blasting

The skill of the person performing the whip blasting is a critical factor that affects the outcome of the desired uniform appearance of the Class 1 surface finish. Surface defects due to concrete forming and placement, such as bug holes, leakage lines, and cold joints between concrete lifts, tend to be accentuated by light blasting. Hardness of concrete surface, which is a function of concrete mix, time, and forming material, is also a major factor that must be considered when whip blasting. Whip blasting generally gives best results when applied to concrete that has a denser than normal surface, such as concrete surfaces that have been formed with steel, fiberglass, or coated high-density plywood forms. Figure 5-33 is an example of an acceptable whip-blasted surface.

Figure 5-33. Whip-Blasted Surface

The following precautions should be taken when using abrasive blasting:

1. To obtain a good appearance, it is necessary to do some experimenting to determine proper grain size, air pressure, and distance of sand blast nozzle from concrete surface, and angle of application of the sand.
2. To aid SC staff and workers in maintaining a uniform whip blast activity, apply a light lumber crayon mark approximately 1 foot long to the surface of the work at random locations. The force of whip blasting should be sufficient to just remove the mark.
3. Aggressive application could result in a damaged surface that would be difficult to repair. The signs of an unacceptable result include excessive pinholes, whip marks, and exposed aggregate.
4. Abrasive blasting must conform to Regional Air Quality Management District regulations and permitting requirements.

Once these factors have been addressed, inspect the work in progress to evaluate the effectiveness of the planned procedures to achieve satisfactory results.

5-13.02B Engineer's Roles and Responsibilities

As provided in the *Contract Specifications,* Section 51-1.03F(1)*, Concrete Structures – General – Construction – Finishing Concrete – General*, SC staff determines the amount of additional finishing, beyond the ordinary surface finish, necessary to produce the smooth even surface of uniform texture and appearance specified for Class 1 surface finish. The finishing requirements are very subjective. Surface finishing is as much a matter of the practitioner's skill as the method or procedure employed. It may be best to view the overall effect of the finished surface from the distance and perspective that it will be viewed by the public.

5-13.02C Unauthorized Class 1 Surface Finishes

Before the Contractor begins Class 1 surface finishing activities, verify the method that they plan to utilize. *Contract Specifications,* Section 51-1.03F(3)*, Concrete Structures – General – Construction – Finishing Concrete – Class 1 Surface Finish,* requires that a Class 1 surface finish be achieved solely by abrasive methods.

Unless otherwise provided for in the contract documents, spraying on a cement mixture, sometimes containing a “glue”, is not recognized as an authorized means of achieving a Class 1 surface finish. This includes the spraying of any off-the-shelf product, as the Department has not authorized any material for this purpose. Improper application or use of poor-quality spray-on material can cause unwanted long-term results, including uneven coverage, fading or discoloration, and the appearance of drips, runs, and streaks after rainfall. Do not confuse a spray-on finish with a Class 2 surface finish, described later in this chapter. Wet sacking is similar, except that the cement mixture is hand applied rather than sprayed. Figure 5-34 illustrates the streaking that can result after a rainfall on a structure that received a spray-on finish.

Figure 5-34. Sprayed on Finish after Rainfall

Likewise, surface finishing by means of painting or similar method is not an authorized method to achieve a Class 1 surface finish.

5-13.03 Class 2 Surface Finish

Class 2 surface finish, or gun finish, is not commonly specified. The contract documents will specify if this class finish is required. Class 2 surface finish consists of the pneumatic application of a mortar coating, similar to shotcrete, after the ordinary surface finish is completed.

Ordinary surface finish must be complete before further continuing with the Class 2 surface finish. The concrete surfaces are abrasive blasted to a rough texture and thoroughly washed down with water. While the washed surface is damp, but not wet, a thin mortar coating is pneumatically and uniformly applied, firmly bonding to the concrete surface. Additional details for the coating material and its application can be found in *Contract Specifications*, Section 51-1.03F(4), *General – Construction – Finishing Concrete – Class 2 Surface Finish*. No additional finishing work is applied after the mortar coat is sprayed on. Figure 5-35 shows a typical Class 2 surface finish.

Figure 5-35. Class 2 Surface Finish

5-14 Concrete Architectural Features

To produce concrete structures that are more aesthetically pleasing than a typical Class 1 surface finished structure, projects may incorporate various types of architectural features, either on the concrete surfaces and/or within the concrete mix itself. Two such methods commonly utilized are applying a concrete surface texture and coloring.

5-14.01 Concrete Surface Textures

Projects that require an architectural finish or texture on exposed concrete surfaces will specify a concrete surface texture. The requirements for concrete surface textures are found in *Contract Specifications*, Section 51-1.03G(1), *Concrete Structures – General – Construction – Concrete Surface Textures - General*.

Some textures that may be specified include stamped and broomed finishes, which can be imprinted on concrete surfaces using applicable methods and tools. Fractured rib, fractured granite, formed relief textures, and mural type textures that mimic a graphic artwork may also be specified. These latter types would likely require specialized form liners be used. Refer to Chapter 3 for discussion on form liners.

Included in the referenced specification is the requirement for the Contractor to construct test panels for each type of specified texture. The intention for requiring test panels is for the Contractor to demonstrate that they can provide the specified surface texture. Contractors must construct test panels using the means and methods they intend to use during production, including the application of a Class 1 surface finish and the concrete mix design they intend to use, especially if the concrete is to be colored. Figure 5-36 shows a test panel that was constructed for a wall specifying a fractured granite texture. Witness and authorize test panels and authorize the finished product. Involve the District Landscape Architect in these processes, including final acceptance.

Figure 5-36. Test Panel for Fractured Granite Texture

5-14.02 Concrete Coloring

This section briefly discusses various methods authorized by the Department for colored concrete. Colored concrete can be produced by either coloring the surface or coloring the concrete mix itself. If colored concrete is required, the contract documents will specify the means to be used.

5-14.02A Painting and Staining Concrete Surfaces

Painting and staining are the primary methods specified for coloring concrete surfaces. Shotcrete, particularly sculpted shotcrete, is typically just stained. The applicable contract requirements are *Contract Specifications*, Section 78-4.03, *Incidental Construction – Miscellaneous Coatings – Painting Concrete,* and Section 78-4.04, *Incidental Construction – Miscellaneous Coatings – Staining Concrete and Shotcrete*. Review these requirements as well as BCM 78-4, *Incidental Construction – Miscellaneous Coatings*. Be mindful of surface preparation requirements, prescribed through the manufacturer's instructions and the *Contract Specifications*. For concrete staining, the Contractor must submit a staining work plan and stain test panels for SC staff to review and authorize.

5-14.02B Integrally Pigmented Colored Concrete

If a colored concrete mix is required, the contract documents will call for "integrally pigmented" colored concrete for specific concrete structures, specifying the color identification. The color is achieved by incorporating and thoroughly mixing pigments into the concrete mix.

Contract Specifications, Section 51-1.01C(6), *Concrete Structures – General – Submittals – Colored Concrete,* requires a work plan from the Contractor. When reviewing the work plan, verify that the proposed pigment material and dosage comply with the manufacturer's instructions and *Contract Specifications*, Section 51-1.02E, *Concrete Structures – General – Materials – Colored Concrete*. Verify, also, that concrete delivery, conveyance, placement, and curing are applicable to the project and comply with *Contract Specifications*, Section 51-1.03D(5), *Concrete Structures – General – Construction – Placing Concrete – Colored Concrete*. This specification emphasizes consistency in concrete material, concrete delivery times, and finishing, in order to optimize the chances for all the concrete structures that are specified to be colored to achieve a uniform appearance. It is best practice to be consistent with the type of forming material between structures that are to be the same color, as different material may result in varying shades of the same color. Figure 5-37 illustrates concrete barriers constructed with integrally pigmented concrete.

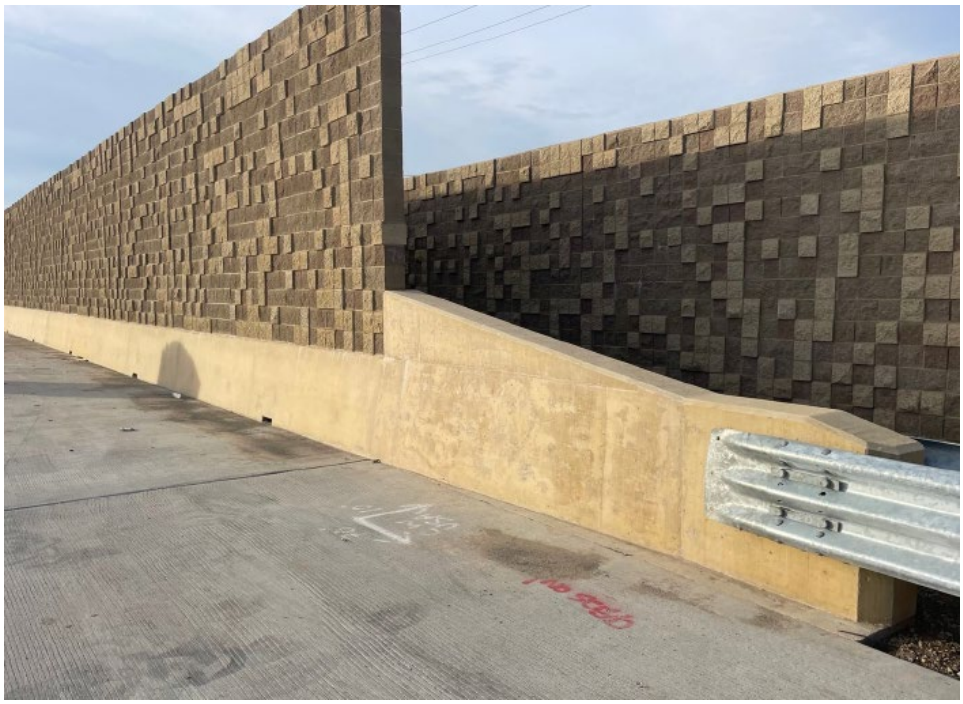

Figure 5-37. Barriers Constructed with Integrally Pigmented Concrete

One item that may get overlooked in the construction of integrally colored concrete structures is the use of correct dobies. Off-the-shelf concrete dobies are typically made of non-colored concrete, so they will likely not match the intended colored concrete. Verify that the type of dobies, or concrete spacers, that the Contractor intends to use will provide the concrete aesthetic required. If needed, contractors may have to special order colored dobies or custom fabricate them for a given project. Dobies to be used must be utilized in the test panel referenced earlier.

If a concrete placement operation is for both colored and non-colored concrete, the Contractor must utilize multiple concrete pumps. One of the pumps must be designated to place only the colored concrete. Similarly, if placement is for different colored concrete mixes, each concrete pump can only place concrete of one specified color.

The Contractor is allowed to cure colored concrete by either forms-in-place or curing compound methods. Check that the proposed curing method is applicable to the type of structure. Curing compound, if used, must either be clear or match the color of the colored concrete. Most contractors choose to use clear curing compound for this purpose since it would be difficult for the curing compound and colored concrete to match color after the curing compound dries.

Surface finishing may affect the resulting color of the concrete surface. Abrasive blasting and grinding will remove some of the pigmented cream that is on the surface. It may be difficult to consistently match the patch colors with the concrete color. As mentioned previously, if test panels are specified, Contractors must apply a Class 1

surface finish using their intended finishing techniques. Even if test panels are not required, it is best practice for contractors to experiment with their finishing techniques on inconspicuous locations of the structure or on test panels they construct on their own.

5-14.03 Concrete Placement for Structures with Architectural Features

It is vital to the final appearance of structures with architectural features that contractors employ sound concrete placement techniques, particularly proper concrete consolidation. Proper placement and consolidation will enable concrete to fill the various textures of form liners and reduce the potential for cold joints and other concrete surface defects. Otherwise, it is difficult to provide an acceptable, uniform appearance for such structures if the Contractor attempts to perform extensive concrete repairs or surface finishing. Figure 5-38 shows cold joints on a wall, with both surface texture and coloring, that will be very difficult to repair and finish to achieve the desired appearance.

Figure 5-38. Cold Joints on Wall with Architectural Features

5-15 Concrete Placement During Extreme Temperatures

This section covers special concrete construction practices employed during adverse weather conditions, especially during extremely hot and cold temperatures. When placing concrete under adverse weather conditions, the most effective means of assuring satisfactory results is keeping the concrete temperature within the acceptable range of 50 °F and 90 °F, as required per *Contract Specifications*, Section 90-1.02G(2), *Concrete – Materials – Mixing and Transporting Concrete – Machine Mixing,* while it is in the plastic state.

High temperatures will increase the water demand, decrease workability, reduce strength, and increase shrinkage. Low temperatures will retard strength gain, while severe damage will occur if the water in the cement paste freezes while the concrete is plastic or during the first few hours of the curing period.

The detrimental effects of adverse weather conditions, and the measures that may be employed to mitigate those effects, are explained in the following sections. SC staff should review contract requirements applicable to such construction, along with the recommended mixing, placing, finishing, and curing procedures that may be employed to ensure that the desired strength and durability of the concrete will be obtained despite the adverse weather.

5-15.01 Hot Weather Construction

When concrete is placed during hot weather conditions, both the placing of the mixture and the characteristics of the hardened concrete are adversely affected by several factors associated with high temperature. For example, unless compensating measures are taken, the water demand increases as temperatures rise, requiring the increase of the water-cement ratio. For a given concrete, the amount of water needed to maintain the same consistency will increase as much as 15 percent as the temperature of the fresh concrete increases from 50 °F to 100 °F.

At high temperatures, the time concrete remains plastic is decreased. In turn, this decreases the window when the concrete must be mixed, delivered to the site, conveyed, placed, and finished. Rapid stiffening encourages undesirable re-tempering of the mixture by adding water to keep the mix in a plastic state. Reduced workability makes placing and consolidation more difficult. This may result in the formation of concrete defects at locations where fresh concrete is placed against partially hardened concrete.

High temperatures will accelerate setting and early strength gain; however, high temperatures appear to adversely affect gel formation during the hydration process, thus resulting in lower ultimate strength. As previously noted, the increase in water

demand associated with higher temperatures will increase the water-cement ratio, resulting in a further strength reduction.

High temperatures increase the tendency for cracks to develop, both before and after the concrete sets. Rapid evaporation of bleed water may cause plastic shrinkage cracking before the surface hardens. Cracks in the hardened concrete may form as a result of drying shrinkage stresses which may be more severe due to the increased mixing water demand or because of volume changes due to cooling of the concrete mass from its elevated initial temperature.

As temperatures increase, preventing loss of water from the concrete becomes more difficult, so maintaining an effective cure method becomes a more critical activity.

5-15.01A Control of Concrete Temperature

The temperature of a concrete mixture varies directly with the temperature of the various ingredients at the time of batching. During hot weather, keeping the temperature of the concrete mixture below the specified maximum of 90 °F may require cooling one or more of the ingredients before batching.

The effect of each ingredient on the temperature of the mix is a function of the quantity of the ingredient used, its specific heat, and the temperature of the ingredient at the time of batching. Since the aggregates comprise about 70 to 80 percent of the combined mix, aggregate temperature has the greatest influence on mix temperature. In hot weather, aggregate stockpiles can reach temperatures up to 120 °F. When compared to aggregate at 70 °F, and with other factors being equal, the use of the warmer aggregate may increase the concrete temperature by about 30 °F.

Several methods may be used to lower aggregate temperature. Shading stockpiles and storage bins from the direct rays of the sun will provide some benefit, although this may not be feasible at many plant locations. Sprinkling coarse aggregate stockpiles with water is very effective and can lower the temperature to a normal range of 60 °F to 80 °F under optimum ambient conditions. Spraying the coarse aggregate immediately before use will produce some cooling, but this method is not as effective as continuous sprinkling.

Unless the stockpiles remain unused for a long period of time, sand in stockpiles is more difficult to cool. It is also less likely to experience a significant increase in temperature because of its normally higher moisture content.

Lowering the temperature of the mixing water is the easiest and most effective way of lowering the mix temperature. This is the case because of the high specific heat of water, which is four to five times that of most aggregates.

Mixing water should be used from the coldest available source. If above ground storage tanks are used, they should be shielded from the sun. An alternative, if this is not possible, is to paint storage tanks white so that heat from the sun will be reflected.

Some concrete plants are equipped with refrigeration coils in the water storage tank, which can lower the mixing water to about 40 °F. If this is not cool enough to produce the desired concrete temperature, and if cooling aggregate is not feasible, it will be necessary to replace some of the mixing water with chipped or shaved ice.

Using ice in the mixing water is highly effective in reducing the concrete temperature because melting ice removes heat at the rate of 144 British thermal units (BTU) per pound. For example, if 50 percent of the water in a typical six-sack mix was replaced by ice, the melting ice would lower the concrete temperature about 20 °F, and the resulting water at a temperature of 32 °F would produce further cooling of about 8 °F. The amount of ice and water used may not exceed the specified maximum water content for the mix. If ice is used, it must be completely melted and mixed before discharged from the mixer.

Cooling cement is not generally feasible; but this is not of serious consequence because of the low specific heat of cement and the relatively small amount used in the mix.

The use of liquid nitrogen to cool aggregates is a viable procedure and may be worth considering under extreme conditions.

5-15.01B Mixing and Delivery

When transit-mixing equipment is used, remind the Contractor, including during the pre-pour meeting, to plan and organize the work and dispatch the trucks to avoid any delay in placing the concrete after it is delivered to the site. The heat generated by prolonged mixing, even at agitating speeds, will cause a noticeable increase in the concrete temperature, particularly when the trucks are exposed to the direct rays of the sun. This is an important and frequently overlooked consideration.

If an unavoidable delay should occur, the heat generated by mixing can be minimized by stopping the mixer and then agitating intermittently. Keep in mind that this is strictly an emergency procedure. The important point is that truck mixers are unloaded as soon as possible after arrival at the site, and work is planned accordingly.

If truck mixers are painted white, they will absorb less heat than when painted other colors. For example, after an hour of exposure to the sun, surfaces painted gray may be 5 °F to 10 °F warmer than similar surfaces painted white. Black painted surfaces may be as much as 30 °F warmer. The inside of the mixer will have been heated proportionally.

Some suppliers have installed spray bars to apply water to the outside of the drum to create an evaporative cooling effect.

As mentioned earlier in this chapter, SC staff is allowed to reduce the 90-minute discharge and placement time during hot weather conditions. Look for signs that the concrete may be setting too soon, such as the vibrator having difficulty consolidating the concrete, the concrete becoming too stiff for the finishers to work with, or a visible change in the fluidity of the concrete in the chute.

5-15.01C Placing and Finishing

It is important to estimate the probable placing rate, giving due consideration to crew size and equipment available before work begins. Concrete delivery to the work site must be controlled so it does not exceed the estimated placing rate.

As mentioned previously, the forms and subgrade must be moistened before the start of concrete placement. Wetting the rebar can also be considered. Wetting the area around the work is also beneficial since it cools the surrounding air and increases humidity, thus reducing both the rate of evaporation and temperature rise during the concrete placement.

Concrete hardens (cures) more rapidly as temperatures increase, so extra care is needed to avoid cold joints. For column and wall pours, it may be necessary to reduce the thickness of each lift as it is placed to ensure bonding with the previously placed lift. Controlling the quantity, as well as the rate, of concrete placed may be an important consideration for bridge decks. Rigorous surface finishing requirements make it imperative that finishing operations follow closely behind placing so that moisture loss from evaporation is minimized. Preventing excessive surface moisture loss is important for two reasons. First, surface moisture is necessary for satisfactory deck finishing. Second, loss of surface moisture is the primary cause of plastic shrinkage cracking.

Keep in mind that plastic shrinkage cracking is not caused by high temperature alone, since such cracking can occur whenever ambient conditions lead to rapid evaporation of surface moisture. However, the conditions that contribute to plastic shrinkage cracking are exacerbated by hot weather. Special care is necessary to minimize the rate of evaporation of surface moisture when high temperatures prevail.

During extremely hot periods when temperature conditions are critical, discuss with the Contractor the possibility of scheduling placement during the early evening or at night, when lower temperatures will reduce concrete set time and the rate of evaporation.

5-15.01D Curing

During periods of hot weather, a concerted effort is required to ensure that the purpose of curing, which is to keep the concrete in a moist condition within an optimum temperature range, is achieved. These conditions become increasingly more difficult to obtain as ambient temperatures rise.

All curing equipment and facilities must be at the site of the pour and available so that curing may begin as soon as the concrete is placed and finished. During hot weather, all exposed surfaces are to be kept continuously wet to prevent moisture loss before the final curing medium is applied.

In the case of bridge decks, it may be necessary to apply a mist of water to the deck surface before all finishing is completed to maintain a moist surface. After finishing, the surface must be kept moist until the curing compound is applied. In either case, the Contractor must control the amount of water applied carefully without being too excessive. Additional details on the curing process for bridge decks are provided in Chapter 7.

Concrete must be kept cool as well as moist during the curing period when temperatures are high. Cooling can be achieved by the application of water, beyond the amount needed for moisture retention. Formed surfaces, as well as exposed surfaces, may require cooling.

Contract Specifications, Section 51-1.03H, *Concrete Structures – General – Construction – Curing Concrete Structures,* states that during periods of hot weather, SC staff may direct the Contractor to apply water to concrete being cured by the curing compound method or the forms-in-place method, until the Engineer determines that a cooling effect is no longer required. Application of water pursuant to this specification is paid for as extra work at force account.

When applying water to cool exposed surfaces, water that is excessively cooler than the concrete should not be used. Extremely cold water may cause cracking as a result of thermal stresses due to temperature change at the surface.

5-15.01E Use of Admixtures

Even though admixtures may not be specifically called for in the contract documents, their use can be considered during hot weather as a means of mitigating some of the undesirable side effects of hot weather construction.

A set retarding admixture may be used to delay the initial set, compensating for the accelerating effect of heat. A water reducing admixture will mitigate the loss of workability, resulting from moisture loss during mixing and placing under hot weather conditions.

An admixture having both set retarding and water reducing properties will be doubly beneficial.

For a given concrete, increased workability may be obtained by using an air-entraining admixture; however, some caution may be advisable for bridge deck construction since air-entrainment slows the rate at which bleed water reaches the surface. This may have a detrimental effect on surface finishing. If the use of air-entraining admixture is not specified, the limitations set in *Contract Specifications*, Section 90-1.02E(3), *Concrete – General – Materials – Admixtures – Air-Entraining Admixtures,* must be followed. This requires that the average air content of three successive tests must not exceed 4 percent, with no single test value exceeding 5.5 percent.

5-15.02 Cold Weather Construction

Provided certain precautions are taken, concrete construction can continue throughout protracted periods of cold weather. To best ensure acceptable results, the temperature of the concrete mixture must be high enough that the mixing water will not freeze while the concrete is plastic, the newly placed concrete must not freeze while it is setting, and the hardened concrete must be protected from the cold to maintain an internal temperature that is high enough to assure the required strength gain during the curing period.

5-15.02A Mixing and Delivery

To prevent freezing while the concrete is still plastic, *Contract Specifications*, Section 90-1.02G(2), *Concrete – General – Materials – Mixing and Transporting Concrete – Machine Mixing,* sets 50 °F as the minimum concrete temperature at time of placement. When the temperature falls below 50 °F, it will be necessary to heat the water, the aggregates, or both, to keep the concrete mixture above the required minimum temperature.

When aggregate temperatures are above freezing, in most cases it will be necessary to heat only the water to obtain the required concrete temperature. When ambient temperatures drop below the freezing point, the moisture in the aggregates will freeze if the stockpiles and batch bins are not protected and/or the aggregate not heated. Frozen aggregate must be thawed before use; otherwise, thawing in the mixer will result in excessively high water content.

Taking measures to prevent aggregate from freezing is easier than thawing aggregate after it has frozen. To this end, aggregate stockpiles can be protected by covering them with tarpaulins and applying heat. Heat may be applied by space heaters or by circulating hot water or steam through pipes at the bottom of the stockpile.

When using hot water, it will be necessary to adjust the batching cycle to prevent the water from mixing directly with the cement. Direct contact may induce premature setting, also known as flash set, or the formation of cement balls. The usual procedure is to add the water and most of the aggregate before adding the cement.

Neither water nor aggregate is allowed to be heated above 150 °F per the previously mentioned specification. This is a reasonable limitation, since 150 °F is well above the temperature needed to produce a concrete mixture within the specified temperature range, even under the most severe conditions likely to be encountered in the state.

5-15.02B Placing and Finishing

The temperature of all surfaces that the fresh concrete will contact must be above freezing before concrete is placed. As mentioned previously, *Contract Specifications*, Section 90-1.03C, *Concrete – General – Construction – Protecting Concrete,* prohibits concrete placement on frozen or ice-coated ground, subgrade, forms, or any other contact surface. To achieve this condition, it may be necessary to heat the forms and reinforcing steel with space heaters ahead of the concrete as it is placed. If the ground is solidly frozen, however, suspend the concrete placement until the ground thaws and will not freeze again during the curing period.

It is essential that, after placement, concrete be protected during the hardening (curing) period and a temperature favorable for hydration be maintained. *Contract Specifications*, Section 51-1.03I, *Concrete Structures – General – Construction – Protecting Concrete Structures,* requires concrete to be maintained at a temperature of not less than 45°F for 72 hours and not less than 40 °F for an additional 96 hours. Additionally, when requested by the Engineer, the Contractor must submit their proposed method of complying with this requirement. These are important and necessary provisions because the rate at which hydration occurs slows as the temperature drops, and from a practical standpoint, strength gain stops entirely when the temperature is below about 35 °F.

5-15.02C Curing

Many methods are available to maintain concrete temperature during the cure period. When the work area can be enclosed or covered, space heaters are an effective heating method, as demonstrated in Figure 5-39. The use of steam released within an enclosure provides both heat and moisture for proper curing, but a steam generator is less economical than space heaters, so this method is not widely used. Bridge decks are usually covered with a straw blanket, which is an effective means of retaining the natural heat of hydration. Thermal blankets are expensive, both from a cost and operational standpoint, but they are effective and may be economical under severe weather conditions.

Figure 5-39. Maintaining Concrete Temperature in Cold Weather

Concrete generates heat rapidly during the first few days of the curing period. If the forms are well insulated and the exposed surfaces of the concrete are covered properly, it may not be necessary to apply additional heat from outside sources to maintain the required minimum temperature during the cure period. In any case, it is essential to conserve the heat generated, thereby minimizing the amount of external heat needed. For maximum effectiveness, insulation used to conserve the heat must be in close contact with the concrete surface.

Rapid cooling of the concrete at the end of the curing period must be avoided to prevent surface cracking. As a guide, the maximum temperature drop during the first 24 hours following the end of a curing period when external heat has been applied should not exceed approximately 40 °F.

5-15.02D Measuring Concrete Temperatures

Use thermometers provided by the Department to measure concrete temperatures. Measure the temperature of hardened, placed concrete by inserting the stem of the thermometer full depth into a previously formed water-filled hole in the concrete. A drinking straw placed into concrete before it hardens makes a good form for this purpose. When no longer needed, plug the hole at the surface to keep out debris. When measuring the concrete temperature, allow sufficient time for the thermometer to stabilize before recording the temperature. Since corners and edges are particularly vulnerable, make a special effort to check temperatures at these locations.

5-16 Mass Concrete

Concrete piles that have a diameter greater than 14 feet and other structures specifically identified as mass concrete in the *Contract Specifications* are subject to temperature monitoring and control requirements outlined in *Contract Specifications*, Section 51-6.01D(2)(b), *Concrete Structures – Mass Concrete – Quality Assurance – Quality Control – Temperature Monitoring*. *Contract Specifications*, Section 51-6.03, *Concrete Structures – Mass Concrete – Construction,* allows contractors to utilize a mechanical cooling system of their design for concrete thermal control measures. Details of their means to monitor temperature and provide a cooling system must be included in their thermal control plan and authorized. Figure 5-40 shows a schematic for a mechanical cooling system from a contractor's authorized thermal control plan.

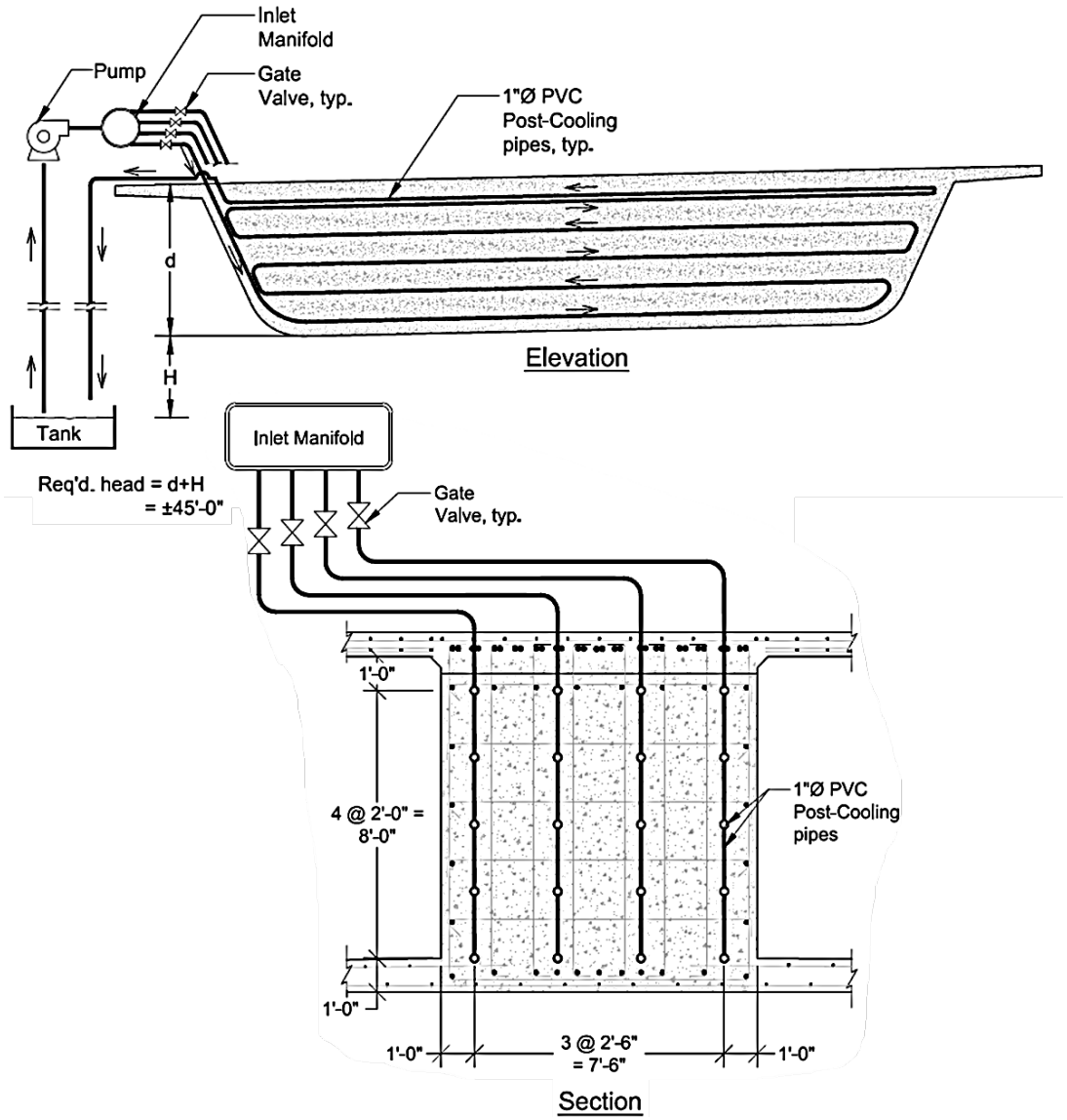

Figure 5-40. Schematic of Mass Concrete Cooling System

A mechanical cooling system is typically comprised of a series of cooling pipes cast into the mass concrete, circulating cold water or other coolant during concrete placement and initial curing period. The circulated coolant absorbs heat from the concrete as it hydrates and needs to be chilled before being recirculated into the system. Pumps, manifolds, and valves are usually included to help control the coolant flow. Figure 5-41 is a photo from a cooling system, showing cooling pipes attached to a manifold.

Figure 5-41. Manifold and Cooling Pipes for Mass Concrete Cooling System

During installation of the cooling system, verify that cooling pipes and other accessories are installed per the authorized thermal control plan. They must also be secure and installed so that they don't interfere with the permanent features of the bridge. Before the concrete pour, the Contractor must pressure test the system to confirm that no leaks are present. After use, cooling pipes must be grouted completely.

5-17 Placing Concrete Under Water

Bridge foundations in streams and rivers, and bridge and building construction below the ground water elevation at other locations, may require concrete placement below the water surface. Typical situations include concrete placed to seal cofferdams, concrete placed below groundwater in CIDH piles and caissons, and concrete placed under and around precast sections of subaqueous tunnels and subways. Refer to the SC *Foundation Manual* for more information regarding construction of reinforced concrete under water.

While a detailed discussion of underwater construction is beyond the scope of this manual, the following discussion of seal course concrete placement and concrete placement using water and slurry displacement procedures has been included as an introduction to the subject.

5-17.01 Seal Course Concrete

A seal course is a layer of concrete that is placed within a watertight cofferdam. Its purpose is to block the intrusion of water into the bottom of an excavation and may be used if the Department believes dewatering alone will be ineffective or unachievable. The seal course must be strong and thick enough to resist the hydrostatic pressure developed at the bottom of the cofferdam when the cofferdam is dewatered.

Contract Specifications, Section 51-1.03D(3), *Concrete Structures – General – Construction – Placing Concrete – Concrete Placed Under Water,* provides the contractual requirements for a seal course. This specification permits seal course concrete placement using either tremie methods or concrete pumps. In the past, tremie methods were used exclusively, and the terms "tremie seal" and "tremie pour" are still used informally in connection with seal course concrete placement. Today, most seal course concrete will be placed with a concrete pump; however, tremie placement remains a viable construction procedure and will be the method of choice at any location where the use of pumping equipment is economically infeasible. From a construction standpoint, the principal difference between tremie placement and pump placement is that tremie concrete is placed by gravity flow alone, whereas when a pump is used, placement is aided by pump pressure.

A "tremie" is a watertight tube not less than 10 inches in diameter with a hopper at one end. The hopper is supported by a working platform above the water surface. The tremie tube must be long enough to reach from the platform to the lowest point of deposit. The lower end of both tremie tubes and pump discharge tubes will be equipped with a valve that may be closed to prevent water from entering the tube. This makes it possible to fill the discharge tube with concrete without removing it from the cofferdam.

Seal course concrete must be workable and cohesive with good flowability. *Contract Specifications*, Section 90-1.02G(6), *Concrete – General – Materials – Mixing and Transporting Concrete – Quantity of Water and Penetration or Slump,* requires a nominal slump of 6 to 8 inches when concrete is placed under water. The proportions of fine and coarse aggregates may be adjusted to produce the desired workability with a somewhat higher proportion of fine aggregate than would be used for normal conditions.

To begin placement, the valve at the lower end of the discharge tube is closed, and the tube is lowered into the cofferdam and filled with concrete. The valve is opened to begin placement. As placement continues, the discharge tube should be kept as deeply submerged in the previously placed concrete as conditions will permit. For tremie

placement, the depth will depend largely on the head of concrete that can be maintained in the tremie tube. For either placement method, the tube must be lifted slowly to permit the concrete to flow out, care being taken not to lose the seal at the bottom. If the seal is lost, it is necessary to raise the tube, close the discharge valve, refill the tube with concrete and then lower it into the concrete before placement may resume.

Segregation must be minimized as work progresses. The previously placed concrete needs to be disturbed as little as possible, with the top surface of the concrete kept as near level as possible. The discharge tube must not be moved laterally through previously deposited concrete. When it becomes necessary to move the discharge tube to a new position, the valve is to be closed and the tube removed from the concrete before relocating.

5-17.02 Water and Slurry Displacement Method

The water and slurry displacement methods, which are two methods of underwater concrete placement, are similar in that structural concrete is placed without dewatering the excavation in the traditional manner. Displacement methods provide an acceptable alternative construction procedure for concrete placement in CIDH piles and mined shafts where subsurface conditions make dewatering economically infeasible. Requirements for water displacement or slurry displacement procedures will be found in the *Contract Specifications* for the project where that construction method is specified, which will include concrete materials and production requirements, placing procedures, and testing requirements.

For both methods, concrete is pumped into place through a discharge pipe or hose, which initially is set at the bottom of the drilled hole or excavated shaft. As concrete placement continues, the discharge end of the pipe or hose remains at the bottom, so that the heavier concrete, as it rises in the hole or shaft, displaces the slurry; hence the name "displacement" method.

Generally, slurry displacement is specified when needed. Slurry displacement is most often used to facilitate CIDH piles installation in “wet hole” conditions. This is when all or a portion of the pile is below groundwater, the drilled hole is experiencing water intrusion, and the sides of the pile may not be self-supporting. In such cases, the slurry, which is commonly a synthetic drilling slurry or a commercial quality mineral drilling mud, prohibits water intrusion and supports the sides of the drilled hole until concrete is placed. Reference *Contract Specifications*, Section 49-3.02, *Piling – Cast-In-Place Concrete Piling – Cast-In-Drilled-Hole Concrete Piling,* and the SC *Foundation Manual*, for CIDH construction with slurry displacement method.

Water displacement is only acceptable when allowed by the *Contract Specifications*. For this method, concrete is placed continuously. High-pressure pumping equipment is used

to deliver the concrete through a discharge system to the bottom of the drilled hole or excavated shaft. To reduce the required pumping pressure, the discharge tube is raised when the height of the concrete in the pile or shaft reaches about 10 feet. This head is maintained as the remainder of the concrete is pumped into place.

Because the first concrete placed eventually reaches the top of the pile or shaft, it is essential that the concrete remains in a fluid state throughout the placement period. To achieve the desired fluidity, the mix design will include a high-range water-reducing admixture. Additionally, a "test" batch is required to demonstrate that the proposed concrete mix meets contract requirements.

5-18 Environmental Stewardship

Over the years, there has been increasing emphasis placed on mitigating the impact of concrete construction on the environment. Environmental requirements for construction projects, both general and project specific requirements, are contained in the contract documents, supplemental project information, and in permits from regulatory agencies. SC staff must be familiar with these requirements, as they pertain to concrete construction, and the project's authorized Stormwater Pollution Prevention Plan (SWPPP) or Water Pollution Control Program (WPCP), whichever is applicable. Most importantly, SC staff must participate in enforcing these requirements.

In general, the Contractor must not allow concrete materials and waste to potentially pollute water, stormwater, and environmentally sensitive areas (ESA). This includes protection from ancillary concrete related materials, such as curing compound, water used to clean concrete placement equipment, and residue from abrasive or pressure wash blasting. As seen in Figure 5-42, the Contractor is using plywood to shield the nearby ESA from curing compound overspray.

Figure 5-42. Curing Compound Shield

One simple step to help reduce the risk of contractor non-compliance is to check that forms are mortar tight, to prevent any contaminants from reaching the ground or the traveling public. Figure 5-43 shows the result of soffit forms not being mortar tight. Chapter 3 discusses additional means for protecting locations underneath soffit forms from grout leakage.

Figure 5-43. Leaking Soffit Forms

Verify there are sufficient protections in place to keep contaminants off the ground and to aid in cleanup. The transfer of concrete from the truck mixer into the concrete pump hopper is one of the times when concrete contamination is the most likely. Most contractors place Visqueen underneath the concrete pump's hopper, as shown in Figure 5-44, to prevent concrete contaminants from reaching the ground. After the pour, any contaminants that may have fallen onto the Visqueen can be easily removed.

Figure 5-44. Visqueen Protection Under Concrete Pump

Verify that construction site best management practices (BMP) are properly implemented, especially at locations close to concrete construction. BMPs the Contractor intends to use are detailed in their SWPPP or WPCP. Figure 5-45 shows inlet protection and a berm used as BMPs incorporated for this specific site. Secondary containment for storing curing compound, as shown in Figure 5-46, may be a required BMP.

Figure 5-45. BMPs for Waterway

Figure 5-46. Curing Compound Secondary Containment

Temporary concrete washouts are used for collecting concrete wastes. This includes wastes such as those resulting from priming the concrete pump before its use and washing concrete conveyance and placement equipment, particularly the inside of a truck mixer's drum or a concrete pump. Figure 5-47 shows a picture of a typical concrete washout. *Contract Specifications*, Section 13-9, *Water Pollution Control – Temporary Concrete Washouts,* defines the expectations of a concrete washout. Often overlooked is the requirement for the Contractor to provide an informational submittal for their use of temporary concrete washouts. Per *Contract Specifications*, Section 13-9.01C, *Water Pollution Control – Temporary Concrete Washouts – General – Submittals*, information for locations of concrete washouts, disposal sites, and permits must be provided.

Figure 5-47. Temporary Concrete Washout

Discuss with the Contractor their use of temporary concrete washouts and the washout submittal, verifying the following:

a. Washout locations are easily accessible for truck mixers and their locations comply with *Contract Specifications*, Section 13-9.03, *Water Pollution Control – Temporary Concrete Washouts – Construction*, including being at least 50 feet from drainage facilities and ESAs.

b. Washouts will have sufficient capacity to handle the size of the anticipated concrete pour.

c. Secondary containment, if necessary, has been installed.

Do not allow the Contractor to use “kiddie pools”, which are portable and shallow water pools such as the one shown in Figure 5-48, as temporary concrete washouts. They are not considered acceptable due to their small size and questionable ability to contain washout materials.

Figure 5-48. Unacceptable Concrete Washout

5-19 Public Safety for Bridge Construction Over Traffic

Bridge construction often requires work to be performed over live traffic. The Contractor is obligated to protect the public from any of their work activities per *Contract Specifications*, Section 7-1.04, *Legal Relations and Responsibility to the Public – Public Safety*, including during bridge construction work over the traveled way. The primary concern in this case is the potential for falling hazards, including dust and debris, to reach the roadway and travelers. The Contractor must install and maintain protective measures if there is a risk to the public.

Discuss with the Contractor if any bridge construction operations may need protective measures. Forms and falsework can act as primary methods for protecting from falling hazards; however, additional measures may be necessary. Railing, toeboards, and screens are standard protective measures for overhead work required by the Construction Safety Orders. They act both to protect the workers above as well as protect the people and area below. Other acceptable protective measures include netting, secondary platforms, containment, or canopies such as pedestrian walkways. Figure 5-49 shows railing, screens, and netting acting as measures to protect the

traveling public below. Refer to the Caltrans *Code of Safe Practices* for additional insight on safety when working within elevated work areas.

Figure 5-49. Protective Measures over Traffic

Not all protective measures have to be barrier type protection as the ones stated above. Protective measures can also include incorporating lane closures or staging equipment to eliminate the potential for “booming” over traffic.

Chapter 6: Bridge Construction Practices for Cast-In-Place Bridges

Table of Contents

Chapter 6: Bridge Construction Practices for Cast-In-Place Bridges 1
Table of Contents 1
6-1 Introduction 2
6-2 Substructure 2
6-2.01 Concrete Piles 3
6-2.02 Footings 4
6-2.03 Columns, Abutments, and Walls 6
6-2.04 Drop Bent Caps 8
6-3 Superstructure 9
6-3.01 Integral Bent Caps 9
6-3.02 Stem and Soffit 11
6-3.03 Diaphragms 16
6-4 Other Bridge Elements 16
6-4.01 Barrier Rails 16
6-4.02 Structure Approach Slabs 20

6-1 Introduction

Cast-in-place (CIP) concrete bridges are the most common type of bridges constructed by the Department. This chapter primarily reviews typical construction practices for various components and elements of a CIP concrete bridge.

The major components of CIP concrete bridges are the substructure and superstructure. These bridge components are made of several elements. Concrete for each element of the bridge must be placed continuously. Do not allow the contractor to begin a concrete pour unless the falsework, forms, rebar, and all embedded items (if applicable) are completely installed and have been inspected by both the Contractor and Structure Construction (SC) staff. The Contractor must have sufficient labor, equipment, and material on hand to complete the planned work without interruption.

As suggested in Chapter 2, *Preconstruction Planning*, although not contractually required, consider holding a pre-operation meeting with the Contractor before starting field activities, including concrete placement-related activities. A list of items that SC staff should consider discussing with the Contractor include the following:

1. Safe access and a controlled access zone (if needed), particularly for the girder stem and soffit concrete placement.
2. Concrete mix design to be used. Contractors may utilize multiple mix designs for various uses on the same project.
3. Anticipated rate of concrete placement.
4. Direction and sequence of concrete placement.
5. Equipment and labor force on site.
6. Traffic control.
7. Contingency plans for unforeseen events.
8. Proper storm water pollution prevention plan (SWPPP) measures that need to be in place for the concrete pour, including concrete washout stations.
9. Special consideration to protect epoxy coating when epoxy-coated reinforcement is exposed beyond a construction joint (for example, barrier rail reinforcement above a bridge deck).

6-2 Substructure

The bridge substructure supports the bridge superstructure, transferring bridge and traffic loads to the ground. Substructure elements include piles, footings, columns, caps (or bent caps), abutments, and wingwalls. Piles and footings are considered foundations. A bridge bent is comprised of a column, or set of columns, and bent cap.

Bridge foundations set the location, position, and alignment of a bridge and must be verified as consistent with the project plans. The primary means of establishing the line and grade for bridges is through the "control stakes" provided by District surveyors for the bridge foundations. Since bridge foundations control the bridge lines and grades, SC staff should verify the survey stakes for the bridge foundations are correct before construction begins. Refer to Chapter 2 for additional discussion regarding line and grade control. In addition to the ensuing sections in this chapter, refer to the *Foundation Manual* for further discussion about bridge foundation construction.

6-2.01 Concrete Piles

Two types of concrete piles are commonly used in bridge construction projects: precast concrete piles and CIP concrete piles. CIP concrete piles include cast-in-drilled-hole (CIDH) and cast-in-steel-shell (CISS).

CIP concrete piles are further classified by whether the concrete is placed in a dry or dewatered hole, or if it is placed in a wet hole.

For piles cast in dry or dewatered holes, the concrete placing, consolidation, and finishing requirements are similar to those of any other structural concrete, with some special requirements unique to this type of pile. Per *Contract Specifications*, Section 49-3.01C, *Piling – Cast-In-Place Concrete Piling – General – Construction*, only the top 15 feet of concrete for CIP piles is to be vibrated. The exception to this is for piles placed under slurry, as vibration is not required for piles placed in this condition per *Contract Specifications*, Section 49-3.02C(9)(a), *Piling – Cast-In-Place Concrete Piling – Cast-In-Drilled-Hole Concrete Piling – Construction – Placing Concrete Under Slurry – General*. For dry or dewatered holes, concrete may be allowed to fall greater than 8 feet during concrete placement, provided that the concrete falls without hitting reinforcement, reinforcement bracing, or other objects in the hole on the way to the bottom, which can potentially cause the concrete to segregate. Otherwise, the Contractor must control concrete placement into the drilled hole using a delivery system such as a tremie tube or tubes. Rebar cages for piles are usually fabricated horizontally and require internal bracing (usually crossed diagonal rebar) to prevent the cages from collapsing. Unless a tremie is used for concrete placement, when the cages are lowered into position vertically, the bracing must be removed to prevent the falling concrete from striking the bracing.

For dry hole piles, concrete may be placed directly from concrete truck mixers using the truck-mounted chute. The use of a small hopper with a drop chute, or "elephant trunk", at the top of the pile shaft will reduce segregation since it will recombine the concrete as it leaves the chute and provide a vertical fall through the reinforcing cage (see Figure 6-1). The advantage of using a chute was explained previously in Chapter 5, *Concrete.* This may be particularly important if a more fluid mixture is being used.

Figure 6-1. Hopper Placed at Top of Drilled Hole

To minimize the formation of voids and rock pockets in the lower, un-vibrated length of the pile, consider allowing water content to be increased to achieve a more fluid mixture. In no case, however, should the water content exceed the specified maximum amount.

For wet hole piles, the Contractor must be especially careful during concrete placement because of the higher likelihood of concrete defects. Because of the high risk associated with concrete placed under wet hole conditions, the *Contract Specifications* include requirements for acceptance testing, which is to be performed by the Department.

6-2.02 Footings

As discussed in Chapter 5, immediately before placing concrete, the ground surface on which the footing concrete will be deposited must be thoroughly dampened with water (in addition to the forms, if used), per *Contract Specifications*, Section 51-1.03D(1), *Concrete Structures – General – Construction – Placing Concrete – General*. This reduces the amount of water absorbed from the concrete by the ground, thus allowing concrete to cure more evenly. Although the ground should be thoroughly moistened during concrete placement, there should not be any puddles of standing water.

Footing concrete is usually deposited by tailgating from the mixers of concrete trucks. In cases where the distance between the truck mixer and the footing is too great to be reached with truck-mounted equipment, the Contractor may employ special chutes or pumps. Figure 6-2 shows a concrete pump being utilized for placing concrete for a footing. Water should not be added to facilitate the use of chutes. In the event that the bottom of the footing excavation is on a slope, the concrete should be placed first at the low end and then proceed up the slope. In all cases, concrete should be deposited near its final location. Do not permit vibrators to be used to extensively shift concrete.

Figure 6-2. Footing Concrete Placement

For contractors, building forms for footings or pile caps is not always worth the additional time, effort, and expense. Instead, contractors typically install the reinforcement in the proper location within the excavation, with the walls of the excavation functioning as formwork for the concrete. This is commonly called “pouring neat”. Depending on the skill of the excavation crew and the stability of the ground, the excavation may either be close to the dimensions of a constructed formwork system or irregular and significantly oversized.

SC staff should discuss with the Contractor whether to allow the footing to be poured neat or require forms to be installed to adhere to the dimensions shown in the project plans. In either case, any dimensional variance from the plans should be carefully

measured and documented in the as-built plans. The top and bottom dimensions of the footing are important since variation will affect the stiffness of columns or piling incorporated into the footing.

If the footing is significantly over-excavated, do not allow it to be poured to that depth without consulting the Bridge Design (BD) Project Engineer. The over-excavated depth may have to be made up by placing structural backfill or filling with an incompressible material such as pea gravel or rock base. A layer of non-structural concrete, or "rat slab", below the footing, with a bond breaker between the slab and footing, can be another option to fill the over-excavation. Curing compound can be used as a bond breaker if authorized. Confirm that the planned top of footing elevation is marked on the forms or excavation before the pour, and that the footing is poured to the proper elevation. If the footing was not constructed to the planned elevation, discuss options with the BD Project Engineer. If a variance is permitted, it must be documented in the as-builts.

Contract Specifications, Section 51-1.03D(1), *Concrete Structures – General – Construction – Placing Concrete – General,* requires concrete reconsolidation or re-vibration for footings that are more than 2-1/2 feet thick and have a top layer of reinforcing steel. The purpose of this re-vibration is to minimize the presence of voids below the top layer of reinforcing bars. Such voids, which may occur because of bleed water collecting below the bars, will reduce the bond between the concrete and the reinforcing bars. Contractors must re-vibrate concrete as late as the concrete will respond to further vibration, but no sooner than 15 minutes after initial screeding. To hasten final finishing, most contractors prefer to perform the required re-vibration sooner, rather than later. When determining the optimum delay period, keep in mind that for maximum effectiveness, re-vibration should be delayed as long as possible.

Following the usual striking-off of concrete to the planned grade and after re-vibrating the concrete, the concrete should be hand-floated to obtain an even-textured surface, free of voids, water, and air pockets. As the concrete sets, the top of the footing should be re-floated to seal the surface.

6-2.03 Columns, Abutments, and Walls

Concrete for columns (or piers), abutments, and walls is usually placed using a concrete pump or by crane and bucket. In Figure 6-3, the Contractor is using a concrete pump to place concrete for a column.

Figure 6-3. Column Concrete Placement

As mentioned in Chapter 5, when the form height exceeds 8 feet, *Contract Specifications*, Section 51-1.03D(1), *Concrete Structures – General – Construction – Placing Concrete – General,* requires concrete delivery using pipes or tubes. As mentioned earlier, a hopper with a drop chute helps to prevent segregation and aid in directing the concrete so that it does not strike the bar reinforcing steel or the sides of the forms above the level of placement. Adjustable-length metal or plastic tubes are commonly used for this purpose. When pumps are used, the pump discharge hose may be used to satisfy this requirement, in which case a hopper will not be needed.

Concrete should be placed in successive lifts and in a manner that the horizontal level of the concrete rises at a uniform rate over the entire area being placed. The lifts should be limited to those stated in the forming system design for walls and columns. The pressure exerted against the side form is directly related to the height of the plastic concrete in the form. If the placement rate is greater than assumed in the form design, the resulting higher pressure may produce excessive deflection or failure. To achieve uniform consolidation between lifts, the Contractor should penetrate vibrators into the previously placed lift. In any case, no more concrete should be deposited into the forms than can be vibrated conveniently and effectively. Be aware that, because vibration

makes concrete more fluid, form pressures are greater in areas being vibrated. An otherwise stable pour could experience form failure while undergoing vibration.

Contractors typically pour an extra 1 to 2 inches of concrete on top of the theoretical top of column elevation. This additional height provides a solid vertical surface for the bent cap soffit forms to butt against, providing a good seal and hiding the construction joint above the plane of the soffit. It also acts as a concrete spacer for the bent cap bar reinforcement, helping to achieve the required cover. However, a column poured too high may result in bar reinforcement placed too high, potentially leading to additional issues such as reduced bar reinforcement clearance at the top. If project plans require polystyrene placed at the top of column, the top of concrete pour elevation must account for this polystyrene.

6-2.04 Drop Bent Caps

Bent caps are the topmost portion of a bridge bent. For bridges with steel or precast concrete girders, the end or ends of the bridge girders are seated on the bent caps. This type of bent cap is known as a drop bent cap. Figure 6-4 is an elevation view for a detail of a two-column bent with a drop bent cap for a precast girder bridge.

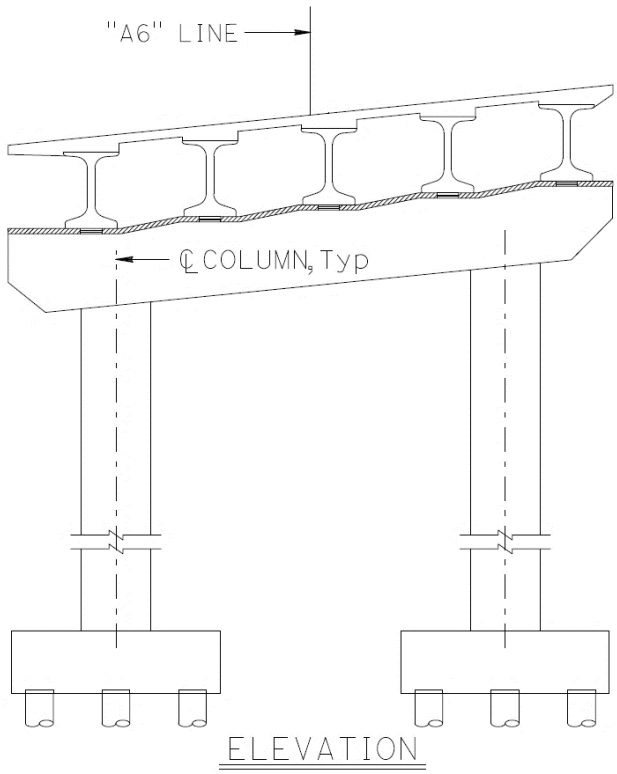

Figure 6-4. Two-Column Bent with a Drop Bent Cap

The construction sequence for a drop bent cap will occasionally require a column and bent cap to be cast in the same pour. In such cases, it is essential to delay the placing of the cap concrete until the column concrete has started setting. This allows the settlement and shrinkage of the column concrete to occur before the cap concrete is placed, thus substantially reducing shrinkage stresses at the joint between the column and cap.

6-3 Superstructure

The superstructure is the component of the bridge that supports the bridge deck loads, as well as other loads, and transfers them onto the substructure. The bridge deck, girder stems (or stems), and soffit (or bottom slab) are the primary elements of the superstructure for CIP concrete box girder bridges. Although the design of bridges considers bent caps as substructure elements, the concrete placement of bent caps for CIP concrete box girder bridges is integrally tied to the concrete placement of the superstructure.

The bridge deck provides the traveling surface for vehicles, pedestrians, and cyclists. It carries the traffic loads and distributes them to the girder stems and other portions of the superstructure. *Contract Specifications*, Section 51-1.03D, *Concrete Structures – General – Construction –Placing Concrete,* requires that the deck comprise a final and separate pour from other elements of the girder span. This prevents incorporating construction stresses into the deck due to shrinkage and falsework settlement, which can cause deck cracks. Chapter 7, *Bridge Deck Construction*, discusses bridge deck construction in detail.

6-3.01 Integral Bent Caps

The ends of concrete girder stems and soffit for CIP concrete bridges are embedded into the bent caps. For this reason, this type of bent cap is known as an integral bent cap, and its concrete placement is performed in the same concrete placing operation as the girder stems and soffit. Figure 6-5 is an elevation view for a detail of a two-column bent with an integral bent cap for a CIP box girder bridge, and Figure 6-6 shows bar reinforcement installation of an integral bent cap.

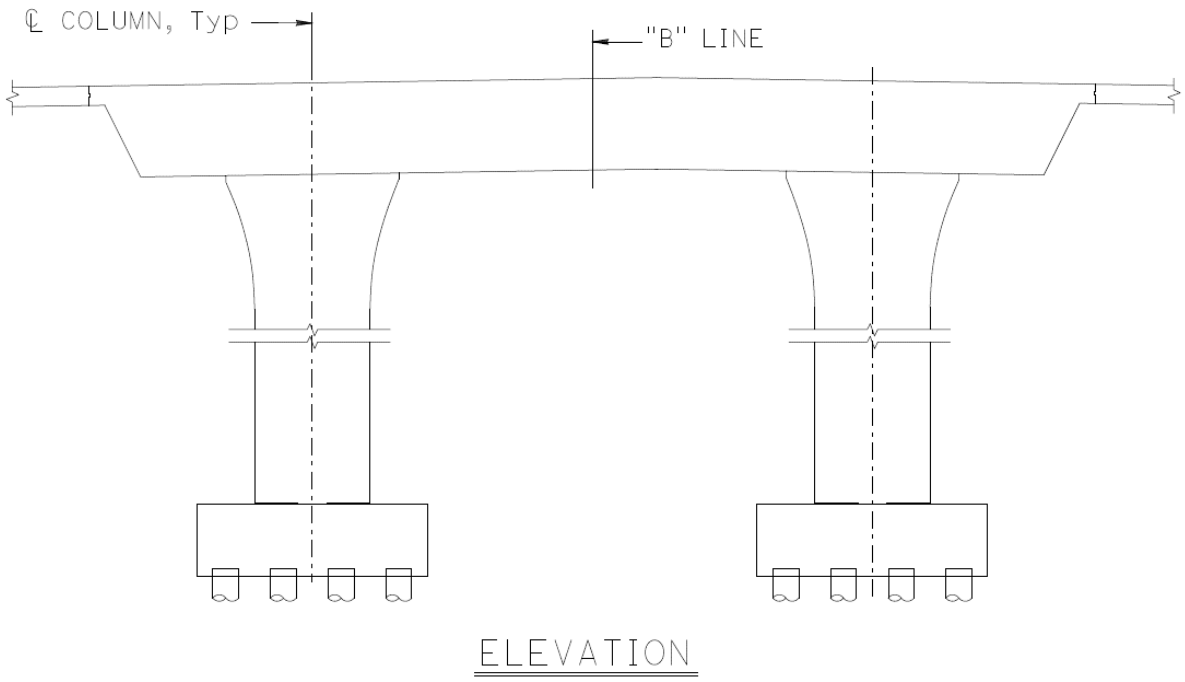

Figure 6-5. Two-Column Bent with an Integral Bent Cap

Figure 6-6. Bent Cap Bar Reinforcement Installation with Blockouts

The project plans may show openings through bent caps and other portions of the bridge to accommodate bridge access, utilities, and drainage. During reinforcement installation, confirm that the Contractor installs appropriate formwork or blockouts so that openings will be in place after the bent cap is cast. A blockout for a bent cap opening has been installed within the reinforcement, as shown in Figure 6-6.

Concrete placement for integral bent caps is comparable to placement for columns and similar elements, in that concrete should be placed in lifts at a uniform rate. The space inside the formwork tends to be congested due to the amount of reinforcement and the possible installation of prestressing ducts and deck drainage system or other utilities. Check that concrete fills all voids and is well consolidated during concrete placement.

6-3.02 Stem and Soffit

In conventional CIP concrete box girder bridge construction, the concrete for the soffit is placed with the concrete for the girder stems (and bent cap) in one concrete placement operation. Although there is no specified construction sequence, when the soffit and girder stems are placed in a single operation, most contractors place soffit concrete first and follow with the girder stems. For this placing sequence, the Contractor must decide how far ahead the soffit concrete should be placed before placing concrete in the stems. Several factors influence this decision, including the length and width of the superstructure, the expected rate of concrete placement, and probably most importantly, the size and experience of the construction crew. Ideally, the soffit concrete should be allowed to set until it is stiff enough to retain concrete placed in the stem, but not so long that it cannot be reworked.

From a construction standpoint, there is no harm if stem concrete is placed before the soffit begins to stiffen, except that additional work will be required in placing the concrete. However, if too much time elapses, a cold joint may occur between the fresh girder stem concrete and the older concrete in the soffit. This would reduce the bond at the cold joint interface. The major drawback to placing the soffit first is the need for additional finishing after the stems are poured. In the typical operation, the soffit will have been struck off and initial hand floating completed before concrete is placed in the adjacent girder stems. Vibrating the girder stems will force some concrete out of the stem below the bottom of the stem form, which will require additional cleanup and floating of the soffit.

Placing the girder stem concrete first may be advantageous because this reduces the soffit finishing effort, but this savings may be illusory when all factors are considered. When the girder stems are placed first, the vibrating of the soffit slab adjacent to the stem tends to draw concrete from the lower part of the stem into the soffit slab area. This creates voids around the longitudinal reinforcing at the bottom of the stem and, for CIP prestressed construction, below the prestressing ducts near mid-span. Unless the

stem concrete is thoroughly re-vibrated after the soffit concrete is placed and vibrated, rock pockets will likely result as illustrated in Figure 6-7.

Figure 6-7. Rock Pockets Below Prestressing Ducts

For long bridge frames, and for longer spans having relatively deep girders, the stem and soffit may be cast in separate segments by utilizing transverse construction joints. Authorize construction joint locations proposed by the Contractor that are not shown in the project plans per *Contract Specifications,* Section 51-1.03D(4), *Concrete Structures – General – Construction – Placing Concrete – Construction Joints.* Per *Contract Specifications*, Section 48-2.01C(2), *Temporary Structures – Falsework – General – Submittals – General,* proposed construction joint locations must be shown on the Contractor's falsework shop drawings (see Figure 6-8).

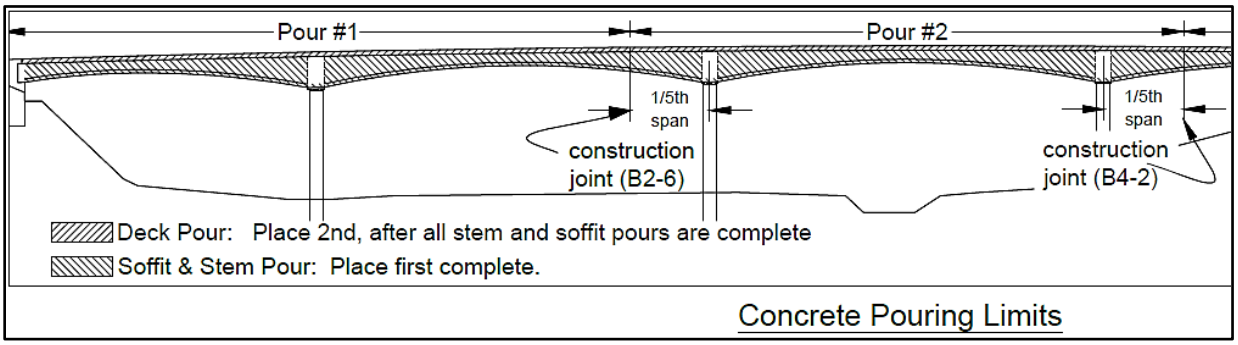

Figure 6-8. Stem and Soffit Construction Joints

Consult with the BD Project Engineer before authorizing proposed construction joint locations. Standard Plan B7-1, *Box Girder Details*, provides the details for construction joints. An example of a construction joint for a girder stem, constructed per the *Standard Plans*, is shown in Figure 6-9.

Figure 6-9. Girder Stem Construction Joint

Regardless of the placing sequence followed, as the soffit is cast, the top surface should be struck off to grade and hand-floated with a float. While the concrete sets, the Contractor should re-float the soffit as necessary to seal the surface. Girder stem concrete should be placed in lifts, and each lift must be thoroughly vibrated. To ensure the bond between successive lifts, the vibrator must penetrate through the fresh concrete and into the previously placed lift. As previously noted, if the first lift of the stems is placed prior to the soffit, the Contractor should thoroughly re-vibrate to the bottom of the stem after the soffit slab is poured to reduce the potential for voids and rock pockets near the bottom of the stem. Figure 6-10 shows a soffit and partially poured stem, as the stem is being placed in lifts.

Figure 6-10. Stem and Soffit Concrete Placement

The project plans oftentimes call for openings or items to be cast into the concrete. These may include the following:

1. Soffit access openings
2. Soffit vents
3. Utility openings
4. Ladder rungs

Make sure that these are addressed before the girder stem and soffit concrete placement. The project plans typically reference details in the *Standard Plans* for these items.

Since the bridge girder stems and bridge deck are not placed in one single operation, the construction joint between these two bridge elements is critical in making the box girder function as a monolithic structural member, as intended by its design. The horizontal shear capacity across the stem-to-deck joint increases significantly when the construction joint is intentionally roughened to a minimum amplitude of 1/4 inch, as required by *Contract Specifications*, Section 51-1.03D(4), *Concrete Structures – General – Construction – Placing Concrete – Construction Joints*. In theory, roughening the surface at the construction joint interface allows for the joint surfaces to ride up on

each other as they attempt to slip. This action places the reinforcing steel across the joint (stirrups) in tension and provides a strong clamping force. Design codes allow for significantly more horizontal shear capacity when the construction joint is intentionally roughened to a minimum of 1/4 inch amplitude. Figure 6-11 illustrates the type of roughening required for the top of girder stems.

Figure 6-11. Construction Joint 1/4 Inch Roughening

Roughening the top of the stems can be accomplished by many different methods. The intent is to obtain a rough concrete surface that is not floated or troweled and provides an uneven surface with a minimum of 1/4 inch amplitude across the entire top surface of the girder stem, partially exposing, but not loosening, the coarse aggregate.

During the roughening activity, the Contractor should avoid the following:

1. Excessively dislodging coarse aggregates when using the roughening tool.
2. Floating or trowelling the top surface of the stem. Doing so forces coarse aggregate into the paste and makes the surface smooth.
3. Excessively vibrating concrete, which causes the cement paste to rise and cover coarse aggregates and potentially making the surface smooth.

In addition to roughening the stem concrete, the Contractor is required to clean the surface of the construction joints by abrasive means before deck concrete placement. This helps to remove laitance, curing compound, loose concrete, and other deleterious materials.

6-3.03 Diaphragms

Diaphragms are superstructure elements constructed transverse to the bridge. Their primary purpose is to connect girder stems together and provide stability to the bridge, while also helping with load distribution. CIP concrete bridges may incorporate various types of diaphragms. End diaphragms are located at the ends of the bridge frames at the bridge supports. Abutment diaphragms are a type of end diaphragm that connects the bridge girder stems at abutment ends, while hinge diaphragms serve a similar purpose at hinge ends. Interior diaphragms are located at intermediate locations within the bridge span, adding additional stability and stiffness.

Concrete for diaphragms is typically placed in the same concrete placement operation as the girder stems, soffit, and bent caps. For this reason, construction practices for diaphragm concrete placement are similar to girder stems and bent caps. As with bent caps, abutment and hinge diaphragms may be congested with the inclusion of hardware and additional bar reinforcement for prestressing or hinge tie-downs. Ensure that the Contractor uniformly places concrete in lifts and adequately vibrates concrete, as discussed previously in this chapter.

6-4 Other Bridge Elements

Although the substructure and superstructure are essential components of CIP concrete bridges, other bridge elements serve their own purpose and should be considered just as important. Faulty construction of any of these elements could result in a poorly constructed bridge. This section addresses the construction of various miscellaneous bridge elements.

6-4.01 Barrier Rails

Barriers are an important safety feature of bridges and roadways. They help reduce the risk of vehicles driving off the traveled way or may act as a physical separation between opposing lanes. Barriers can also reduce the severity of accidents by absorbing some of the impact energy during collisions. Various types of concrete barriers may be used on projects. Factors such as structure type, regulatory speed limit, and aesthetics govern the type chosen. This section will mostly focus on the construction of CIP concrete barriers on bridges. Bridge Construction Memo (BCM) 83-3, *Railings and Barriers - Concrete Barriers* is another resource related to concrete barrier and rail construction.

The surface of the deck where the concrete barrier is to be constructed is considered a construction joint. The Contractor must prepare the surface as described in *Contract Specifications*, Section 51-1.03D(4), *Concrete Structures – General – Construction – Placing Concrete – Construction Joints.* To prevent damage to the coating of epoxy-coated bar reinforcement cast into the deck, non-abrasive means of cleaning the deck surface may be required where these type of bars are used for concrete barriers, as discussed in Chapter 4, *Reinforcement* and Chapter 5, *Concrete*.

After they release the falsework, contractors may begin concrete barrier construction. In addition to deck surface preparation, below is a list of items to verify before or during formwork installation:

1. Bar reinforcement is properly installed, including those that should have been previously cast into the deck. Be especially attentive to additional reinforcement details at special locations, such as electroliers, pedestals, pull boxes, end of walls or deck joints, as well as barriers that are to support sound walls.
2. Concrete dobies are not installed at the side of the barrier facing traffic.
3. Embedded items such as conduits, pull boxes, and electrical mounting hardware are acceptable materials and are placed correctly.
4. Blockouts or formwork for openings such as for Midwest guardrail connections, scuppers, expansion joints, wildlife passageways, and post pockets are properly located and sized.

Projects may include architectural features, such as surface textures or colored concrete, on concrete barriers. Chapter 3, *Forms*, and Chapter 5 discuss these items in more detail.

Contract Specifications, Section 83-3.03A(3), *Railings and Barriers – Concrete Barriers – Construction – General – Adjusting Barrier Height,* requires the Contractor to adjust the height of concrete barriers for newly constructed bridges if necessary. This is to provide a smooth, finished profile along the top of the barrier. Adjusting barrier heights compensates for possible irregularities to the deck profile of newly constructed bridges, such as camber and dead load deflection. Projects that involve bridge and roadway overlay may also require barrier height adjustments so that the minimum required barrier height will result after the roadway overlay. Concrete barriers constructed on asphalt concrete (AC) or existing pavement have similar height adjustment requirements.

Adjusting the height of CIP concrete barrier forms is the typical means for adjusting the barrier height. SC staff establishes how much the forms are to be adjusted. One practice is to give the Contractor fills, or the calculations to increase heights, for barrier forms. Below is a common method for determining fills:

1. At 10 feet intervals, place marks on the deck near the inside edge of where barrier forms will be placed. Discuss with the Contractor the best place to start making marks. They should be at a close and consistent distance from the forms, strategically located so that they will not be covered, and ideally coincident with the location of joints between adjacent form panels. Three feet offset from the edge of deck is generally adequate.
2. Survey the existing deck elevations at the placed marks.

3. Generate a profile of the surveyed deck elevations.
4. Generate a smooth, best-fit profile. The newly generated profile should be at or above the existing deck elevations.
5. Calculate the elevation differences between the new profile and deck at the marked points. These differences are the fills to provide the Contractor.

Contractors may use the stringline method to check the profile smoothness when placing barrier forms initially. This method is particularly effective where the planned deck profile does not include a vertical curve. It involves setting a taut string with the ends set equidistant from the top of forms and then measuring the distance between the string and form at intervals along the string. The measured distances should be nearly consistent throughout. This same method can be used for checking the alignment of barrier forms, with the string placed along the side; note that this applies to sections of the bridge which do not contain a horizontal curve.

After all the barrier forms are in place and the Contractor has made initial adjustments, verify the smoothness of the forms by eyeballing, or viewing, along the top edge of forms. Require the Contractor to adjust the forms as needed, to achieve the desired profile.

Figure 6-12 shows a contractor using a hopper and drop chute to help with the barrier concrete placement. During concrete placement, insert copper nails into the top surface at locations referenced in BCM C-13, *Permanent Reference Elevations.*

Figure 6-12. Concrete Barrier Pour

Unless otherwise stated in the *Contract Specifications*, CIP concrete barriers must be cured using the forms-in-place method. Applying curing compound after form removal is not required. The time for forms to stay in place varies and is dependent on the type of barrier. Most CIP concrete barriers forms must stay in place for a minimum of 12 hours, with the following exceptions:

1. Sound wall supporting concrete barriers are to be cured for the timeframe specified in *Contract Specifications*, Section 90-1.03B(5), *Concrete – General – Construction – Curing Concrete – Forms-In-Place Method*.
2. Type 80 (Figure 6-13) and 85 series barriers are to be cured for at least 36 hours.

Figure 6-13. Type 80 Series Barrier

After forms are removed, test the smoothness of the top and exposed faces of barriers using a 10-foot straightedge. Both surfaces should not vary more than 0.02 feet from the straightedge. Obtain and record the elevations of permanent elevation reference points on the as-built plans. Additionally, install expansion joint scribes at each deck joint per Attachment 1, *Guidance for Verifying Contract Compliance for Sealed Joints*, of BCM 51-2, as shown in Figure 6-14. If required, the Contractor must paint the bridge name, number, and other bridge identification information at locations identified in the project plans. These locations are usually at the approach side of the structure and near the paving notch, if applicable. Text must be colored black and 2-1/2 inches high. Modify the text size and paint color if the text is not clearly visible to approaching traffic.

Figure 6-14. Expansion Joint Scribe

6-4.02 Structure Approach Slabs

Structure approach slabs, or approach slabs, are reinforced concrete slabs that connect the roadway pavement to the bridge deck. Over time, roadways may settle while bridge abutments experience little to no settlement. This is known as differential settlement. Approach slabs serve as a transition for vehicles between the two in case of differential settlement. Concrete placement of a structure approach slab is shown in Figure 6-15.

Figure 6-15. Approach Slab Concrete Placement

As suggested in Chapter 2, review the structure and roadway sections of the project plans, specifically the roadway profile and section, deck contours, and adjacent top of retaining wall elevations, to verify that elevations agree and a smooth profile will result. Bridge decks are typically constructed before Type N approach slabs. Check the as-built profile of the bridge deck to verify that the future approach slabs will provide an acceptable transition. Typically, profiling the last 100 feet of the bridge deck is sufficient to make any adjustments between the as-built deck profile, the new approach slab, and the new roadway profile. If any grade discrepancies are found before or during construction, collaborate with the Bridge Design (BD) and District Project Engineers, Resident Engineer, and the Contractor to develop a solution. Changing the bridge profile may not be possible due to minimum vertical clearance requirements or if bridge elements have already been constructed, such as the permanent installation of precast girders. In these cases, adjusting the roadway profile from the planned location may be the best solution, since the roadway is typically constructed after the bridge. Performing these checks early on can save potential rework, costs, and delays.

There are two standard approach slab designs that the Department commonly uses, found in the *Standard Plans*:

1. **Type N (30)** – typically for construction of new approach slabs (Standard Plan B9-1, *Structure Approach – Type N (30)*)
2. **Type R (30)** – typically for replacement or rehabilitation of existing approach slabs (Standard Plan B9-2, *Structure Approach – Type R (30)*).

The minimum length of the above standard approach slabs is typically 30 feet, However, their shapes can vary. The approach slab edge adjacent to the bridge is always parallel to the bridge skew. The orientation of the edge adjacent to the roadway, on the other hand, may not match the bridge skew. In some cases, this edge may be staggered. Its configuration depends on the bridge skew angle and the type of roadway pavement material it abuts, whether Hot Mix Asphalt (HMA) or Portland Cement Concrete (PCC). Figure 6-16 and 6-17 display approach slabs with roadway edges at different configurations. Verify the steel bar reinforcement will fit the actual required shape of the approach slabs.

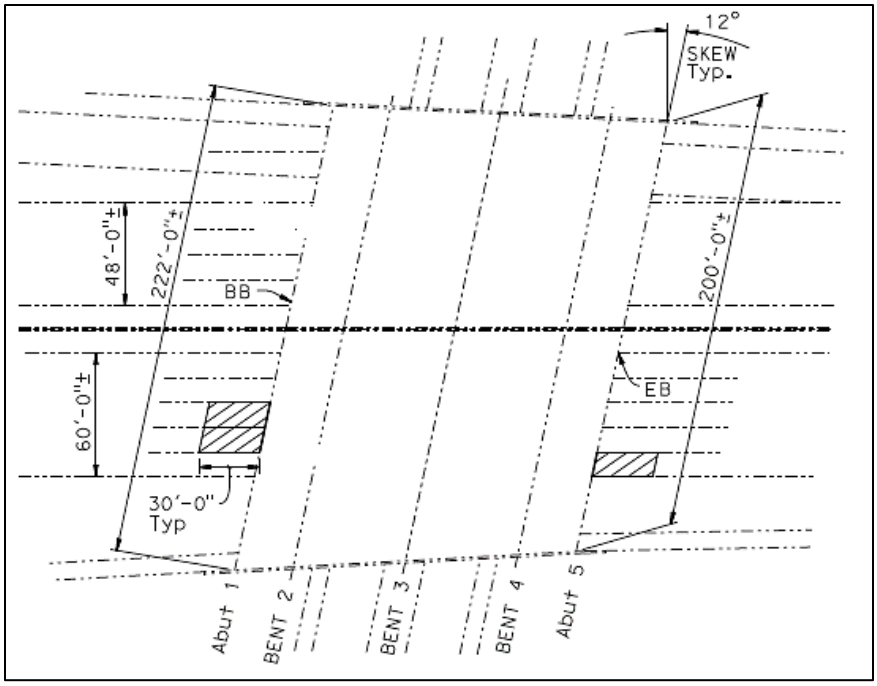

Figure 6-16. Approach Slabs with Roadway Edges Parallel to Skew

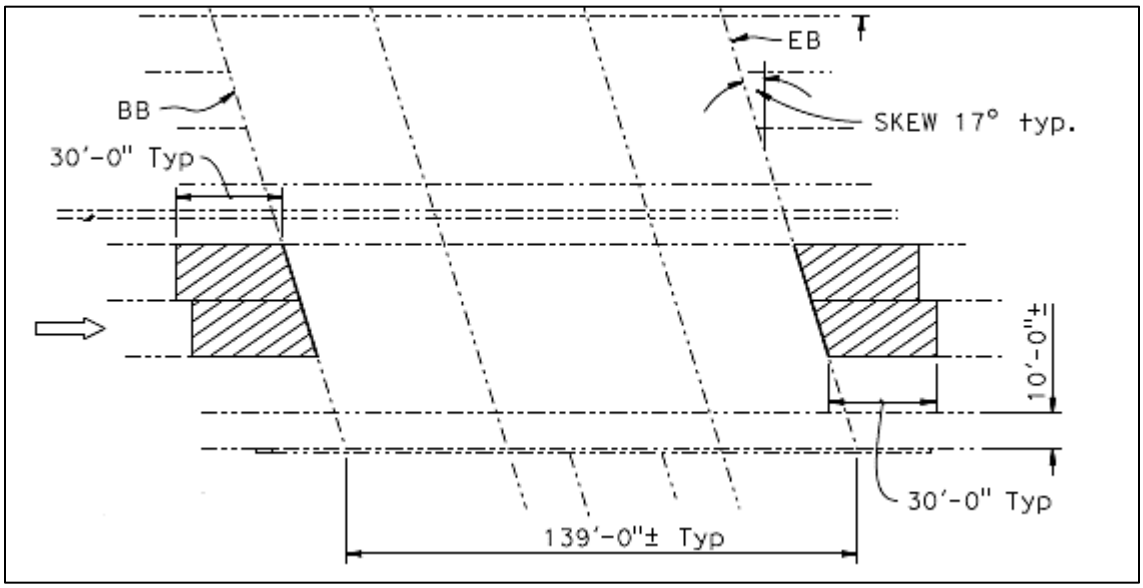

Figure 6-17. Approach Slabs with Staggered Roadway Edges

One key difference between Type N and Type R approach slabs is that Type N slabs include the placement of a 6-inch treated permeable base (TPB) with slotted pipe drains. The time afforded for Type N approach slab construction allows its design to incorporate a drainage system. Verify that filter fabric is installed per both the manufacturer's instructions and *Contract Specifications*, Section 51-5.03B(2), *Concrete*

Structures – Approach Slabs – Construction – Type N Approach Slabs – Filter Fabric, and the TPB is uniformly mixed and properly compacted, as shown in Figure 6-18. *Contract Specifications*, Section 51-5.03B(3), *Concrete Structures – Approach Slabs – Construction – Type N Approach Slabs – Treated Permeable Base*, provides direction for compacting TPB. Observe the consistency of cement treated permeable base (CTPB) during placement. Cement paste from CTPB must not plug the drain openings.

Figure 6-18. Cement Treated Permeable Base for Approach Slab

The Contractor has the option to cast approach slabs with either structural concrete or rapid strength concrete (RSC). The choice is usually dependent on whether construction staging is needed or when the approach slab needs to be open to traffic. Type N approach slabs are usually constructed at locations isolated from traffic, such as for newly constructed bridges or behind temporary railing. In these instances, the time for the approach slab to set and cure is not critical, so contractors usually elect to use structural concrete.

For all types of approach slabs, the Contractor must accommodate the type of joint seal to be installed, including blockout installation, if a joint seal assembly is called for. If the joint seal requires sawcutting grooves, make sure that approach slab rebar is not placed too close to the joint. Otherwise, rebar may encroach into intended clear cover. Additionally, confirm the installation of miscellaneous items, as they can be easily overlooked. These items include paving notches, waterstops, diaphragm abutment ties, edge angles, snowplow deflectors and barrier guards, as well as provisions for

longitudinal construction joints of adjacent slabs. These items may need to be installed before, or with, the approach slab concrete placement.

The roadway surfaces of all bridge approach slabs have the same smoothness criteria and coefficient of friction requirements as bridge decks. Refer to Chapter 7 of this manual for guidance. The Begin Bridge (BB) and End Bridge (EB) are locations on approach slabs that typically require grinding. This should be considered when setting top of slab grades and installing rebar.

Chapter 7: Bridge Deck Construction

Table of Contents

Chapter 7: Bridge Deck Construction 1
Table of Contents 1
7-1 Introduction 3
7-2 Bridge Deck Preconstruction Planning 3
7-2.01 Construction Details 3
7-2.02 Deck Placement Work Plan and Preconstruction Meeting 4
7-3 Bridge Deck Forms 11
7-3.01 Types of Form Details 11
7-3.02 Structural Adequacy and Deflection 19
7-4 Bridge Deck Formwork Construction 19
7-4.01 Form Alignment 19
7-4.02 Formwork and Bridge Deck Elevation 20
7-4.03 Deck Grade Control Considerations 28
7-4.04 Bridge Deck and Overhang Form Workmanship 32
7-5 Bridge Deck Reinforcement 33
7-5.01 Standard Plans 33
7-5.02 Detailing and Fabrication 34
7-5.03 Bar Reinforcement Installation 34
7-6 Pre-Pour Construction Activities 37
7-6.01 Screed Rails 37
7-6.02 Deck Construction Joints and Bulkheads 39
7-6.03 Paving Notches and Expansion Joints 40
7-6.04 Bridge Deck Finishing Machines 41
7-7 Bridge Deck Concrete 47
7-8 Deck Concrete Placement 47
7-8.01 Concrete Delivery 48
7-8.02 Conveyance and Placement 50

7-8.03 Consolidation 51
7-8.04 Bridge Deck Pour Inspection 52
7-9 Finishing Roadway Surfaces 54
7-10 Curing Bridge Decks 58
7-11 Testing Roadway Surfaces 60
7-11.01 Surface Smoothness 60
7-11.02 Coefficient of Friction 64
7-11.03 Crack Intensity 65
7-12 Pedestrian Overcrossings 66

7-1 Introduction

This chapter updates and replaces Structure Construction's (SC) *Bridge Deck Construction Manual*, first published in 1991 and updated in 2015.

Bridge decks are often considered the most critical element of a bridge. They are subject to complex loading and various environmental conditions. They must not only be structurally sound but also meet specific performance criteria to ensure a smooth and safe ride, especially for high-speed traffic, as they are the bridge element that most directly affects the traveling public. The service life and maintenance costs of a bridge are most closely linked to the quality of its deck. Attention to detail, combined with sound engineering and construction practices, will help achieve a bridge deck that provides exceptional drivability and increased durability throughout its lifespan.

Contract Specifications, Section 51-1.03D, *Concrete Structures – General – Construction – Placing Concrete,* requires that the deck be poured separately from the girder stems. This prevents construction stresses such as shrinkage and falsework settlements from being incorporated into the deck, which can lead to premature cracking and deterioration.

7-2 Bridge Deck Preconstruction Planning

Chapter 2, *Preconstruction Planning,* emphasizes the importance of planning and preparation for construction of reinforced concrete structures. The following subsections outline additional steps for preparing specifically for the construction of bridge decks. The subsequent sections of this chapter, along with the other chapters of this manual, provide further details on the items mentioned below.

7-2.01 Construction Details

Thoroughly and carefully review the contract documents and relevant submittals, paying particular attention to the following aspects related to bridge deck construction:

1. Skew, camber, strike-off devices, and screed rail (rails for the surface finishing machine) grade.
2. Horizontal curves, and any varying deck widths.
3. Super-elevation including any transitions.
4. Interaction between bent cap and bridge deck bar reinforcement (bent caps typically have large diameter bar reinforcement that are placed underneath the deck reinforcing, and poured together with the deck concrete).
5. Openings through deck and clearance around bent cap steel.
6. Hinges, prestressing hardware, and their relationship with deck grades.

7. Deck grading for steel girder bridges.
8. Precast prestressed (PC PS) concrete girders and slabs, particularly deck grades and thickness adjustments for uneven cambers and cross slopes.
9. Variable span lengths and non-parallel abutments or bents.
10. Stem and diaphragm stirrup hook placement and resulting effect on placement of deck bar reinforcement.
11. Longitudinal and transverse construction joints.
12. Paving notch details.
13. Sidewalk and barrier rail bar reinforcement layout and height, including the effects of superelevation (cross slope) and planned deck overlays.
14. Lane line locations relative to required longitudinal construction joints and planned closure pours.
15. Utilities, drains, etc.
16. Block-outs in the deck for prestress duct vents
17. Traffic impact bars hooked into the abutment diaphragms.
18. Deck reinforcement clearance at locations likely to require a profile grind, including across joints, hinges, and planned transverse construction joints.
19. Additional deck thickness if grinding and grooving is Contractor's selected means and method for meeting friction and sound requirements.

7-2.02 Deck Placement Work Plan and Preconstruction Meeting

Because the deck is the final element in the bridge superstructure to be constructed, deck construction must be coordinated with - depending on the bridge type - the construction of the stem and soffit or the fabrication and erection of the PC/PS concrete girders and slabs. SC staff must thoroughly understand the Contractor's proposed bridge deck construction methods and confirm they comply with the contract requirements. Review and authorize the Contractor's deck placement work plan per *Contract Specification*s, Section 51-1.01C(1), *Concrete Structures – General – Submittals – General,* and Chapter 2, *Preconstruction Planning*.

Schedule a deck placement preconstruction meeting with the Contractor before scheduled deck pours. In addition to discussing structural concrete QC per *Contract Specifications*, Section 90-1.01D(9), *Concrete – General – Quality Assurance – Preconstruction Meeting for Cast-In-Place Structural Concrete Members*, this meeting offers an opportunity to identify and address any potential issues that may have been overlooked or ones that may have developed since the deck placement work plan was authorized.

While the specifications do not explicitly list the required items for the deck placement work plan, the following subsections highlight key considerations to review when assessing the plan. These points should also be addressed during the bridge deck placement preconstruction meeting. Detailed guidance on these topics can be found throughout this manual, with specific references to bridge deck construction in subsequent sections of this chapter.

7-2.02A Sequence and Limit of Placement

Address the following questions as they pertain to the deck pour sequence and placement:

1. Are specific concrete placement sequences outlined in the contract documents or in the authorized falsework shop drawing?
2. How will the Contractor manage screed rail grades on projects with challenges such as varying deck widths, multiple pours, and screed rail supports buried on girder stems, etc.?
3. Will the Contractor need to place any longitudinal or transverse construction joints not indicated in the project plans? (Standard Plan B0-5, *Bridge Details.*)
4. Are longitudinal construction joints located at or near a lane line?
5. Is stage construction required or being proposed by the Contractor?
6. Are there any time-dependent hinge behaviors that need to be addressed?
7. What quantity of concrete is required for the pour(s)?
8. Will placement interfere with public traffic, existing power lines, or other obstructions?
9. What direction is the pour(s)?
10. Are closure pours planned? If so, how will they be formed, poured, and stripped and have the related bar reinforcement details been addressed?
11. When is falsework release scheduled, and does this timeline comply with the contract requirements?

7-2.02B Location of Screed Rails and Construction Joints

The proper placement of screed rails and construction joints is critical. Address the following details:

1. Potential locations of rail supports for the bridge deck finishing machine:
    a. At the edge of deck.
    b. At longitudinal construction joints.
    c. At exterior or intermediate girder locations (it is best practice to locate screed rail supports at the bridge girder).

2. Details for longitudinal construction joints – Refer to Standard Plan B0-5, *Bridge Details*.
3. Evaluation of screed rail support system – Assess the deflection, rotation, and overall stability of the system.
4. Adjusting and checking screed rail elevations – Understand the methods required to achieve correct screed rail elevations which will produce the desired deck elevations, deck thickness, and smooth profile.
5. Grade control at construction joints – Understand the methods necessary to maintain proper grade at longitudinal and transverse construction joints.
6. Stability of bulkheads for construction joints – Discuss the measures to ensure the stability of bulkheads during construction.

7-2.02C Concrete Conveyance, Placement Method, and Rate

Discuss the following regarding the length and timing of haul from batch plant to delivery point, and from delivery point to final placement:

1. Can the concrete be delivered at a consistent, uniform rate (i.e., time between each concrete truck delivery)?
2. Will the delivery, placement, and finishing of concrete pose any safety hazards to the public?
3. What method will be used to place the concrete on the deck after delivery (e.g., pump, tailgate, bucket and crane, slick line, etc.)?
4. Does the placement method require additional support considerations for the formwork or bar reinforcement?
5. What is the anticipated rate of placement? Is this rate consistent with the delivery rate, and how will it impact the surface finishing process?
6. How will the concrete be properly consolidated after placement? How many vibrator crew members are required to accomplish proper consolidation?
7. What slump and range is specified for the concrete mix? How will the slump affect the placement method (e.g., pumping) or the finishing machine's ability to properly finish the concrete? (Refer to *Contract Specifications*, Sections 90-1.02A, *Concrete – General – Materials – General,* and 90-1.02G(6), *Concrete – General – Materials – Mixing and Transporting Concrete – Quantity of Water and Penetration or Slump)*
8. Could the conveyance and placement be interrupted for any reason (e.g., moving the pump truck, crane, or finishing equipment)? What provisions are in place to keep the concrete fresh during interruptions?
9. Will the placement method cause segregation or result in a non-uniform or uneven pour front?

10. What measures are in place to comply with *Contract Specifications*, Section 13-9, *Water Pollution Control – Temporary Concrete Washouts*? Ensure the Contractor provides the required concrete washout submittal within the required timeframe.
11. For decks requiring pumping from multiple locations, will pumps be in place ahead of the hand-off, or will placement need to stop while pumps relocate? Are these transitions supported by the truck spacing/timing?

7-2.02D Finishing Roadway Surfaces

Consider the following roadway finishing topics:

1. The Contractor is responsible for the finishing process, as outlined in the following *Contract Specifications*:
   a. Section 51-1.03F(5), *Concrete Structures – General – Construction – Finishing Concrete – Finishing Roadway Surfaces*
   b. Section 51-1.03F(6), *Concrete Structures – General – Construction – Finishing Concrete – Finishing Pedestrian Overcrossing Surfaces.*
2. Deck Surface Acceptance Criteria – The resulting bridge deck surface must meet several criteria:
   a. Longitudinal Texture – Provided using acceptable tining or grooving methods.
   b. Smoothness and Rideability – Assessed using a profilograph.
   c. Friction – Coefficient of friction verified via skid testing.
   d. Surface Crack Intensity – Number and size of cracks within a defined area must not exceed specified limits.
3. SC Staff's Responsibility – SC staff is responsible for establishing elevation control points.
4. Special Finishing Considerations – The following factors require special attention during finishing:
   a. Lightweight Concrete – Its tendency to be more porous than typical concrete can lead to an uneven finish.
   b. Adverse Weather Conditions – Pouring during inclement weather, including heat, wind, cold, rain, etc., can negatively impact the quality of surface finish.
   c. Deck Overlays – Techniques for achieving required finish may be different than for typical concrete deck pours.
   d. Shrinkage Reducing Admixtures and Polymer Fibers – Consider their potential effects on the concrete properties. Concrete workability may be affected if not mixed properly.
   e. Superelevation and its effect on concrete placement, allowable slump, and impact to curing operations.

7-2.02E Finishing Crew and Operators

The Contractor determines the size and classification of the crew. Staffing for a concrete bridge deck pour is an important topic to discuss with the Contractor, as it directly impacts both the time required to complete the deck pour and the overall quality of the work.

While the degree of mechanization and the skills of individual laborers may vary from project to project, Table 7-1 provides a suggested average crew size for a typical 2-lane bridge deck. Labor type may be interchangeable:

Table 7-1. Finishing Crew and Operators

Number of Positions	Duties
1	Foreman who oversees the concrete pour
2	Laborers to rake ahead of the deck finishing machine
1	Operator of the deck finishing machine
2	Finishers for edging
1	Broom and cure laborer
2	Crew members operating vibrators
1	Bridge carpenter to monitor the falsework on slab bridge pours and overhang supports for large and heavy overhangs
1	Laborer tending concrete truck

7-2.02F Special Equipment and Material

Discuss the potential need for special or additional equipment and material for bridge deck concrete pours:

1. Cooling of Concrete in Hot Weather Conditions (*Contract Specifications*, Section 90-1.02G(2), *Concrete – General – Materials – Mixing and Transporting Concrete – Machine Mixing)*:
    a. Use of an ice machine at the plant or chilled water.
    b. Employ fogging systems or sprinklers over the coarse aggregate stockpiles.
    c. Provide shade cover over the aggregate stockpiles.
    d. Ensure a cool water supply at deck pour.
    e. Fogging rebar and forms with cool water ahead of placement. Be cautious of over-watering, to avoid runoff which pools at falsework supports or causes erosion and storm water discharges.

2. Critical Back-Up Equipment and Machinery – Good practice is to provide the availability of backup machinery and essential spare parts, including pumps, light plants, generators, vibrators, etc., to minimize operational disruptions.
3. Heating and Protecting Concrete in Cold Weather:
    a. Heated water for mixing.
    b. Heating coarse aggregate as needed.
    c. Cover aggregate stockpiles with black polyethylene sheeting (Visqueen).
    d. Protect completed deck as required to maintain temperature requirements, as specified in *Contract Specifications,* Section 51-1.03I, *Concrete Structures – General – Construction – Protecting Concrete Structures*. (Based on SC experience, deck curing temperatures have been kept over 60° F, even in freezing conditions, by using Burlene or carpets on the deck, followed by black polyethylene sheeting, followed by additional carpets.)
4. Rain Precautions – The Contractor should avoid scheduling concrete deck placements during anticipated inclement weather. If there is a chance of rain, they must take precautionary measures and ensure necessary materials are readily available at the site, such as:
    a. Polyethylene sheeting (Visqueen) for covering.
    b. A method of placing and removing polyethylene sheeting efficiently.
    c. A plan to remove excess water from the low side of deck.
    d. Provisions for building a bulkhead (usually metal or wooden) with additional bar reinforcement, if required by SC staff, for an emergency construction joint.

7-2.02G Curing Equipment

Address the following considerations regarding curing methods:

1. Water Supply at the Site – Verify an adequate water supply is available to the Contractor.
2. Sufficient Supply and Pressure – The system must provide enough water pressure to produce a fog mist for curing.
3. Atomizing (Fog) Nozzle – The nozzle must be adequate to evenly distribute water as a mist.
4. Water Quality – The water used for curing and in deck construction must meet the requirements of *Contract Specifications*, Section 90-1.02D, *Concrete – General – Materials – Water*.
5. Curing Blankets – Adequate supply of Burlene or other cure blankets for the deck area must be provided.

6. Identification of Curing Compounds – Different types of curing compounds must be kept separate and clearly identifiable to avoid confusion during application. Shelf life of curing compound.
7. Securing Curing Blankets – Measures must be taken to prevent curing blankets from being displaced by strong winds. In addition to the weight of any cure water, contractors should consider using additional methods, such as placing 2-inch nominal lumber along the edges of the blankets at edges.
8. Curing Water Application – Determine whether water will be applied continuously or if blankets or carpets will be watered on a regular schedule during the initial 7-day water cure.
9. Application of Curing Compound After Initial 7-day Water Cure (*Contract Specifications*, Section 90-1.03B(3), *Concrete – General – Construction – Curing Concrete – Curing Compound Method*):
    a. The Contractor must demonstrate the adequacy of the curing compound application system before applying. The method must employ the use of power-operated spraying equipment with an operational pressure gauge.
    b. The use of conventional hand pump garden sprayers, including Hudson-type spray cans, is **not permitted** for applying deck curing compound.
10. Curing Compound Hose Lines – Check that there are no leaks in the curing compound hose lines.
11. Are staff scheduled to monitor ongoing curing operations which span across non-working days and weekends?

7-2.02H Construction Conditions and Safety

Address the following construction conditions and safety precautions:

1. Fall Protection – Ensure proper installation of rails and toeboards at the edge of the deck and any elevated temporary work platforms in accordance with Cal/OSHA Construction Safety Orders (CSO) §1620, *Design and Construction of Railings* & §1621, *Railings and Toeboards*. If installation of railings poses a safety risk, use of controlled access zones per CSO §1671.2, *Controlled Access Zones and Safety Monitoring Systems* may be considered.
2. Avoid Equipment Interference with Overhead Lines – Do not allow the placement or operation of equipment that will interfere with overhead power or utility lines. Advanced planning is required, and depending on proximity and line voltage, the utility owner may provide a spotter to monitor concrete placement near power lines.
3. Impact of Concrete Delivery on the Public – Assess whether the delivery of concrete will adversely affect the public or if there is a risk of interruptions to the placement process.

4. Bridge Deck Finishing Machine Placement – Ensure that the location of the bridge deck finishing machine does not interfere with the handrails. Handrails should remain intact throughout the process. Sufficient runoff length should be provided to ensure the finishing equipment can be run beyond the pour limits.
5. Walkways for Foot Traffic – Check that walkways designated for foot traffic are not less than 20 inches wide, as specified in Cal/OSHA CSO, § 1624, *Runways For Foot Traffic*.
6. Eye-Wash Stations – Verify that eye-wash stations are properly placed and spaced in accordance with Cal/OSHA General Industry Safety Orders (GISO) § 5162, *Emergency Eyewash and Shower Equipment*.
7. Nightwork – Sufficient lighting should be setup before shift and proper reflective PPE worn by all persons on site.

7-3 Bridge Deck Forms

Constructing a bridge deck that is structurally sound and durable requires thorough planning and preparation, beginning with the construction of the formwork for bridge decks. While Chapter 3, *Forms*, provides a general overview of formwork construction and inspection, the following section focuses on formwork specifics for bridge deck construction.

7-3.01 Types of Form Details

The bridge superstructure dictates the Contractor's method for supporting the cast-in-place (CIP) concrete deck forms. The forming systems typically fall into two categories:

1. Stay-in-place forms
2. Exposed surface forms.

7-3.01A Stay-In-Place Forms

Stay-in-place forms are concrete forming systems that usually are not required to be removed, or stripped, after the concrete structure has been poured unless specified otherwise. Rather, these forms can be left permanently in place.

The most common stay-in-place forming system is the lost deck form system. It is used to construct the deck of cast-in-place (CIP) box girder bridges, usually for the interior portion of the deck above the bridge cells. Formwork used inside the bridge cells will typically remain inside of the cell after the deck concrete is poured. There are various methods for lost deck design and construction. Figure 7-1 shows a general detail for lost deck that is commonly used by contractors, and Figure 7-2 and 7-3 are construction photos illustrating that lost deck form detail.

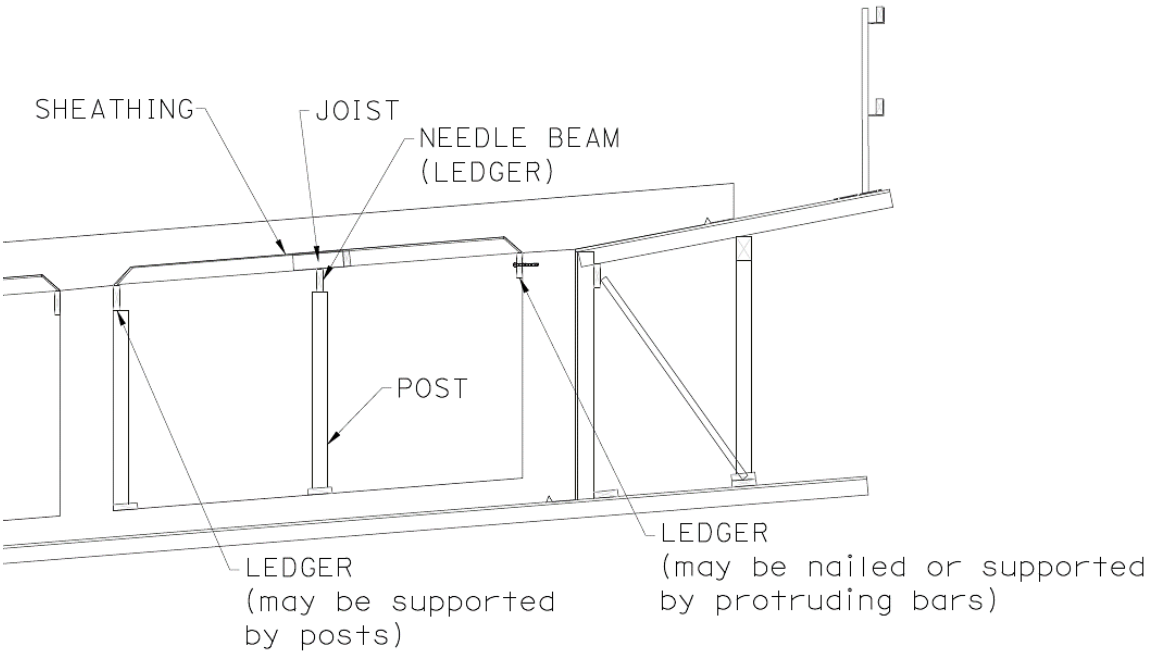

Figure 7-1. Lost Deck Detail

Figure 7-2. Ledger Support for Lost Deck Forms

Figure 7-3. Typical Deck Sheathing and Supports on a CIP Box Girder Bridge

For typical CIP bridge structures, the lost deck forms that support the bridge deck concrete are usually comprised of the following:

1. Sheathing – Forming material in direct contact with concrete.
2. Joists – Horizontal members that distribute loads from sheathing.
3. Ledgers – Support for a set of joists, typically at their ends and sometimes intermediate points (the latter may also be called a “stringer”).
4. Needle beams – Midspan support line that serves to reduce the span of the joists (may also be labeled as “ledger” in shop drawings).
5. Posts – Support for ledgers and other formwork pieces mentioned above.

Sheathing can be made of the following:

- Plywood, interior or exterior grade
- Oriented strand board (OSB)
- Other adequate board.

Sheathing must be mortar-tight with holes patched as required. The sheathing sits atop the joists which are generally 4-by-4-inch or 2-by-4-inch material. A useful note about OSB – although some experienced carpenters are unaware of it, the OSB has a “strong” direction; refer to the stamp on the sheathing and look for details and notes on

the lost deck portion of the authorized falsework plans, that may require a certain orientation.

Ledgers support the joists and are typically supported by posts or short dowel bars cast into, and protruding from, the girder stem. They may also be attached directly to the girder face using low velocity powder driven nails.

Although lost deck is typically intended to remain in place, there are situations when the forms and materials must be removed. For example, if utility facilities are to be installed within the bridge cells or if bridge cells will have permanent access, the deck forms within those forms must be removed. Refer to *Contract Specifications*, Section 51-1.03C(2)(b), *Concrete Structures – General – Construction – Preparation – Forms – Removing Forms,* for additional situations when removal is required, including guidelines as to what extent the forms must be removed.

For precast or steel girder bridges, stay-in-place deck forms are sometimes used in locations where:

- The removal of the forming would be difficult or disruptive to the public.
- The removal of forms would cause an unacceptable delay to the completion of the project, possibly adding a season to the work.
- Unacceptable environmental impacts would result, if forms were removed.

Stay-In-Place Precast Concrete Deck Panels (PDP) are a specific type of stay-in-place form system specified for projects with precast concrete girder superstructures. PDPs are partial-depth precast, pretensioned concrete deck panels that span between girders. The panels are designed for multiple purposes: first, to act as forms for the remainder of the deck concrete to be cast above, and as a composite deck structure when the CIP portion gains strength. Structure Technical Policy, STP 9.1, *Stay-in-Place Precast Prestressed Concrete Deck Panels for Precast Concrete Girder Superstructures* details the policy for the inclusion of PDPs on projects.

Permanent Steel Deck Forms (PSDF) are another stay-in-place form system that has been used to form bridge decks. This system may either be specified for a project, or its use proposed by contractors. Refer to Chapter 3 for further details regarding PSDF.

7-3.01B Exposed Surface Forms

Exposed surfaces are concrete surfaces that will be visible; thus, as mentioned in Section 3-3, *Forming System* of this manual, plywood must at least meet the requirements for U.S. Product Standard PS 1 for Exterior B-B (Concrete Form) Class I Plywood, as required per *Contract Specifications*, Section 51-1.03C(2)(a), *Concrete Structures – General – Construction – Preparation – Forms – General,* and Section

51-1.03F(2), *Concrete Structures – General – Construction – Finishing Concrete – Ordinary Surface Finish*. Additionally, the forms for these surfaces must be removed in accordance with *Contract Specifications*, Section 51-1.03C(2)(b), *Removing Forms*. Exposed surfaces of CIP bridges include:

1. Edge of the deck.
2. Soffits of concrete box girder and slab bridges.
3. Deck soffits for T-beam, steel girder, precast concrete girder bridges.
4. Deck overhangs (projection of the deck that overhangs the exterior girder) for all bridge types.

For slab bridges, the plywood soffit forms are directly attached to and supported by the falsework joists or stringers, making them an integral part of the falsework. Deck slab forms for T-beam bridges, steel and precast concrete girder bridges, and deck overhangs may be made of conventional joist and plywood construction. Figures 7-4, 7-5, and 7-6 are examples of a slab bridge, a steel girder bridge, and a T-beam bridge, respectively. These bridge types typically require their deck forms be removed, unless otherwise specified.

Figure 7-4. Example of a Slab Bridge (Mojave River Bridge, Br No. 54 0278L)

Figure 7-5. Example of a Steel Girder Bridge (Pfeiffer Canyon Bridge, Br No. 44 0298)

Figure 7-6. Example of a T-Beam Bridge (Newton Road UC, Br No. 04 0125)

Figure 7-7 shows a general detail for overhang formwork that may be used by contractors for CIP box girder bridges. Edge of deck forms, which set the placement limit for the deck concrete, are typically installed above the overhang posts. Overhang posts are supported on the falsework.

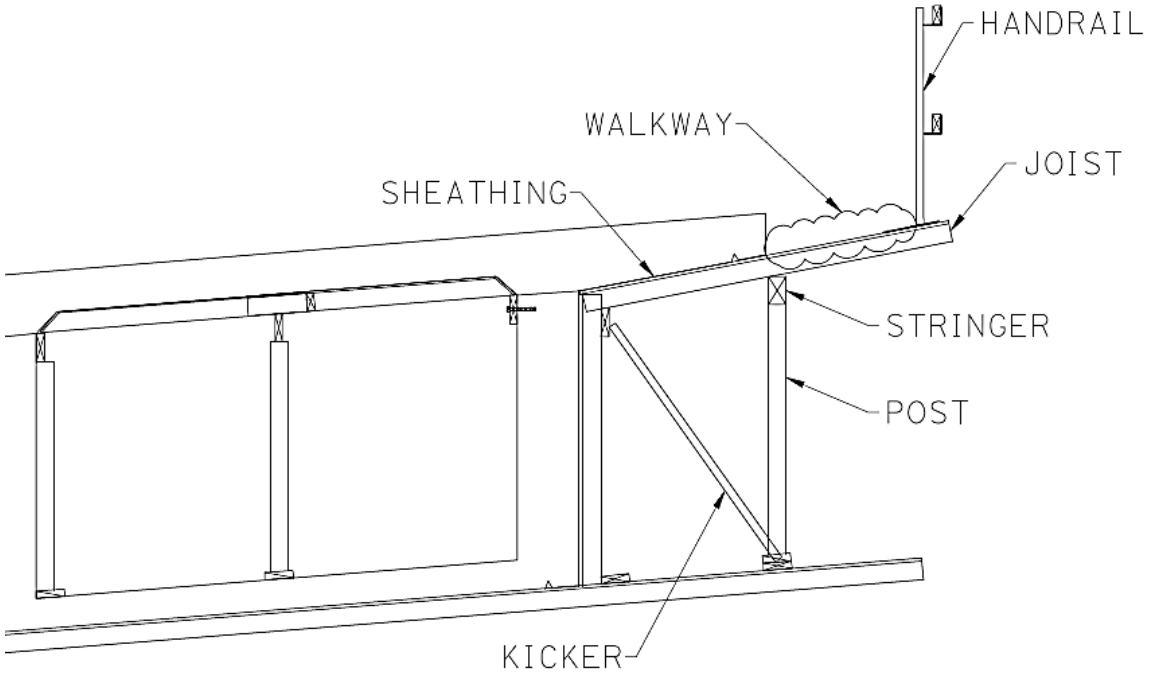

Figure 7-7. Overhang Formwork Detail

Construction of deck and deck overhangs on steel and precast concrete girder bridges, as well as reconstruction of deck overhangs on existing bridges, typically incorporate manufactured products like brackets to support the overhang formwork. Additionally, interior deck forms for steel and concrete girder bridges may utilize manufactured brackets. Figures 7-8 and 7-9 are details of deck formwork for a precast concrete girder bridge.

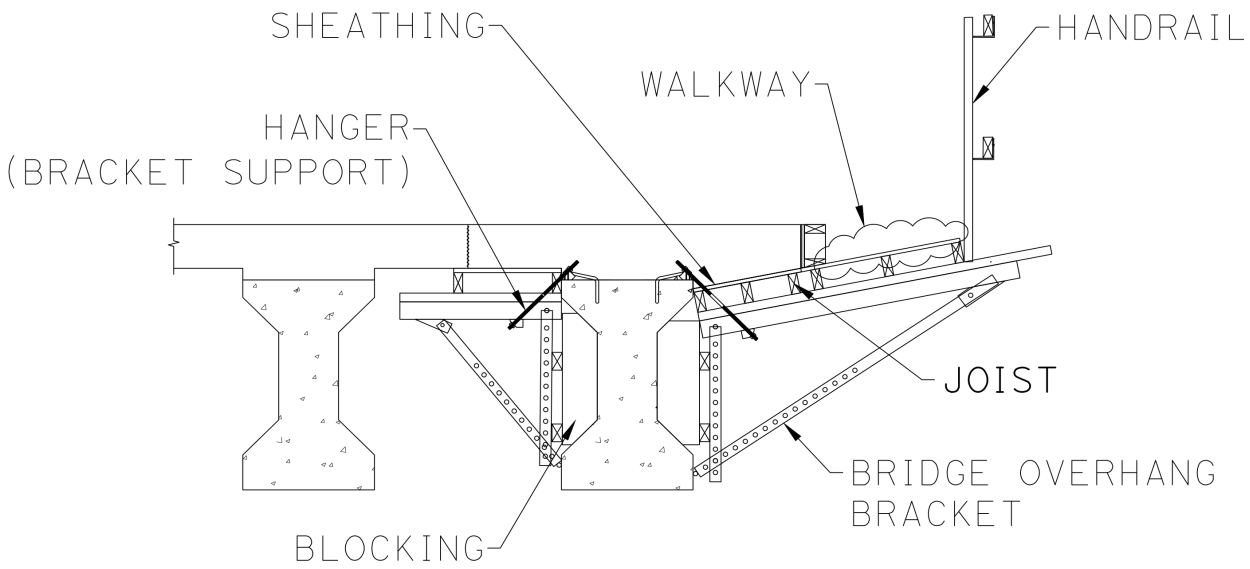

Figure 7-8. Precast Concrete Girder Overhang Formwork Detail

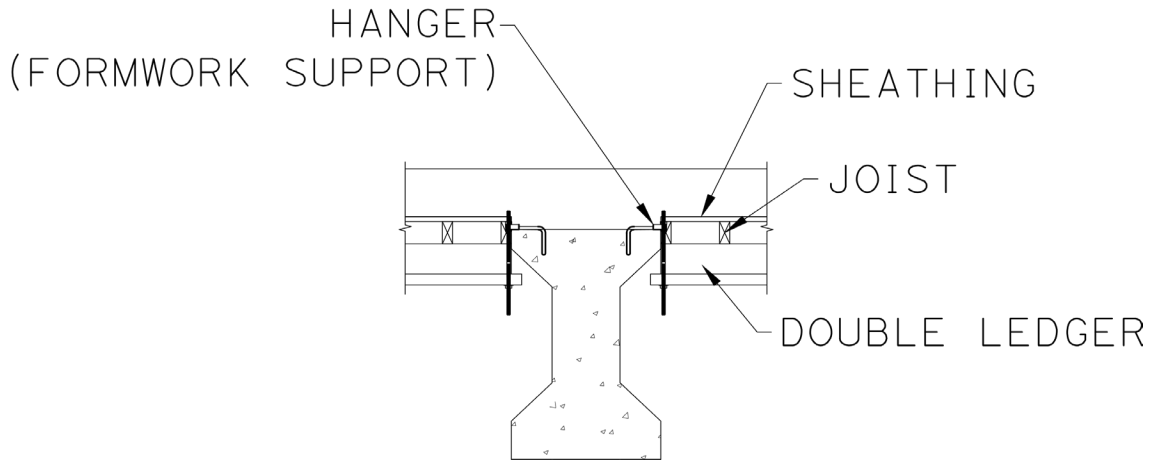

Figure 7-9. Precast Concrete Girder Deck Formwork Detail

7-3.02 Structural Adequacy and Deflection

Contract Specifications, Section 48-2.02B(1), *Temporary Structures – Falsework – Materials – Design Criteria – General,* states that bridge deck forming systems, including lost deck and overhang formwork, must be considered and designed as falsework. Perform an independent engineering analysis to verify the forming system is structurally adequate and complies with the contract requirements. The Structure Construction (SC) *Falsework Manual* provides detailed guidance on the analysis required when reviewing and authorizing the design of a concrete bridge deck forming system, including for deck forming systems that use timber and manufactured products, such as overhang brackets.

In addition to the requirements of *Contract Specifications*, Section 48-2, *Temporary Structures – Falsework*, the design and construction of deck forms for steel girder bridges are governed by *Contract Specifications*, Section 55-1.03B, *Steel Structures – General – Construction – Falsework*. These contract requirements reduce the potential for damage and distortion/deflection of the girders and new deck.

Form deflection and settlement usually occur during and after concrete placement. This movement is generally not structurally detrimental to the deck slab, provided that the deflection does not continue after the initial set. If deflection does continue, it could result in an irregular deck profile surface and may lead to cracking. The same can also result if forms deflect more than anticipated.

When screed rails are located in the overhang area, deflection must be minimal for appearance and satisfactory grade control. Accurately determining deflection is difficult, particularly when brackets or jacks with cantilevered joists or outriggers are used.

7-4 Bridge Deck Formwork Construction

Proper bridge deck formwork construction plays a major role in achieving an acceptable bridge deck. Preconstruction planning is critical for constructing the bridge deck to correct alignment and profile. The Contractor must determine and propose a deck forming system, the types of material to use, where screed rails will be located (for example, on the edge of deck forms), and how they will be adjusted. Discuss survey and grade control requirements and procedures with the Contractor, starting at the preconstruction meeting and continuing throughout the process.

7-4.01 Form Alignment

The Contractor positions and aligns the bridge overhang formwork based on the theoretical location of the deck, specifically its edges. These lines are known as the “edge of deck” (EOD) lines. SC staff usually provides edge of deck survey control points for the Contractor’s use to lay out edge of deck lines, which SC staff subsequently

verifies. For typical construction of new CIP box girder bridges, edge of deck lines are laid out first on the soffit forms. The Contractor then lays out the exterior and interior bridge girders.

The edge of deck layout can be performed using a transit, total station, or stringline. Edge of deck on horizontal curves can generally be established with stringline using simple survey techniques such as the chord offset method. As the horizontal radius becomes small (a 'tight' curve), more accurate calculations may be warranted, or the chord distances shortened to maintain a close approximation. District surveyors may be able to assist with edge of deck layout for bridges with complex geometry.

Edge of deck layout is also needed on top of the overhang forms for setting edge of deck forms, or bulkhead; however, for most bridges, the overhang distance is a constant dimension relative to the exterior girder, so establishing EOD may be simplified. Before setting the layout line for the edge of deck forms, the Contractor must roughly set the overhang forms to planned elevation. The Contractor can accomplish this rough grading with the use of templates or the lost deck grade dowels, the latter which will be discussed in the following sections.

No matter what method of establishing line is used, always check the following:

1. Verify both edges of deck plane into known points at each end of the structure.
2. Verify the overall deck width at several locations throughout the length of the structure, considering bridge cross slope (refer to Section 2-2.01 of this manual), especially at key locations like the beginning and end of superelevation transition zones, at hinges, and at all deck joint locations.

7-4.02 Formwork and Bridge Deck Elevation

The elevations that bridge deck forms are set to, including overhang forms, are controlled by the theoretical deck grades, with consideration given to designed long-term bridge camber, calculated short-term falsework deflection, and anticipated falsework deflection. Per *Contract Specifications*, Section 51-1.03F(5)(a), *Concrete Structures – General – Construction – Finishing Concrete – Finishing Roadway Surfaces – General*, the Department is responsible for providing elevation control in the field for the Contractor to construct the bridge deck. Accounting for the known deck thickness, the Contractor can set deck forms to the proper elevations.

7-4.02A Deck Elevation Control Points

Before the stem and soffit pour, plan where deck elevation control points should be placed on the bridge. Deck elevation control points are typically established in pairs, one on each exterior girder. Wide bridge decks or ones with a crown may require an additional control point at an interior girder. Mark their locations on the deck contour

plots, or 4-scales, to create a set of grid grades along the bridge girders so that a plane can be established for the deck. This can also be performed using CAD software if using an electronic version of the bridge deck contours.

Per *Contract Specifications*, Section 51-1.03F(5) – *Concrete Structures – General - Construction – Finishing Concrete – Finishing Roadway Surfaces*, provide deck elevation control points at all breaks in the grade and intervals not closer than 8 feet longitudinally and 24 feet transversely to the centerline of bridge. A typical longitudinal distance between deck elevation control points is approximately 10 feet along the bridge centerline, evenly spaced within the span. Common practice is to have the first and last control point within a bridge span be 1 foot from the faces of end diaphragms and bents, then establish the spacing in between as described previously. If the deck is on a horizontal curve, the spacing of the control points will be larger on the outer girder compared to the inner girder.

If deck grading will be complicated, additional control points may be necessary. Discuss deck elevation control point layout with the Contractor in advance. Consider the amount of vertical curve and camber when determining these intervals so that both short-term camber and long-term bridge camber and vertical curve profile are accounted for. When using the deck contours to pick theoretical grades, recall that the vertical curve is captured thereon, while the design bridge camber is not.

Next, draw the design bridge camber from the “Camber Diagram”, located in the project plans, onto the deck contour plots. Design camber for the decks of conventionally reinforced concrete box girder, T-beam, and slab bridges is the sum of the anticipated long-term deflection due to concrete creep and the initial dead-load deflection of the superstructure. This camber is built into the initial deck grades to help counteract the eventual long-term bridge deflection. Long-term deflection of conventionally reinforced concrete bridges can continue for about four years. Approximately 25 percent of the total deflection occurs immediately after falsework is removed.

Then determine if falsework settlement or deflection needs to be considered. Experience shows that for box girder and T-beam structures, essentially all the falsework deflection occurs when the soffit and/or girders are poured. For post-tensioned bridges with long falsework spans, studies indicate that 50 percent or less of the theoretical deflection due to the deck slab dead load is realized when the deck is poured. Similarly, most of the falsework settlement occurs during the placement of the stem and soffit concrete. Therefore, the deck camber for conventional reinforced or post-tensioned box girder and T-beam structures would normally not include falsework settlement or deflection; however, assess the potential for deflection on a case-by-case basis, accounting for variables such as structure type, weight, falsework span length, etc. For instance, in the event of long falsework spans, it may be appropriate to include a small allowance for settlement. Note that this reduction in dead load of the deck is

applicable only for determining falsework settlement and deflection. It is not applicable when determining dead loads to be used for formwork or falsework design. Refer to *Contract Specifications*, Section 48-2.02B(2), *Temporary Structures – Falsework – Materials – Design Criteria – Loads,* and the *Falsework Manual* for additional guidance regarding the calculations of dead loads for falsework.

Lastly, calculate and record the bridge deck elevations for each of the deck elevation control points. This is done by adding the following values for each of the control points:

1. Contour (deck) elevation
2. Design bridge camber value
3. Falsework settlement/deflection (if applicable).

The above calculation does not account for grinding and grooving. Before determining deck elevations, verify if the Contractor plans to texture the bridge deck by grinding and grooving. If grinding and grooving will be performed, an additional 1/4-inch of sacrificial concrete cover must be included to the bridge deck elevation.

Refer to Section 7-4.03, *Deck Grade Control Considerations*, for potential issues and items that may need to be accounted for when planning for grade control of bridge decks. These may affect the calculations of deck control points.

7-4.02B Deck Dowels

Control for the elevation of the deck and lost deck forms in box girder bridges is usually established using “deck dowels”, which are placed at the deck elevation control points. Deck dowels are typically short, straight pieces of rebar placed and cast into the girders at the deck elevation control point locations. They are installed vertically into the stems after the girders have been poured and while concrete is still plastic. Unlike permanent embeds, the dowels are permitted to be “wet-set”, making the timing of installation critical - if installed prematurely, the dowels may lean or sink; if too late they will be difficult or impossible to insert. Alternatively, they can be tied to the girder rebar beforehand and cast with the pour. The top ends should be set above the deck elevation. Before the stem and soffit pour, mark the locations of the deck elevation control points on the forms. The Contractor usually sets the deck dowels (if they are to be set) during the pour. When deck dowels are being installed, be cautious of interference with prestress ducts. This may be an issue when dowels are close to the bent cap, as that is where the high points of ducts are located.

After the stem and soffit pour, shoot and record the elevation of the top of the deck dowels during the following shift. In addition, prepare as-built sketches of the actual dowel locations which are used to fine tune the 4-scale layout of dowel locations, as required. On the days following the stem and soffit pour, contractors typically remove the walkways with the girder forms used during the stem and soffit pour. Girder forms are allowed to be removed 24 hours after the pour and are usually reused as lost deck

forms. When the walkways are removed, safe access to deck dowels is lost. If this occurs, the Contractor must install adequate safety features to safely access the deck dowels before establishing decks grades in the field.

Instead of using straight bars, hook bars or "candy canes" may be used as deck dowels, as shown in Figure 7-10. This is to eliminate the need for impalement protection which is required if using straight bars. In this case, reference nails are installed next to the hook bars. Use the elevation of the reference nail rather than the dowel. Taking readings at the top of a hook bar can provide inconsistent elevations, as measurements will vary depending on the point of the curve the rod is placed on.

Figure 7-10. Deck Dowels (Hook Bars)

After determining the deck dowel (or reference nail) elevations, calculate the difference between these and their respective calculated bridge deck elevations. It’s good practice to summarize these calculations on a spreadsheet, showing all values used to determine the grade differences for ease of verification. Share the “cut” (or “fill”) calculations with the Contractor, along with a map (or simply a numbering system) indicating the locations of the corresponding control points/deck dowels within the bridge.

In the field, the Contractor will measure the “cut” dimension down from the top of dowel, then mark that dimension on the dowel. This mark signifies the deck elevation at that control point (see Figures 7-11 and 7-12). In some cases, they may use a hacksaw to make a saw cut on the deck dowel; this is preferred as tape used for marking may wear off, and the scored dowel is useful to secure stringline (explained in following pages).

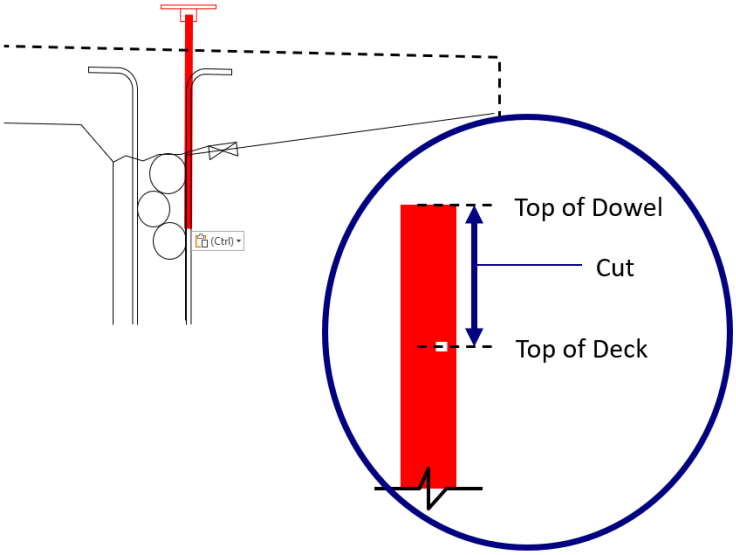

Figure 7-11. Deck Dowel Schematic

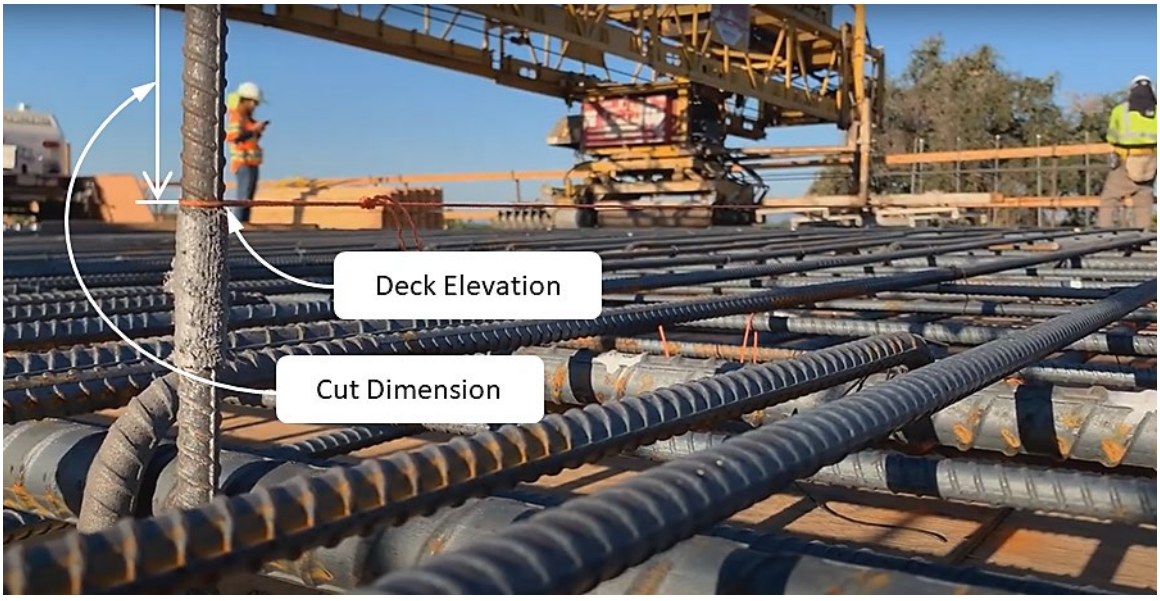

Figure 7-12. Cut Dimension Provided to Contractor on Deck Dowels

The Contractor will then stretch a stringline transversely across the deck to the deck dowel at the corresponding station. The solid lines in Figure 7-13 represent these stringlines, which indicate the target deck elevation to be constructed. Using the stringlines as reference, the Contractor can measure down the planned deck thickness to establish the correct elevation for setting the lost deck forms and supporting ledgers.

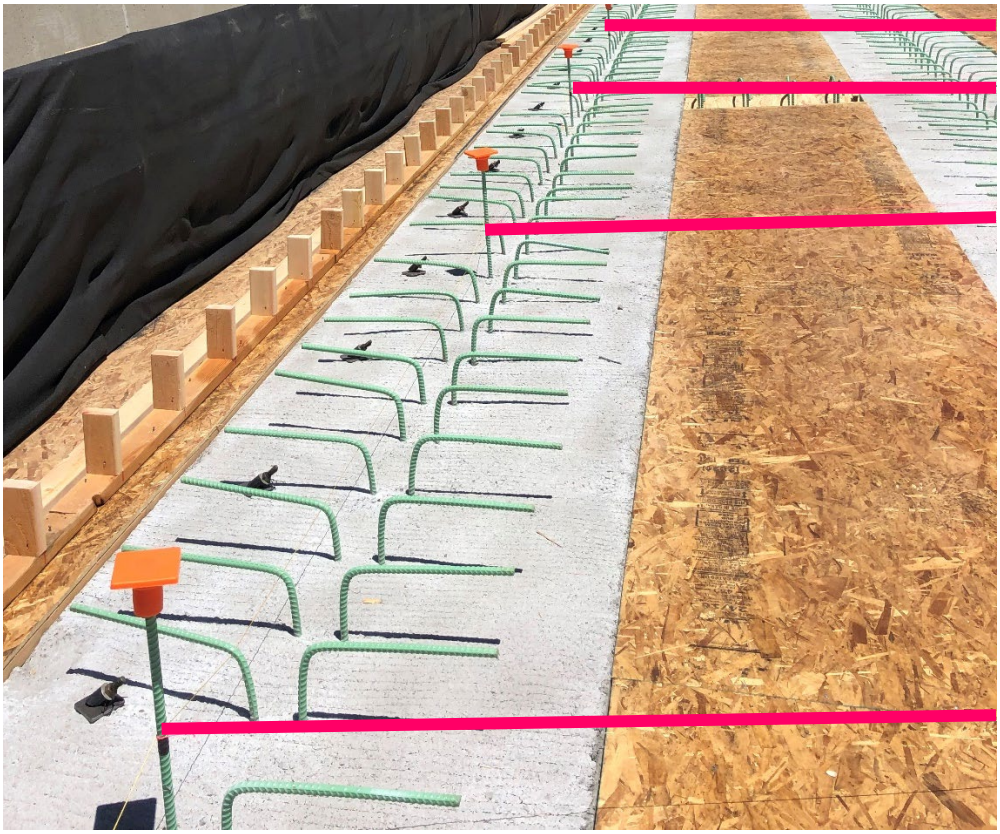

Figure 7-13. Deck Dowel Stringlines

If 1/4 inch is added to the deck elevations due to grinding and grooving, this additional deck thickness must be accommodated for when establishing the lost deck form elevations. Discuss with the Contractor how to account for added deck thickness.

SC staff should also pull string lines transverse and longitudinally to assess visually, or “eyeball”, the deck elevations. Verify that deck elevations make sense, looking for potential grade busts or discontinuities. One way to accomplish this is by graphing the dowel elevations with distances from a referenced point using a spreadsheet program The carpenters may notice a grade bust as they snap out the ledgers that support the lost deck. Check how these grades correlate with previously placed concrete and rebar, such as proper stirrup height. Check also the height of previously poured girder stems and bent caps. The concrete may need to be built up to seal the forms or bushed down to place rebar at the proper location. Verify overall structure depth to top of deck.

7-4.02C Deck Overhang Grading

The deck overhang is formed, graded, and poured as part of the deck. Grade for the deck overhangs requires extra attention since these grades produce one of the more obvious lines of the structure.

Discuss the plan, methods, and manpower requirements for grading the overhang with the Contractor in advance. To get the required smooth lines that are the telltale hallmark of pride in workmanship, constantly review formwork construction with the Contractor throughout the project. Emphasize form continuity and the importance of rechecking previously graded points with the Contractor. Sometimes, previously graded points change in elevation as the overhang is graded.

As mentioned previously, the overhang should have been rough graded earlier to prevent potential incorrect alignment when edge of deck forms were set.

First, determine overhang elevation control point locations along the edge of deck, where grade adjustments can be performed on the forms. Typically, these will be directly over the overhang supports or posts. Spacing must conform with *Contract Specifications*, Section 51-1.03F(5)(a). Shoot and record the elevations of the overhang forms at the overhang elevation control points. If at this stage, edge of deck forms have been installed with chamfer strips attached to set the top of the concrete pour line, it is acceptable to shoot and record directly the elevations of the chamfers at the control points. Verify that the height of the chamfers with respect to the overhang forms matches the planned edge of deck thickness.

Next, field-measure the locations of the overhang elevation control points and plot these on the 4-scale plot. From the plot, determine the deck elevations at the overhang elevation control points. Using this information, calculate the theoretical elevations at the overhang elevation control points on the forms itself by adding the following values:

1. Contour elevation
2. Long-term bridge camber
3. Overhang thickness (subtract)
4. Adjustments to account for falsework stringer deflection (if applicable).

If using elevations shot on the overhang forms, subtract the edge of deck thickness; however, do not subtract this thickness if using elevations shot directly on the chamfer strips. Lastly, calculate the difference between the elevations shot and their respective theoretical elevations. Provide these “cut” or “fill” calculations to the Contractor, as these values represent the required grade adjustment.

Before the Contractor grades, or adjusts, the overhangs, enough load should be on the forms to tighten up the joints. Usually this is accomplished when a major portion of the deck reinforcement is in place.

It is common practice for the Contractor to rough grade the overhang approximately 0.25 to 0.50 inches low because it is easier and quicker to jack or wedge the overhang up rather than to try to lower it (see Figure 7-14). Another common practice for overhang posts is to shoot grade and set elevation at every other post and then shim up the intermediate posts, thus reducing the amount of effort without compromising quality. For overhang forms with multiple supports, both the interior and exterior supports should be graded simultaneously before the final grading work to prevent overhang support geometry from causing a grade change at the edge of deck. After grading, the Contractor should feather wedge or shim the joists tightly. As a final check, eyeball the edge of deck profile with the Contractor. Confirm that the overhang forms and chamfer strips create a smooth and consistent appearance.

Figure 7-14. Wedge System for the Overhang

If the Contractor uses jacks for grading, verify that they are installed and used per the manufacturer's recommendations. For example, monitor that jacks do not extend too far and vertical legs and screw adjustments are plumb. Check lumber for defects and watch for tipped joists.

7-4.03 Deck Grade Control Considerations

When widening or constructing a new bridge deck, SC staff and the Contractor must work together to ensure the new deck is graded properly. The potential for grade and elevation issues can be minimized, particularly at the project start, with careful attention to detail, an understanding of potential hurdles and problems, and foresight. It is more efficient and effective to do the job correctly and thoroughly the first time than to attempt reworking improper grading at the last minute. Below are several grade control considerations for construction of various types of bridge decks.

7-4.03A Bridge Widenings

Contours for bridge widening are typically not provided by the Bridge Design (BD) Project Engineer. Instead, the contours of the new deck are derived from the contours of the existing bridge deck that is being widened. SC staff usually develop the new deck contours by first generating the as-built contours of the existing deck and then extending those contours onto the layout of the new deck; District Surveyors may be utilized to assist with this process. This process can be completed manually or with the assistance of CAD software. Figure 7-15 shows a concrete deck pour for a bridge widening which required its deck contours be developed based on the existing bridge decks.

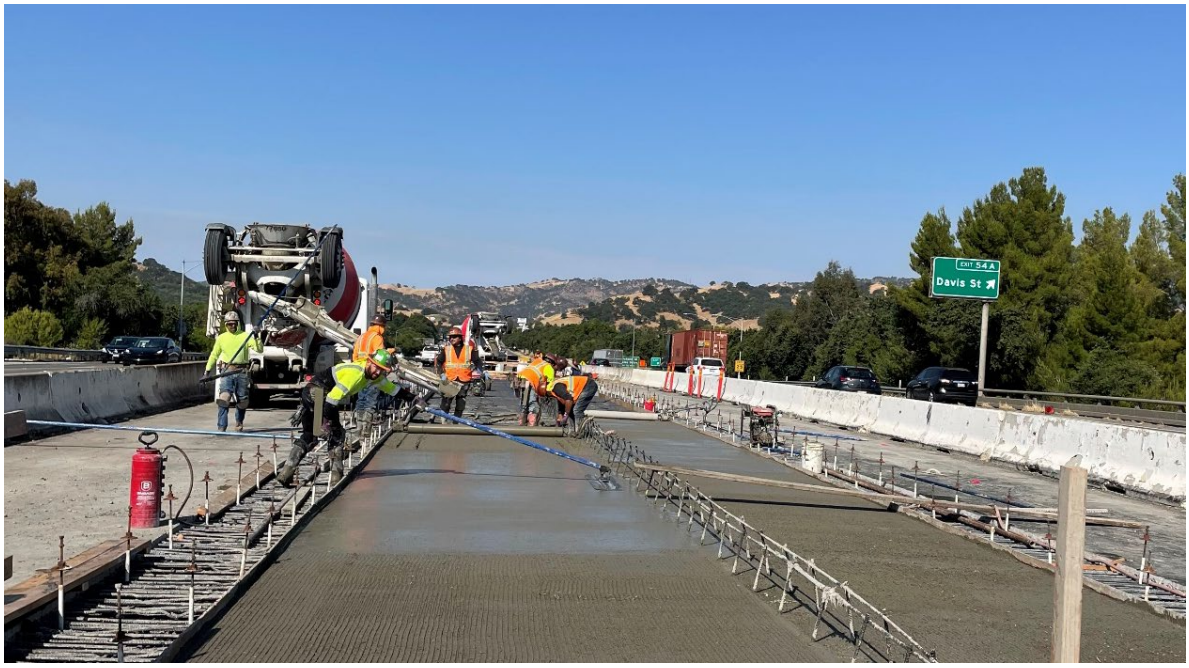

Figure 7-15. Bridge Deck Widening

Some features of existing decks that may cause problems include:

1. Too much camber.
2. Too little camber.
3. Bumps not corrected on the original contract.
4. Rough surfaces and other defects under removed overlays, curbs, and rails.

These problems can be corrected with grinding or overlays.

Sometimes medians are widened so that the new deck must match two existing bridge decks and a theoretical centerline profile. This type of widening may result in the existing bridge deck profiles conflicting with each other and the theoretical centerline profile. If this occurs, adjust the profiles, vary the deck slopes, or explore alternative solutions. Keep in mind the potential impacts to surface flow and any proposed drainage inlets or appurtenances.

Closure pours between new left and right structures pose similar challenges. If possible, determine the existing bridge deck profile elevations and cross slope by requesting the Contractor to pothole overlays on existing bridges that need widening.

Identify grade problems and potential solutions early. When edge profiles for the existing decks and roadways are included in the project plans, verify they match the actual deck profiles before construction starts to determine if remedial work is necessary. This can be performed by developing the as-built profiles of the existing deck and comparing them with those in the project plans. For structures that cross over ramps, roads, or tracks, verify that required permanent clearances will not be impaired by using the field-acquired grades and projecting the planned widening girder bottoms or soffit elevations from the existing structure.

7-4.03B New Construction

On long ramp structures, viaducts, and structures requiring multiple pours, bumps may develop at transverse bulkheads or construction joints, expansion joints, or hinges. Proper profiling and grade control of the adjacent work safeguards against grade or slope discontinuities at the edge of deck grades.

Extra care and caution are required when a subsequent deck pour must match a previous deck pour at a hinge or a transverse construction joint. Proper attention at the end of the previous pour is essential to obtain a satisfactory joint. It is much easier and more effective to match a correctly poured joint than it is to correct irregularities later on.

After the initial deck pour, create a cross-section and profile of the deck. Establish a grid of points the day after the pour at even stations and offsets. Shoot and monitor

elevations of the initial deck pour regularly, until it is time to establish elevations for the next deck pour.

While monitoring the elevations, check for the possibility of long-term falsework settlement and movement of post-tensioned hinges, including hinge curl; this is especially critical on the short end of hinges, which creep upward due to prestressing forces. Refer to Bridge Design Memo, 5.23, *Hinge Curl,* for more information regarding this phenomena. Adjust soffit grades, lost deck, and screed grades if necessary. Extend and compare profiles of the initial deck to the subsequent deck profiles with theoretical values. Then, adjust the grades for the subsequent deck pour accordingly. If major adjustments appear to be needed, consult with the BD Project Engineer.

7-4.03C Dead Load Deflection, Camber, and Settlement

Deck camber for PC PS concrete girder and slab bridges is dependent on the elapsed time between stressing the girders and placing the deck. Because concrete for a PC PS member continues to gain strength and a significant portion of the dead load is not applied to the girders until the deck is placed, the girders tend to creep, or deflect, upwards (see Figure 7-16). The Contractor furnishes camber calculations for PC PS girders and shows them on the shop drawing submittal. When reviewing the shop drawings, pay attention to the time between casting and storage of the girders and the placement of the deck, especially for stage construction projects and widenings. This topic is discussed further in Chapter 8, *Precast Concrete*.

Figure 7-16. PC PS Girder Camber

Deck camber for steel girder bridges includes the initial deflection of the girder(s) from the dead load of the deck but does not include the deflection caused by the weight of the girder(s). In the case of composite design, add a residual amount to compensate for the additional deflection due to drying shrinkage of the slab; contact Bridge Design for guidance as required.

On bridge widenings, the *Contract Specifications* frequently requires falsework supports to remain in place for a longer period, compared to new construction. The specifications may also require that a minimum time elapse between closure pour and falsework release to reduce relative movement between two structures across a closure pour between widened and existing decks. Depending on the amount of camber and the time of the closure pour, the total anticipated deflection for the widening section next to the existing bridge may never be realized. Therefore, it may be necessary to reduce the amount of camber for this section to reduce possible grade differentials that could develop between the widened and existing decks.

As with falsework members, the dead load deflection of steel girder bridges must be checked. Before steel girder fabrication, check the effect of built-in camber using the 4-scale layouts. Use fills from the girder flanges to grade deck forms and screed rails for steel girder bridges.

There are three important factors to remember in connection with steel girder profiles:

1. Safety: Do not perform any work without adequate personal protective equipment and safety measures, such as fall protection equipment and safety rail running the length of the girder. See Caltrans *Health and Safety Manual*[1], Chapter 12, *Personal Protective Equipment,* and Chapter 25, *Fall Protection.*
2. Grade points: Accurately lay out grade points and reference them to the centerlines of bearing.
3. Elevation check timing: Only run level circuits early in the morning when temperature variation is minimal and while the girder temperature is uniform and constant. Do not return later in the day and attempt to check elevations. These elevations may not even be the same the next morning. Record the ambient temperature of every survey.

For most bridge types, settlement can occur in the falsework and the forming system. Bridge deck settlement normally results from form take-up, assuming that falsework settlement has stabilized.

Exceptions include:

1. Slab bridges where settlement is compensated for by screed adjustment during concrete placement activities.
2. Post-tensioned bridges where falsework settlement occurs because of prestressing forces applied after deck pour.
3. Deck-forming systems like overhangs, designated as falsework.

[1] Caltrans Internal use only

The SC *Falsework Manual* addresses the issue of falsework settlement. Some degree of settlement is normal due to the take-up in forms; however, the quality of workmanship must ensure that the falsework that will support the anticipated loads without excessive settlement or compression beyond what is specified in the falsework shop drawings.

Tie together all grades used for deck construction and always check back and tie in to previously shot grades for continuity. Check deck dowel grades when shooting overhang grades to check for long-term falsework settlement. Coordinate stationing and level data between adjacent pours to provide a matching deck surface. Location and accessibility to benchmarks require foresight to prevent the loss of key elevation points.

7-4.04 Bridge Deck and Overhang Form Workmanship

The quality, workmanship, and inspection of bridge deck and overhang formwork are no different than for other bridge elements and structures. The guidance outlined in Chapter 3, *Forms*, applies to the construction of bridge deck formwork. Any formwork issues should be resolved before reinforcement is placed, as any corrective action would be difficult to perform afterwards. The following provides additional considerations for bridge deck formwork.

Verify that lost deck and overhang formwork is being constructed per the authorized falsework shop drawings. Items to be aware of include correct material types and sizes, connections, layout, spans, spacing, etc. Any changes to the formwork construction may require the Contractor to submit revised shop drawings per *Contract Specifications*, Section 5-1.23B(2), *Control of Work – Submittals – Action Submittals – Shop Drawings*.

Check that forms are being installed at the correct elevations. For lost deck forms, reset stringlines transversely between the deck dowels. Then measure from the stringlines to the top of the plywood as shown in Figure 7-17. This measurement must closely correspond to the planned deck thickness.

Figure 7-17. Lost Deck Measurements

Joints in overhang forms must be solid to prevent differential deflections due to the weight of the finishing machine. Look for potential stability problems such as a tipping overhang caused by loads being concentrated along the outside section of the overhang.

As with all forms, deck forms must be mortar tight. Because the concrete placed on lost deck forms is not visible, the importance of mortar tightness is sometimes overlooked. However, forms that are not mortar tight can cause hidden rock pockets and affect the structural viability of the deck.

When the concrete surface will be exposed after construction, mortar tightness and surface condition of the forms are especially important. Plywood overhang forms must conform to the same conditions as soffit plywood.

When overhang forms are constructed simultaneously with the exterior girder stem forms, the overhang forms must be kept clean and protected from hazards that may negatively affect the deck overhang's surface finish. One method to protect overhang forms is to install protective covers over the form using plastic sheeting, lost deck plywood, or building paper. If the overhang forms are built after the girder stem pour, check the grade at the exterior girder before the deck reinforcing steel is placed. Always check the lumber for defects as the overhang forms are being constructed. On sharp radius curves, gaps will occur between plywood and stem, and at joints. Some patterns must be developed to mitigate this. Verify that standard plan drip grooves are installed if the plans require them.

Before lost deck forms are completed, check that material other than lost deck formwork has been removed from inside the bridge cells. *Contract Specifications*, Section 51-1.03C(2)(b), *Removing Forms,* requires these areas to be clear of loose material.

7-5 Bridge Deck Reinforcement

The guidance and practices detailed in Chapter 4, *Reinforcement*, are applicable to bar reinforcement of bridge decks. The following sections provide additional considerations specifically relevant to bridge deck reinforcement.

7-5.01 Standard Plans

Standard construction details for bar reinforcement are located in the *Standard Plans*. The *Index to Plans* sheet of the structure portion of the project plans usually lists the referenced standard plan sheets.

Following are examples of commonly used details for bridge deck construction from the *Standard Plans*:

1. Standard Plan B0-5, *Bridge Details,* lists transverse and longitudinal reinforcing spacing requirements, location of deck construction joints, and deck reinforcing placement notes.
2. Standard Plan B7-11, *Utility Details,* if there are access openings in the deck, check B7-11 for reinforcing details. Review the plans to ensure that access openings are not in wheel lines. If there is a conflict, discuss it with the Structure Designer.
3. Standard Plan B7-5 through B7-8 for placement of deck drains.
4. Standard Plan B11-58 through B11-87 for concrete barrier details.

7-5.02 Detailing and Fabrication

SC staff provide 4-scales to the Contractor. In turn, the Contractor should make them available to their reinforcing steel fabricator to reduce the probability of detailing errors. Special details for deck reinforcing and change orders affecting reinforcement should be brought to the Contractor's attention.

Errors in detailing or fabrication are more likely to occur on bridges with the following characteristics:

1. Varying girder spacing
2. Varying deck thickness
3. Large skew
4. Varying skew
5. Small horizontal curve radii
6. High and/or variable cross slope.

The potential effects of some of the above characteristics are discussed further in Chapter 2, *Preconstruction Planning*. Fabrication is seldom a problem if the standard industry practices for fabrication dimensions are followed.

7-5.03 Bar Reinforcement Installation

Periodic and timely inspections are strongly recommended during bar reinforcement placement for early detection and correction of errors. Proactive and timely inspection can reduce construction time and minimize re-work costs.

Check the heights of the girder stirrup tails, particularly in the exterior girders. Stirrups that are too low may require additional blocking for the top mat of rebar to be set at the correct elevation. Stirrups that are too high may need to be bent or otherwise modified, to not encroach into the clear cover. Also, it is common practice for project plans to not

include details of required reinforcement that is shown in the *Standard Plans*, especially modified barrier rail details for barrier mounted utilities.

On bridges with the characteristics listed in preceding Section 7-5.02*, Detailing and Fabrication,* watch for incorrect reinforcing in the corners, incorrect bar termination location, omission of bars at the overhangs and bent caps, etc. In addition, consider the effects of "stack height", or the total vertical height of multiple layers of bar reinforcement placed on top of each other. The calculated stack height can potentially conflict with the specified clearances if not properly accounted for during design and detailing. Conflicts should be discussed with the BD Project Engineer.

7-5.03A Before Bar Reinforcement Placement

Construction joints, including the joint between girder stems and deck, must be adequately prepared to provide a strong bond between both bridge elements. The Contractor is responsible for abrasive blasting the surface of the construction joint to remove curing compound, laitance, and poorly consolidated concrete. This preparation should be performed before the start of bar reinforcement placement.

7-5.03B Transport and Loading

Contractors typically use cranes to transport reinforcement onto the deck forms for placement by the ironworkers. The crane can deposit very large bundles of rebar on the deck. It's possible for the bundles of rebar to overload the falsework. Discuss with the Contractor how and where the reinforcement will be stored and loaded onto the deck forms and compare this with the loading assumed in the authorized falsework shop drawings.

7-5.03C Clearances

Correctly placed deck reinforcement that provides the planned clearance or cover for the bars is vital. Insufficient cover can fail to protect reinforcement from water and chloride intrusion, resulting in rusting. Rusting rebar causes spalling and loss of structural section, dramatically shortening the life of the deck. This is especially true in a marine environment or where de-icing chemicals are used. Project plans may require a cover larger than 2 inches for bridges in these environments. A significant amount of bridge maintenance funding is spent on deck rehabilitation projects. Deck reinforcement and clearances must match project plans to reduce future deck rehabilitation costs.

Always inspect the clearance to the top of the deck, the minimum clearance at the boundaries, and the bar reinforcement ends to make sure they match the typical section in the project plans. Clearance from the top of deck can be verified by checking the distance between deck dowel stringlines and topmost reinforcement. Be attentive to clearances in areas where there is more reinforcement than other locations along the

deck, such as bents and hinges. The same is true at locations where grinding is usually required, such as hinges and bridge deck construction joints.

Check to see if there is adequate space for deck drainage and other bridge deck embeds to be installed in the overhang. It may be more advantageous if these embeds are installed before bar reinforcement placement.

7-5.03D Blocking and Tying

All deck reinforcement must be blocked up off the deck forms so that concrete can encapsulate the lower mat. *Contract Specifications*, Section 52-1.03D, *Reinforcement – General – Construction – Placing,* does not allow wooden, plastic, or aluminum supports to be used. Ferrous metal chairs, if used, must have at least a 1-inch cover. The plastic coatings on the chair feet are not considered an effective cover. The *Contract Specifications* also do not permit placing bar reinforcement into wet concrete during the pour. Precast mortar blocks, or dobies, are frequently used and acceptable to attain the required concrete cover on the bottom rebar and for ferrous chairs.

Between the girders, “ducked" or buried bars are usually shown on the project plans to support the bottom mat. Typically, they are #4 bars spaced at about two feet on center. Details for how buried bars would appear on project plans are shown in Figure 7-18.

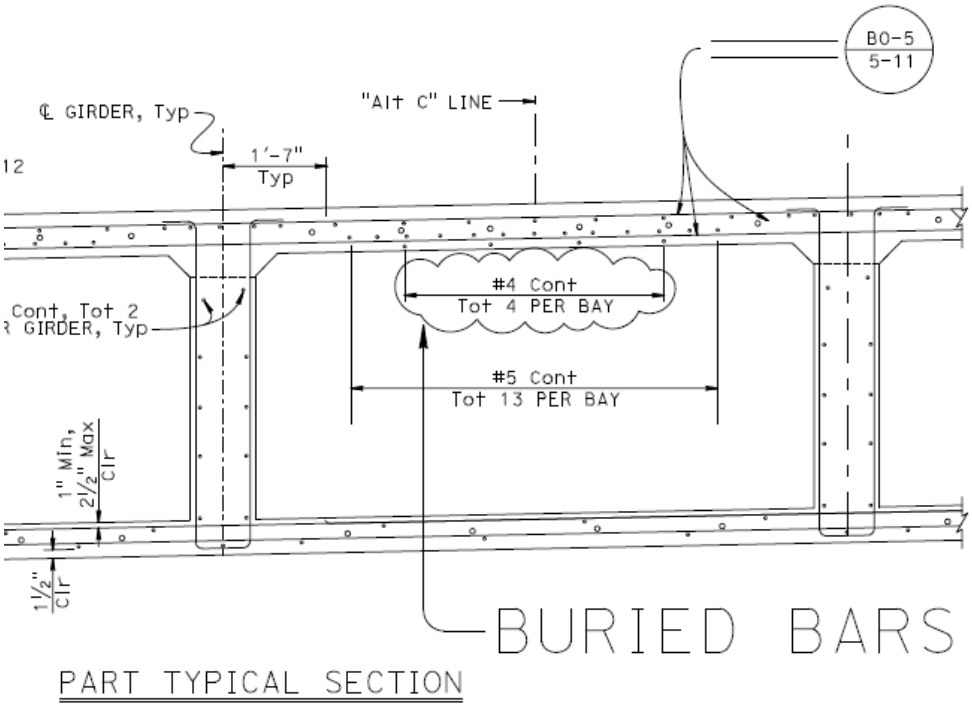

Figure 7-18. Buried Bars Details

Contractors typically use dobies to support the top mat. At or near the girders, some contractors will attempt to support the top deck mat on the stirrup tails. This can be an effective support method, provided that the tails are correctly positioned to perform this task and the bars are securely tied to the tails to prevent movement before or during the pour. The Contractor had previously been given the option to use truss bars, if shown on the project plans, as the transverse bars in the top mat; however, projects dated after 2024 no longer provide the truss bar option.

Mats of bar reinforcement must also be tied firmly and securely in position to prevent movement during deck concrete placement. This is accomplished by wiring at intersections and splices. American Concrete Institute (ACI) recommends that bars be tied at every other intersection, and this may be adequate in most cases. More frequent tying may be necessary at corners, over bent caps, and other special locations.

7-5.03E Splices

Lap splicing is the most common method of splicing small diameter deck bars. Ensure that lap splices are of required length and staggered as required in the *Contract Specifications*.

Service splices or ultimate butt splices in the deck may be required per the contract documents. Record the locations of service splices and ultimate butt splices on the as-built plans per Bridge Construction Memo (BCM) C-6, Attachment 3, *Guidance for Completing As-Built Project Plans*.

7-6 Pre-Pour Construction Activities

The period leading to a bridge deck concrete pour can be quite hectic. The prime contractor and their subcontractors often focus on multiple aspects of the bridge deck until the start of the pour, resulting in several contractor personnel working simultaneously in the same area. Effective preconstruction planning and timely inspections can head off many potential issues. The following subsections outlines some of the activities that typically occur the immediate weeks or even days before the deck pour, which SC staff must be particularly attentive to.

7-6.01 Screed Rails

Since screed rails are normally placed on the overhang forms, one method for grading is to shoot the screed rails using the overhang grades and adjust the Lenker rod to compensate for the elevation difference between the overhang and the screed rail. Alternatively, the Contractor may use a template, or “story pole,” set on the graded overhang to grade the screed rails. As a last resort, they can grade both the overhang and the screed rails from the deck grades on the exterior girder.

Once they are set to the proper elevation, verify smoothness of the profile by sighting ("eyeballing") the screed rails. Reverify reinforcement clearances and deck thickness by measuring from a stringline stretched between the screed rails to the topmost reinforcement and forms, respectively, similar to what should have been done earlier using the lost deck grade dowels.

Spot-check screed rails for adequate support. Screed rails that are not placed on the overhang but rather within the deck should be installed over bridge girder stems, if possible, for best support.

Bridge deck finishing machines ride along screed pipes during the concrete pour. These pipes are typically 2-inch diameter heavy wall pipe with screed chair supports spaced to not exceed the manufacturer's recommendation, typically 24 to 30 inches. Check that the screed pipes are in good condition. Bring to the Contractor's attention any irregularities found on the screed pipes, as they may need to be replaced.

Screed pipes should run the full length of the pour and extend beyond both ends of the pour, enough for the finishing equipment to start and clear the pour area (see Figure 7-19). This is particularly important if any of the ends are on a skew. Screed pipes must be graded beyond the limits of the pour for proper grade at the bulkheads and paving notches. Screed pipe splice sleeves should be placed to prevent cantilever action of the screed pipe.

Figure 7-19. Screed Rails Extended Beyond Pour Limits

Vibrations can cause the adjustment nuts of the screed pipe saddle and overhangs to turn unintentionally. To prevent this, one practice is to wire or secure them. Check all screed support elements during concrete placement.

Non-uniform screed rail displacement or settlement can be caused by:

1. Lack of washers between adjusting nut and edge of deck panel.
2. Spaces between top plate and studs of overhang panel.
3. Spaces between overhang plywood and EOD forms.

Make field notes and have a level available during every deck pour in case of grade problems.

7-6.02 Deck Construction Joints and Bulkheads

Contractors often use construction joints utilizing bulkheads to construct CIP concrete elements in stages. As mentioned in Chapter 5, *Concrete*, planned construction joints are either shown in the project plans, or proposed by the Contractor and authorized by the Department. Treat any construction joint, transverse or longitudinal, as a potential bump or problem area. Check all work in the vicinity of a transverse bulkhead carefully, particularly grade control.

Transverse construction joints for bridge decks should be placed around 0.20 to 0.25 span length from the bent centerline, as noted in *Standard Plans*, B0-5 and B7-1. These locations usually correspond with the inflection points of the bridge span, where bending stress is minimal. Transverse deck construction joints may also be located at the deck compression areas if authorized. The bulkhead for the construction joint must be fabricated to form a keyway or integrate expanded metal mesh, as detailed in the Standard Plan B0-5.

Reprofile the deck adjacent to the bulkhead before the subsequent deck pour to verify deck elevations match.

Contract Specifications, Section 51-1.03D(4), *Concrete Structures – General – Construction – Placing Concrete – Construction Joints,* and Standard Plan B0-5 require longitudinal construction joints be placed at edge of lane lines for bridge decks if not shown in the project plans. Verify that longitudinal bulkheads are installed so that joints satisfy this requirement. In the past, there was a tendency to incorrectly place longitudinal bulkheads within a foot of the lane line.

For positive support, it is good practice for longitudinal bulkheads to be installed close to the girder stems whenever possible. For portions of bulkheads located above a bridge cell and installed on the lost deck, deflection and settlement can be minimized by adding additional vertical supports, or “legging up”, against the soffit.

Discuss reinforcing steel splice details related to joint location with the Contractor before reinforcing steel fabrication, and again during deck concrete placement planning. Grading transverse bulkheads is similar to grading paving notches, described below.

Ensure that bulkheads and other deck forms are constructed, cleaned and stripped in accordance with *Contract Specifications*, Section 51-1.03C(2), *Concrete Structures – General – Construction – Preparation – Forms*. Do not allow early stripping of forms which can result in damage to the concrete. Prohibit simultaneous pouring on both sides of a joint.

7-6.03 Paving Notches and Expansion Joints

Forms for paving notches and expansion joints should be graded approximately 0.25 to 0.5 inches low to clear finishing equipment. When the paving notch (for a diaphragm type abutment) is not formed before the girder stem pour, concrete for the girder stem or abutment diaphragm must be set low enough to receive the paving notch forms. Make sure there is an adequate method for holding the paving notch to proper line and grade.

After final floating, for dressing and edging the joint, the Contractor may attach a filler strip or edger board to the form or saw cut the edge later. After the finishing machine passes, the Contractor should check the section of deck leading up to the joint at several locations with a straightedge held longitudinally to the bridge, as shown in Figure 7-20.

Figure 7-20. Checking Freshly Placed Deck Concrete Near the Expansion Joint Blockout

Proper width, straight, and plumb joints are important when saw-cutting for Type B joint seals. Check reinforcing steel clearances, sealed hinge joints, and paving notches for possible interference with the joint seal saw cuts. Straight material, such as a nailing strip, should be used after finishing operations to establish the grade. The strip should be nailed to the paving notch and used as a guide for edging only. Use of a 0.25-inch edger without depressing the concrete, or similar methods, may be acceptable.

At expansion joints, it may be prudent to slightly increase the deck thickness, thereby slightly raising the deck elevation – while maintaining the bar reinforcement at or just below its planned elevation. This approach accommodates possible future grinding to address potential profile discontinuities between both sides of the expansion joint.

7-6.04 Bridge Deck Finishing Machines

Contractors almost always employ bridge deck finishing machines for striking off and finishing bridge decks, and to achieve the planned deck elevation. Finishing machines from Terex® Bid-Well are used frequently for bridge decks in California. Other brands of finishing machines used include the Allen Engineering Corp and GOMACO Corporation. For guidance on setup, adjustments, grading, and maintenance of specific brands of bridge deck finishing machines, refer to the manufacturer's instructions or manuals.

The basic bridge deck finishing machine features a carriage fitted with concrete finishing equipment. The carriage is suspended from rails attached to an open welded steel truss frame, or the machine truss. Depending on the width of the concrete deck to be poured, the machine truss can be made of one or more truss sections. The machine truss is positioned parallel to the bridge skew. The carriage moves left and right as the machine truss travels forward, maintaining alignment with the bridge skew, if applicable. A typical bridge deck finishing machine is shown in Figure 7-21.

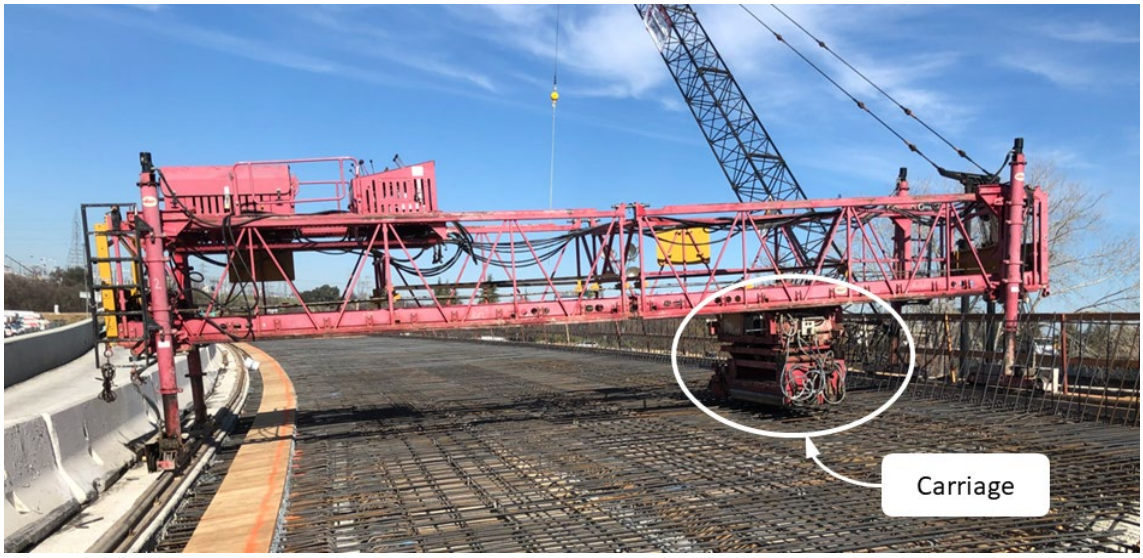

Figure 7-21. Bridge Deck Finishing Machine

The machine truss is supported by adjustable legs equipped with sets of wheels, commonly referred to as “bogie wheels”, which ride on screed pipe rails. Powered bogie wheels move the bridge deck finishing machine longitudinally on the screed rails.

The finishing equipment mounted to the carriage includes augers (typically placed 1/8 to 1/4 inch above finished grade), roller tamper drums, paving rollers, and drag pans. A burlap drag is usually attached at the rear of the carriage. These components are arranged sequentially to spread, finish, and texture the concrete surface with each pass. Figure 7-22 shows the finishing equipment components attached to the carriage. The truss assembly can be adjusted to achieve the designed bridge grade, and cross section. Note that the machine truss in the figure has been adjusted to incorporate a planned crown on the bridge deck.

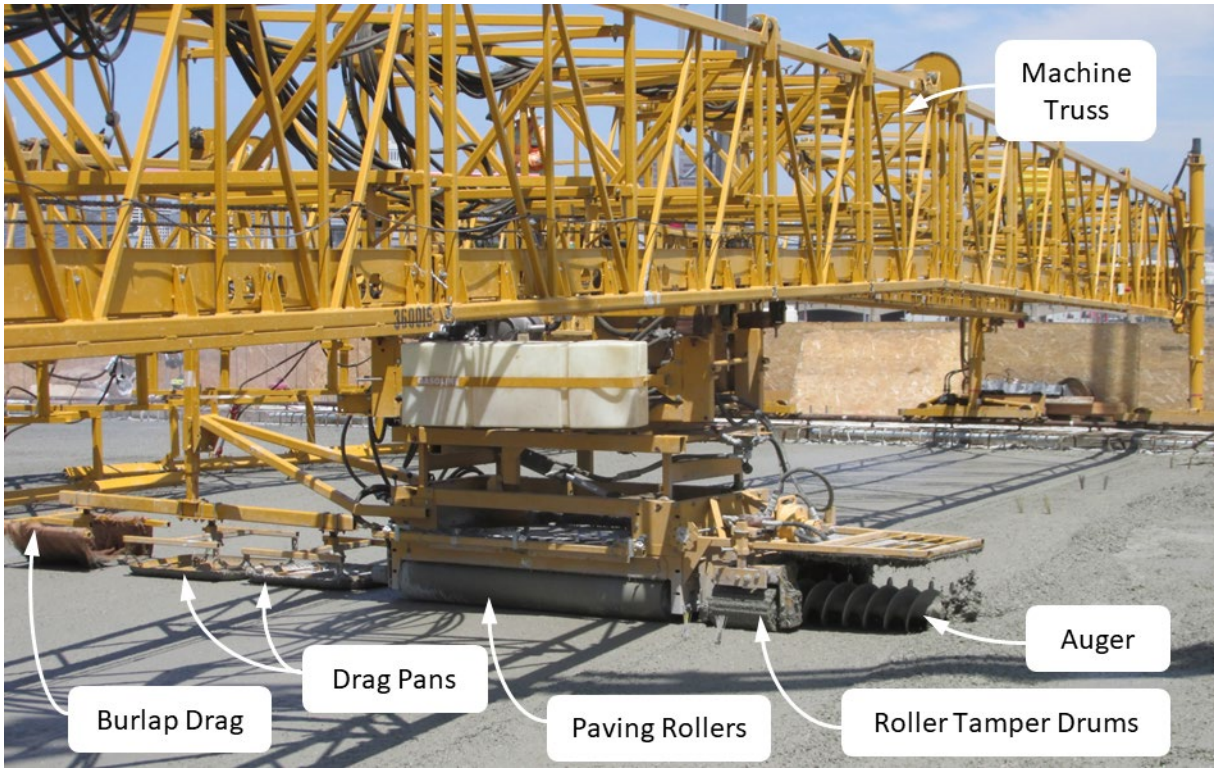

Figure 7-22. Components of a Bridge Deck Finishing Machine

During the deck pour, the augers strike off the concrete to a rough grade and move excess concrete forward. Next, the roller tamper drums compact and consolidate the concrete. The paving rollers follow, further consolidating the concrete and screeding the concrete to grade. After the paving rollers pass, a drag pan or a series of drag pans fill in small voids remaining and seals the surface of the concrete. The burlap drag produces an initial texture before the final longitudinal texture is applied.

The Contractor must be careful when adjusting the bridge deck finishing machine. Depending on the equipment, adjustments may take three to eight hours to complete. Figure 7-23 shows the Contractor adjusting the height of one of the machine truss legs. Proper machine maintenance and care is crucial. Many manufacturers recommend all moving parts be lubricated. If the machine appears to suffer from poor maintenance, be extra cautious. Suggest to the Contractor to have backup material on hand, such as chain repair kits, belts, extra bearings, sprockets, etc. The Contractor usually does not have an alternative deck finishing method readily available in case the finishing machine breaks down.

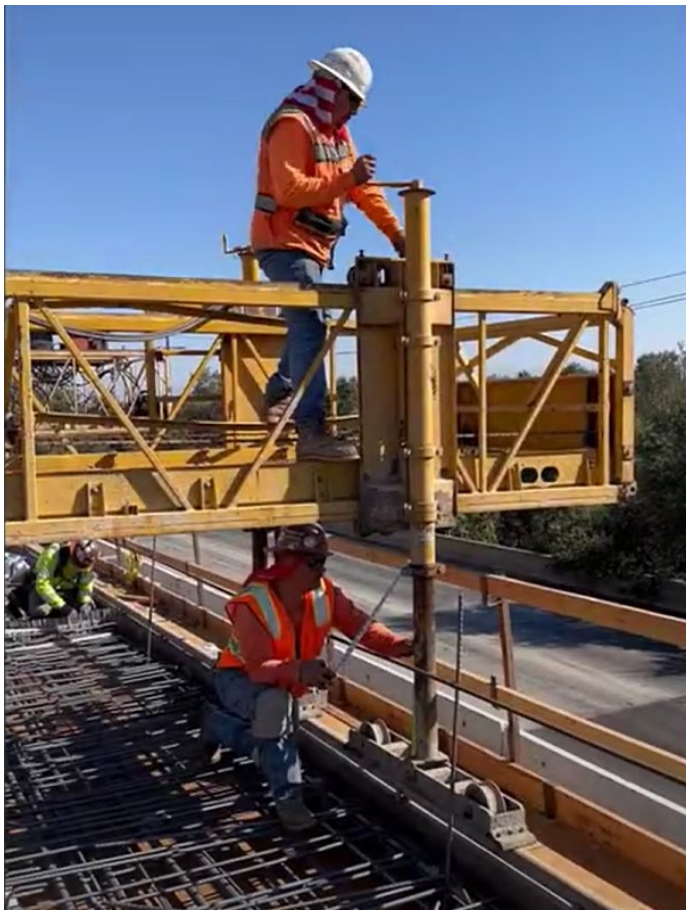

Figure 7-23. Inspect Adjustment of the Finishing Machine

Subtle adjustments of the machine during a pour for a 0.02-foot change in grade often do more harm than good. Although much has been said and written about how a finishing machine can be programmed for various subtle changes in grade, it is more prudent to leave the machine at one setting for the entire deck pour.

Contractors typically, and should, make fine adjustments and perform a final dry run of the finishing machine the day before the scheduled concrete pour. All equipment,

material, and personnel that will be on the finishing machine during the pour should also be on the machine during the dry run. The gas and hydraulic tanks should be filled to account for the additional load, and to properly set the finishing machine truss camber. SC staff must actively inspect and be heavily involved during these critical operations. The following is the typical method followed by contractors for setting up and adjusting the bridge deck finishing machine (double or single roller):

1. Stringline the length of the assembled truss and carriage rail, adjusting for crown or no crown conditions (make sure carriage is at center of truss and string line is not sagging).
2. Move carriage to left or right side of deck adjacent to legs.
3. Place stringline, which represents finished surface, across deck and parallel to trusses. Distance from truss rail to string on both sides of roller carriage should be equal.
4. Move machine over string line until ends of both rollers are over the string. Check finishing machine height with lowest end of paving rollers over string line (see Figure 7-24).

Figure 7-24. Check Finishing Machine Height

5. Check distance from roller surface to string. It should be the same for both rollers.

6. Lower or raise rollers to stringline via leg adjustment. Move both legs-fore and aft-an equal amount.
7. After final adjustment of the legs, mark them with marker or tape to ensure that they do not move prior to or during concrete placement.
8. Repeat steps 4 to 7 by moving finishing machine transversely and forward until back end of rollers are checked. Rollers should also be checked at deck drain inlets and other embedded objects that are to be flush with the bridge deck surface.

In addition to using stringlines as mentioned above, a 4 to 6-foot-long 2-by-4-inch nominal size lumber placed flat on the upper reinforcement can also be used in conjunction with stringlines to verify cover. The advantage of using 2-by-4-inch nominal lumber is that the lumber can be easily moved as the finishing machine progresses forward during the dry run. Also, with the actual thickness of 1.5 inches, a quick visual reference is achieved to the bottom of the rollers. Spot-check clearances at locations that are typically questionable, such as girder stirrups, with the lumber, as shown in Figure 7-25. Another critical location to check is the crown of any vertical curves, especially on skewed or tight-radius bridges. The combination of skew and crown can result in the finishing equipment “scalping” the deck as the equipment effectively straddles the uppermost point of the crown. Afterwards, use the stringline method to double check possible reduced clearances that were found with the lumber.

Figure 7-25. Clearance Checking with Lumber

If reduced bar reinforcement clearances are found during the dry run, the Contractor must adjust or bend the bars down to meet required clearance. It is good practice to carry flagging ribbon and/or paint (typically blue for ironworkers) to mark out areas

requiring adjustment, and keel/crayon to note the amount of adjustment required. This facilitates an efficient correction process and ensures noted issues are not missed. Final grades may be modified as a last resort if authorized by SC staff.

Additionally, take a measurement from the strike-off or rollers of the finishing machine during the adjustment of the machine, to verify desired clearance is achieved.

Pay attention to the auger adjustment and roller skew. At the beginning of the concrete pour, observe the auger adjustment. Often, it is not set low enough, which causes the rollers to load up and results in a ridge behind the machine. The skew of the rollers is critical during the pour. If a ridge is left behind the roller, it may be due to a change in the skew of the centerline of the rollers. This may be corrected by moving one side of the machine forward or back. The SC website features a link to a video titled *Bidwell Operation and Set-up*[1], which offers a basic introduction for SC staff on the standard setup process for a bridge deck finishing machine.

The use of any specific proprietary finishing equipment is not required. Other methods, include hand screeding with a straight edge or the use of a roller screed as depicted in Figure 7-26 may be used if feasible. These are very labor-intensive methods and subject to the skill of the finishers. These activities must be closely controlled and inspected if used.

Figure 7-26. Roller Screed for Deck Finishing

[1] Caltrans internal use only

7-7 Bridge Deck Concrete

Concrete for bridge decks is considered structural concrete. Therefore, in addition to the various requirements outlined in *Contract Specifications*, Section 90, *Concrete,* the concrete for bridge decks must comply with *Contract Specifications*, Section 51-1.02B, *Concrete Structures – General – Materials – Concrete.*

Cracking on a bridge deck is a significant concern, as it can lead to increased maintenance and reduced life span of the bridge. Requirements aimed at minimizing the risk of cracking on concrete bridge decks are included in the specifications. *Contract Specifications*, Section 51-1.02B specifies adding certain materials to the concrete mix for bridge decks, specifically polymer fibers and shrinkage reducing admixture. The required dosages of each are detailed in the relevant specification. The shrinkage limitations noted in *Contract Specifications*, Section 90-1.02A, *Concrete – General – Materials – General* may apply, depending on the amount of shrinkage reducing admixture used.

Likewise, the specified curing method for bridge decks differs from that of other bridge elements and concrete structures. *Contract Specifications*, Section 51-1.03H, *Concrete Structures – General – Construction – Curing Concrete Structures,* outlines the curing method and is discussed later in this chapter.

Concrete containing fibers, such as bridge deck concrete, has the potential to clump and may require pumps to work harder to convey during placement. The Contractor should take such potential issues into consideration when developing a mix design for the bridge deck.

7-8 Deck Concrete Placement

Effective bridge deck concrete placement requires detailed planning and coordination. This section of the chapter adds to the discussion in Chapter 5, *Concrete,* as it covers topics related to concrete placement specifically for bridge decks.

Review the Contractor's authorized deck placement work plan and verify that they comply with the plan throughout the concrete pour. As mentioned previously, it is advisable to hold a preconstruction meeting with the Contractor before deck concrete placement. Discuss their work plan and question if there will be any deviations from the plan. Modifications may be necessary if site conditions are different than what was expected earlier in the project. If they are contemplating deviations, consider requesting the Contractor to resubmit their bridge deck placement work plan.

In addition to the work plan, topics to discuss should include implementation of their concrete quality control (QC) program, pour start time, adequate lighting, worker and public safety, traffic control, potential need for lights, and crews who are able to work an extended shift if necessary. Refer to *Contract Specifications*, Section 90-1.01D(10)(b), *Concrete – General –Quality Assurance – Quality Control – Cast-In-Place Structural Concrete Members,* and Chapter 2, *Preconstruction Planning*, for requirements and practices regarding the Contractors concrete QC program.

7-8.01 Concrete Delivery

7-8.01A Delivery Equipment

For typical CIP bridge construction projects, concrete is usually batched from an outside batch plant and delivered to the job site by truck mixers. Less frequently used concrete delivery methods, such as truck agitators, open-top vehicles, barges, etc., may be warranted if more suitable for schedule or site conditions.

7-8.01B Delivery and Pour Rate

A primary key to a successful pour is preparation that will result in a well-scheduled start and maintain a constant delivery rate. Since the rate of concrete delivery and placement affects the finishing operation, the Contractor should consider the following factors when planning the frequency that concrete is to be delivered:

1. Total theoretical quantity and expected delivery rate for the concrete placement.
2. Number of concrete pumps or concrete buckets and cranes.
3. Number and spacing of concrete trucks assigned to the concrete pour.
4. Method of concrete delivery at the concrete pump hopper.
5. Concrete pump capability to reach all areas of the pour, avoiding overhead hazards and suspended loads over traffic.
6. Possible need to relocate the concrete pump(s).
7. Potential impacts from local traffic (e.g., rush hour, start or end times of nearby schools, accidents, sporting events, etc.).

Once the concrete pour timing and estimated duration are determined, some issues to discuss with the Contractor include:

1. Start time
2. Adequate lighting
3. Safety and traffic control
4. Safe access and facilities for concrete sampling and testing by QC personnel and SC staff.

The following is an example scenario of a potential issue related to pour rate:

The Contractor plans to place 600 cubic yards (CY) at 45 CY per hour. This means that the pour will take more than 13 hours to complete. If the pour begins at 7:00 a.m., the Contractor will finish placement and strike off around 8:30 p.m.

The Contractor informed SC staff that they requested five trucks per hour from the concrete batch plant but could only secure four. However, the batch plant has assured the Contractor that four trucks will be sufficient since each truck carries almost 10 CY of concrete.

During previous pours, SC staff observed that a full concrete truck commonly required approximately five minutes to discharge, 30 minutes to travel to the plant, 10 minutes to charge the mixer at the plant, and 30 minutes to travel back to the jobsite. As a result, the total time for a full truck to complete a round is about 75 minutes.

To achieve a pour rate of 45 CY hour, the Contractor needs 4.5 trucks per hour, or about one truck about every 14 minutes. However, to maintain a steady rate of pour, consider the 75-minute round trip cycle time. Dividing this cycle time by the 14-minute pour rate yields 75/14 = 5.4 trucks, or six trucks to ensure an adequate amount of material delivery.

SC staff must communicate to the Contractor that, based on the information provided, at least six trucks will be required to maintain a 45 CY per hour pour rate.

Increased mechanization and decreased use of manual methods have allowed deck pours to proceed at a rate set by the capacity of the finishing equipment and the rate of delivery rather than by the crew's physical limitations. Therefore, pour rates can be reduced to mathematical calculations (with some allowances for mechanical malfunctions) with little allowance for the "human factor."

Before the pour, mark 10-foot stations along the edge-of-deck handrails, walkway, temporary concrete barrier (if used), or other convenient location and perform a theoretical volume calculation. Use these marks and volumes to track the production rate during the deck pour. This calculation should be done periodically during the pour to fine-tune the estimated time of completion, document the actual quantity of material used, as well as identifying any potential under-run of material that would otherwise necessitate a "cleanup" truck.

7-8.02 Conveyance and Placement

For bridge deck pours and most other concrete pours, concrete is typically placed starting from the low side and progressing uphill. Doing so enables the Contractor to better control concrete placement and travel of the bridge deck finishing machine.

Contractors have tried several different methods of placing concrete during deck pours. Some of the successful methods to date are the use of buggies, conveyor belts, pumps, and buckets. Concrete buckets and pumps are the two most common methods.

7-8.02A Concrete Buckets

Two buckets are typically used for the crane-and-bucket method. Assume an average pour rate of 45 cubic yards per hour when using one crane with two, 1 cubic yard buckets. While the crane is maneuvering and placing the first bucket, the second bucket is being filled. This approach ensures continuous placement of fresh concrete to the pour front.

Contractors often prefer using concrete buckets for pouring small deck spans. Other reasons include ownership of the bucket and crane, as well as the ability to maintain a slower, more controlled pour rate.

Some advantages of using the crane-and-bucket method include:

1. The crane can be used on other phases of work, eliminating the need for special equipment and setup.
2. The crane has a high degree of mobility, allowing concrete placement under difficult conditions.
3. A homogeneous mix is assured in most cases.

Some disadvantages of using the crane-and-bucket method include:

1. There may be areas outside of the crane’s reach that cannot be accessed for the pour.
2. Safety issues may arise from swinging booms during high pour rates, potentially requiring additional cranes.
3. Overhead wires that may be adjacent to or over the pour pose serious potential hazards.
4. The crane may need to boom over traffic, which is not allowed.
5. Impact due to concrete dropping from a high bucket can cause forms to fail.

When the bucket method is used, the Contractor must contain potential spills as the bucket is being filled with concrete and keep the bottom of the bucket frame and boot out of the dirt.

7-8.02B Concrete Pumps

Concrete pumps are the most popular and reliable method for placing deck concrete. Reasons why contractors use the concrete pump method include:

1. Concrete can be delivered at a more constant rate.
2. Pumps can reach farther than a crane.
3. Less labor is required for conveying concrete since the pump does the work.

Cranes with buckets and other previously used concrete conveyance methods are generally limited to receiving concrete at one or two locations. In contrast, pumps are mobile and can quickly change locations. Concrete pumps can place concrete in difficult to reach locations. This is very important for keeping a fresh pour front for deck concrete placement.

As mentioned in Chapter 5, *Concrete*, concrete pumps have advantages where overhead space is congested with utility lines or other obstructions because it requires less headroom. Pumps, in general, are less hazardous than cranes since there is no need for crew to handle or work around heavy swinging buckets.

As mentioned earlier, be aware of possible clumping of the bridge deck concrete containing fibers. This may cause issues with the pump during the pour.

7-8.03 Consolidation

Concrete presents a dry, irregular surface before being consolidated. In contrast, consolidated concrete appears moist once the fine aggregates rise and the large aggregates settle. The Contractor must initially consolidate deck concrete as it is placed immediately in front of the finishing operation, which is typically performed using internal vibrators (see Figure 7-27).

The operator’s technique should vary with the depths and complexity of each section. In deep sections where it is possible for the vibrator to be inserted close to full depth, the operator must insert the vibrator into the concrete approximately every 2 feet and make sure the head enters almost vertically. In deck slabs where vertical insertion is not feasible, the vibrator should be inserted near horizontal to immerse the vibrator.

Figure 7-27. Vibrating Concrete on a Deck Pour

The vibrator should not be dragged horizontally over the top of the concrete surface, nor should it run continuously in a stationary position without the operator's full attention. Doing so can prevent the fine and large aggregates from settling properly, resulting in a non-homogenous deck cross section. Material in this condition leads to added maintenance and costs over the life of the deck.

Typical deck finishing machines are equipped with tamper rolling drums attached to the carriage. The rolling drums consolidate the top concrete surface as the carriage moves transversely during the finishing activity.

7-8.04 Bridge Deck Pour Inspection

Forms and surfaces that will be in contact with fresh concrete must be wet; however, do not allow water to pond, as this is prohibited. The consistency of concrete must be maintained and placed uniformly in front of and parallel to the finishing machine. The concrete must be adequately consolidated but not overly vibrated. Continuously check reinforcing steel clearances. Any displaced steel must be repositioned, blocked, and tied. Broken dobies also must be replaced.

Check that the Contractor is following their authorized concrete QC program, including sampling and testing as required. Likewise, SC staff must be diligent in performing all required concrete quality assurance testing.

Verify the position of waterstops, deck drains, manholes, conduit, prestressing hardware and accessories. They will need to be repositioned if they have been displaced.

During the pour, be mindful of how far ahead the Contractor is placing the concrete with respect to the finishing. If placed too far ahead, the concrete may begin to set prematurely, leading to issues during the finishing. Additionally, verify the actual deck depths by stabbing the plastic concrete following strike-off. Figure 7-28 illustrates the use of a snap tie marked at the deck thickness, a common tool used for checking depth.

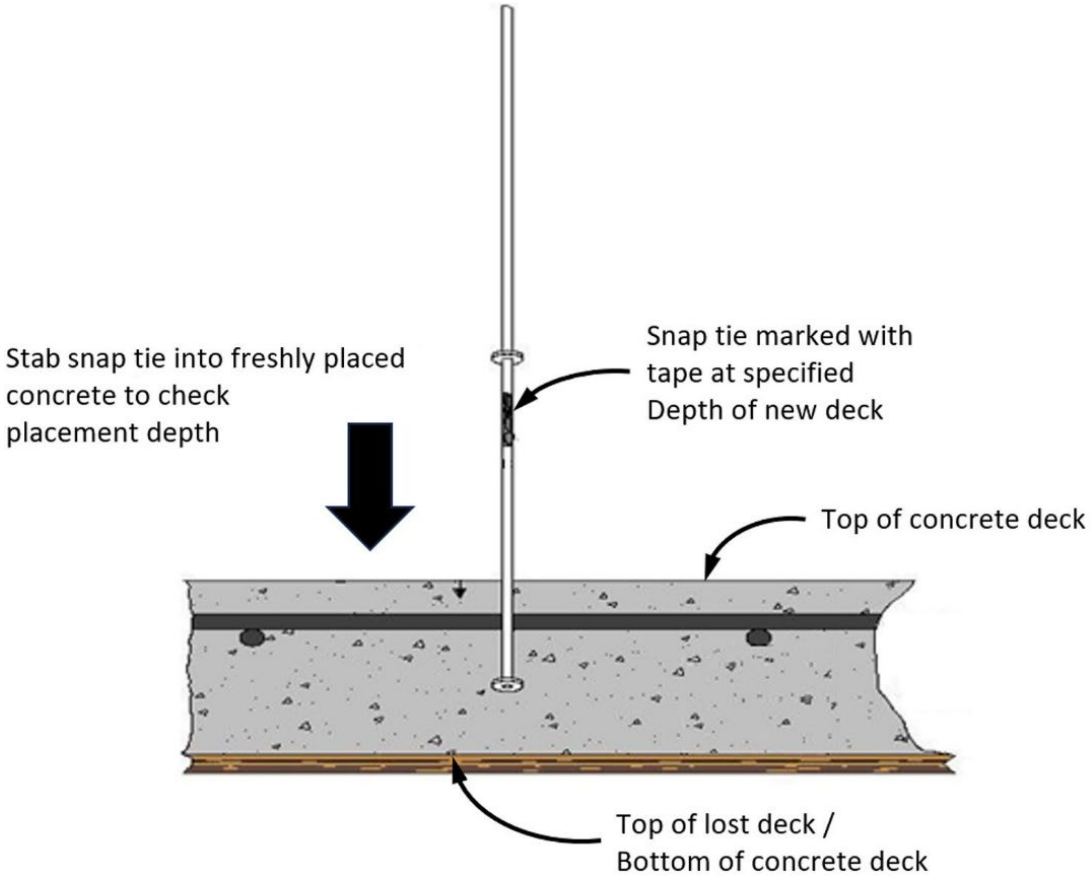

Figure 7-28. Improvised Snap Tie Depth Gauge

As stated in Chapter 6, *Bridge Construction Practices for Cast-In-Place Bridges*, the portion of the bridge deck surface where concrete barriers will be constructed is considered a construction joint. As such, the surface must be prepared per *Contract Specifications*, Section 51-1.03D(4), *Concrete Structures – General – Construction – Placing Concrete – Construction Joints.* This requires an irregular, or roughened surface, at the deck/barrier interface as well as removing laitance, curing compound, and other foreign material. Providing a 1/4-inch amplitude surface, although not required, would be ideal.

7-9 Finishing Roadway Surfaces

The requirements for a finished concrete bridge deck are in *Contract Specifications,* Section 51-1.03F(5), *Concrete Structures – General – Construction - Finishing Concrete – Finishing Roadway Surfaces*. Additional information is available in BCM 51-1.01, *Concrete Structures – General,* and BCM 51-1.03F(5-6), *Concrete Structures – General – Construction – Finishing Concrete – Finishing Roadway and Pedestrian Overcrossing Surfaces.*

The deck finishing operation should be planned and carried out to minimize the need to apply water to the deck surface. Excessive water applied to the surface, either while finishing is in progress or after finishing is completed but before application of the cure, will increase the water-cement ratio at the surface, which may accelerate the deterioration of the wearing surface.

While air-entraining admixtures improve workability, they may also reduce the rate at which bleeding occurs. This may adversely affect the deck finishing operations. In hot weather conditions, particular emphasis should be placed on keeping the temperature of the concrete mixture as low as practicable and minimizing the indiscriminate use of water to increase workability or to facilitate finishing.

Bridge deck surfaces must meet a minimum measured coefficient of friction. Historically, achieving this requirement has been left to the Contractor's means and methods and was usually agreed to by SC staff. Previously, a coarse broom or transverse tined finish was commonly used on bridge decks. Since only minimal friction was required, some of these surface textures developed relatively deep grooves, which could lead to increased tire noise caused by high-speed vibrations as tires engaged the surface texture. Noise would be further amplified by the resonance of the bridge.

The Department has conducted research that has led to the current specifications. *Contract Specifications,* Section 51-1.03F(5)(b), *Concrete Structures – General – Construction – Finishing Concrete – Finishing Roadway Surfaces – Bridge Deck Surface Texture,* requires bridge decks to be textured longitudinally. The texture is intended to produce a lesser amount of noise compared with the previous methods while still achieving the required coefficient of friction. BCM 51-1.03F(5-6), Attachment 1, *Quieter Bridge Deck Construction,* explains the development of the current surface texture specification. Additional historical context and references related to the surface texture specification can be found on the SC webpage[1] under the "Field Resources" tab, through the "Quieter Bridge Deck References" link.

[1] Caltrans internal use only

Contract Specifications, Section 40-1.03H(3), *Concrete Pavement – General – Construction – Finishing – Final Finishing,* requires an initial texture before the final longitudinal texture. As mentioned earlier, the burlap drag produces the required initial texture when using a bridge deck finishing machine.

The specification prescribes two methods for producing the final longitudinal tining on bridge decks:

1. Grinding and Grooving
2. Longitudinal Tining.

The requirements for grinding and grooving are detailed in *Contract Specifications*, Section 51-1.03F(5)(b)(ii), *Concrete Structures – General – Construction – Finishing Concrete – Finishing Roadway Surfaces – Bridge Deck Surface Texture – Grinding and Grooving*. For grinding and grooving, the longitudinal texture is produced by using grinding machines that are configured to grind 12-foot-wide freeway lanes in 3 to 4-foot passes, as shown in Figure 7-29. Figure 7-30 shows the resulting deck after the grinding machine has passed.

Figure 7-29. Grinding Machine Grooving a Bridge Deck

Figure 7-30. Close-up Illustration of Grooved Deck

There may be irregular areas, such as between the barrier and the last pass of the machine, where it is difficult to groove a portion of the deck depending on the bridge geometry. The Contractor may suggest alternative means of providing the required texture at these locations, such as hand-constructing grooves or using multiple saws with walk-behind.

The deck surface must be ground and grooved to within 18 inches of the toe of the barrier. As mentioned earlier, to accommodate for the concrete that will be removed during grinding and loss of cover, an additional 1/4 inch of sacrificial concrete must be placed during the bridge deck concrete pour.

The requirements for longitudinal tining are located in *Contract Specifications*, Section 51-1.03F(5)(b)(iii), *Concrete Structures – General – Construction – Finishing Concrete – Finishing Roadway Surfaces - Bridge Deck Surface Texture – Longitudinal Tining*. Longitudinal tining involves texturing the top surface by dragging a series of steel rakes or similar steel tining devices in the longitudinal direction. This process is done while the concrete is still plastic, but somewhat fluid, after it is struck off to the proper elevation and floated, and just before the application of the mist cure.

For concrete bridge decks, tining is often performed using a work bridge that follows the bridge deck finishing machine. The work bridge may have tining devices attached to its trailing end, as shown in Figure 7-31, or workers may stand on the work bridge and texture the surface with rakes as the work bridge moves. Figure 7-32 is a closeup view of a concrete deck being tined.

When longitudinal tining is the selected method, both the Contractor and SC staff should continually check the condition of the rakes. The use of fiber reinforcement can

lead to accumulation of material between the tines, potentially resulting in gouges in the deck. In severe cases, errant or damaged tines may hook and drag coarse aggregate, similarly resulting in gouges in the deck surface. Early detection of these issues can significantly reduce the amount of corrective hand finishing.

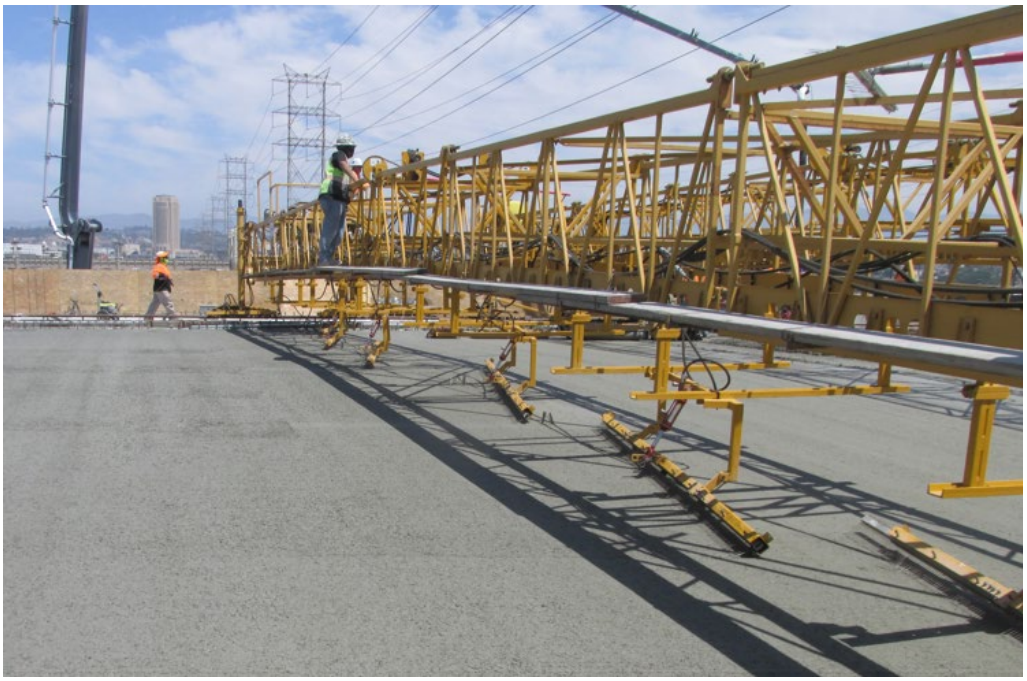

Figure 7-31. Longitudinal Tining from a Work Bridge

Figure 7-32. Longitudinal Tining

7-10 Curing Bridge Decks

Due to its large, exposed surface and its importance in contributing to the service life of a bridge, the requirements for curing a bridge deck are demanding. These requirements can be found in *Contract Specifications,* Section 51-1.03H, *Curing Concrete Structures*.

Once the deck is finished to the proper elevation and texture, the top surface must be kept continually wet by an atomized mist, as shown in Figure 7-33. Afterwards, for a full 7 days, the deck must be cured via the water method by using a curing media, in accordance with *Contract Specifications,* Section 90-1.03B(2), *Concrete – General – Construction – Curing Concrete – Water Method.* Contractors typically use curing blankets, placing them when the concrete is hard enough.

As specified, the Contractor must continue to apply the atomized mist until the deck is covered with the curing media. To prevent the curing media from drawing moisture from the deck, good practice is for the Contractor to pre-wet the curing media before use. Check regularly that the bridge deck is kept wet throughout the 7-day cure period. The Contractor will likely have to reapply water to keep the curing media wet until they are allowed to remove the curing media. This requires the Contractor to schedule staff to work during a weekend to monitor and rewet as necessary. Verify regularly that the curing media is wet throughout the 7 days, as seen in Figure 7-34, and inform the Contractor if they need to reapply water.

Figure 7-33. Application of Atomized Mist on Bridge Deck

Figure 7-34. Wet Curing Blankets

At the end of the 7-day curing period, the Contractor must remove the curing media and apply a uniform coat of pigmented curing compound. Before use, the curing compound material must be accepted by the Department. Chapter 5 details practices for accepting and applying curing compound.

Although not specified, there may be unforeseen situations when SC staff could consider permitting the Contractor to apply curing compound before starting the 7-day water curing process. Such situations might include malfunctions of the misting equipment or adverse environmental conditions, such as extremely high winds. Exercise engineering judgment when evaluating the need for allowing an out-of-sequence curing procedure. Discuss this potential course of action with the Contractor to ensure they are prepared to proceed if required.

Monitor the surface temperature of the deck, particularly during hot weather. Bring to the Contractor's attention if the surface temperature exceeds the allowable for water cure (140 ºF), as they may have to propose alternative curing methods. Additionally,

Contract Specifications, Section 51-1.03I, *Concrete Structures – General – Construction – Protecting Concrete Structures,* requires maintaining minimum concrete temperature during the curing period.

For bridges requiring epoxy-coated reinforcement for concrete barriers, be aware that curing compound sprayed and left on the epoxy-coated reinforcement will negatively affect the bond between the reinforcement and barrier concrete. Curing compound on epoxy-coated reinforcement should be removed as soon as possible, taking care not to damage the coating. Other means for curing the bridge deck after the 7-day water cure method at the barrier areas can be discussed with the Contractor.

7-11 Testing Roadway Surfaces

The Department determines the acceptability of bridge deck surfaces based on three criteria noted in *Contract Specifications*, Section 51-1.01D(3)(b), *Concrete Structures – General – Quality Assurance - Department Acceptance – Testing Concrete Surfaces*:

1. Surface smoothness
2. Coefficient of friction
3. Crack intensity.

Except for coefficient of friction, SC staff performs acceptance testing to verify the acceptability of the above criteria.

7-11.01 Surface Smoothness

The smoothness of a roadway, including bridge decks, indicates its rideability and comfort for travelers riding on the traveled surface. A rough traveling surface will contain noticeable and/or multiple “humps” on the road, whereas a smooth one will have minimal. *Contract Specifications,* Section 51-1.01D(3)(b)(ii), *Concrete Structures – General – Quality Assurance – Department Acceptance – Testing Concrete Surfaces – Surface Smoothness,* lists the requirements of what is considered a smooth riding surface. It also specifies the test methods to be used. The requirements for a pedestrian overcrossing (POC) are discussed later in this chapter. The Contractor shall request testing at least 10 days prior to need and must ensure that the entire area to be tested has been cleared and cleaned of all obstructions.

For typical bridge decks, SC staff uses a bridge profilograph to test the surface along the longitudinal direction, and a 12-foot-long straightedge for testing along the transverse direction. The straightedge can also be used to verify non-compliant locations that were found using the profilograph. California Test 547, *Method of Test for Operation of Bridge Profilograph and Evaluation of Profiles,* provides instructions for using a bridge profilograph to test roadway smoothness (see Figure 7-35).

Furthermore, SC has a Profilograph video[1] to review the assembly and use of this item.

Figure 7-35. Smoothness Testing per California Test 547

SC staff marks with paint the non-compliant high points on the bridge deck. As mentioned in Chapter 6, the Begin Bridge (BB) and End Bridge (EB) are locations likely to not comply with the smoothness requirements.

As soon as possible after surface smoothness testing, write and transmit a letter to the Contractor advising that the deck has been checked for compliance with the requirements. The letter should describe the specific locations that fail to meet the straightedge specifications or describe any deficiencies in meeting the profilograph specification. The letter should state that the specific deficiencies must be corrected before the contract can be accepted. After the deficiencies have been corrected, or if the entire deck initially complies with the applicable requirements, then write and transmit to the Contractor a letter stating that the deck was checked and that it complies with the profilograph requirements and/or the straightedge requirements, whichever is applicable.

See Section 7-11.01A, *Sample Letter #1* below for a sample portion of a letter relative to concrete decks or concrete approach slabs which are to be covered with one inch or more of another material. See Section 7-11.01B, *Sample Letter #2* below for a sample portion of a letter relative to the completed surfaces of bridge decks, approach slabs, and adjoining 50 feet of approach pavement.

[1] Caltrans internal use only

Deck grinding is an acceptable means to improving deck profile and smoothness, hence the term “must grind” given to non-compliant high points. However, it is not without its problems. Grinding reduces the cover over the deck rebar and degrades the finished surface, leaving fractured aggregate particles exposed to the elements. This is particularly harmful in areas subject to freeze/thaw cycles and the application of de-icing salt. Deck grinding is not a complete solution for bridge deck surface issues that careful planning and execution during the deck pour can prevent.

7-11.01A Sample Letter #1

The finished surface of the deck concrete at _____ Bridge No._____ has been tested for compliance with the straightedge requirements in Sections 51-1.01D(3)(b)(ii), *Concrete Structures – General – Quality Assurance – Department Acceptance – Testing Concrete Surfaces – Surface Smoothness,* and 51-1.03F(5)(a), *Concrete Structures – Construction – Finishing Concrete –Finishing Roadway Surfaces – General,* of the *Contract Specifications*.

(USE EITHER)

All areas tested were found to comply with the specified straightedge requirements.

(OR)

Areas that do not meet the straightedge requirements have been marked, and are located as noted below:

(EXAMPLES) Sta. 300+52 (5 ft to 15 ft from Right EOD)

Sta. 301+60 (10 ft from Right EOD)

Hinge in Span 3 (Entire bridge width)

Transversely across longitudinal construction joint (Sta. 300+10 to 302+10)

These deficiencies must be corrected before the _____ overlay is placed. (describe overlay)

Notification must be given to the Resident Engineer prior to performing the corrective action.

7-11.01B Sample Letter #2

The completed surface of <bridge deck> <approach slab> <adjoining 50 feet of approach pavement> at Bridge No. _____, Bridge Name _____ has been tested for compliance with the profilograph requirements and the transverse straightedge requirements of Sections 51-1.01D(3)(b)(ii), *Concrete Structures – General – Quality Assurance – Department Acceptance – Testing Concrete Surfaces – Surface Smoothness ,* and 51-1.03F(5)(a), *Concrete Structures – Construction – Finishing Concrete –Finishing Roadway Surfaces – General,* of the *Contract Specifications*.

(USE EITHER)

All areas tested were found to comply with the specified profilograph (and) (or) the transverse straightedge requirements.

(AND/OR)

The profilograph trace indicates that there are high points in excess of 0.02 foot and that the profile count exceeds 5 per hundred feet. High points in excess of 0.02 foot have been marked with spray paint. A profile trace is available for your examination at the Resident Engineer's office. The completed surface must be ground in accordance with the requirements in *Contract Specifications,* Section 42, *Groove and Grind Concrete*, until the specified smoothness tolerances are met.

(AND/OR)

Straightedging in a transverse direction indicated that the roadway surface varied more than 0.02 foot from the lower edge of a 12-foot long straightedge at the following locations:

Areas that do not meet the straightedge requirement have been marked, and are located as noted below:

(EXAMPLE) 4 feet from the left EOD between Sta. 300+00 and Sta. 300+75.

Longitudinal construction joint at center of left bridge between Sta. 300+50 and Sta. 301+10.

These deficiencies must be corrected before the contract can be accepted. Notification must be given to the Resident Engineer prior to performing the corrective action.

7-11.02 Coefficient of Friction

The friction between vehicle tires and roadway surfaces is crucial, as it provides grip for tires to prevent vehicles from skidding. Friction is particularly important when the roadway is wet or icy. The coefficient of friction is a measurable value that indicates the amount of friction between objects. *Contract Specifications*, Section 51-1.01D(3)(b)(iii), *Concrete Structures – General – Quality Assurance – Department Acceptance – Testing Concrete Surfaces – Coefficient of Friction,* requires bridge deck surfaces and approach slabs to have a coefficient of friction of not less than 0.35.

After the deck surfaces and approach slabs have been textured, the deck surface will be tested for the coefficient of friction of the concrete surface under California Test 342, *Method of Test for Surface Skid Resistance with the California Portable Skid Test*. The test must be performed at a location which is representative of that portion of the deck surface exhibiting the lowest coefficient of friction. Once the representative area has been tested and shown to meet the specifications, more tests will not be required unless, in the opinion of the Structure Representative, the test results are not representative of the bridge deck skid resistance.

To meet the 25-day allowance in the *Contract Specifications* for coefficient of friction testing and to ensure that there are no delays to the contract, the tests will have to be scheduled as soon as possible. Coefficient of friction testing through METS can be arranged by contacting the appropriate staff listed on the instruction tab of the *Request for Portable Skid Test Form*[1]. Instructions for viewing the Skid Testing group's schedule are also included. Instructions for requesting skid testing services through METS Data Interchange for Materials Engineering (DIME) website can be found in the METS Office of Quality Assurance & Source Inspection (OQASI)[1] website. Figure 7-36 shows skid testing being performed. Skid testing can also be performed by the local District Laboratory. The process for requesting testing varies for each District.

SC staff witnessing the skid test must verify that the skid test machine has a valid calibration under California Test 114, *Method of Test for Calibration of California Portable Skid Tester*.

[1] Caltrans internal use only

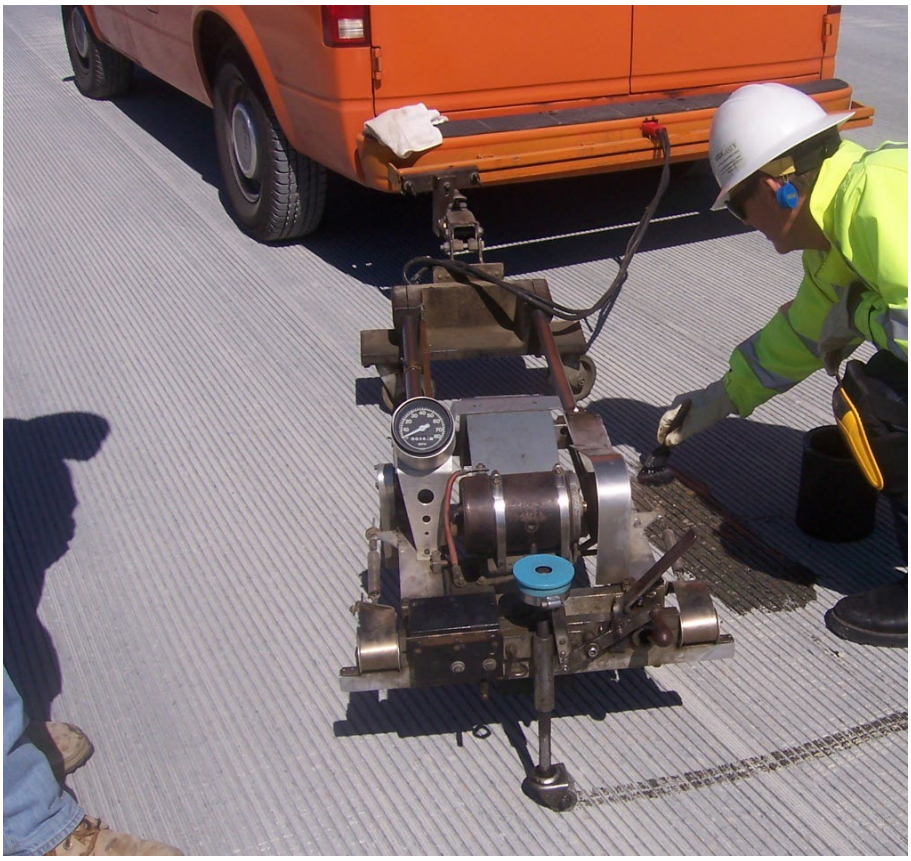

Figure 7-36. Coefficient of Friction (Skid) Testing per *California Test 342*

Deck and approach slab portion surfaces not meeting the minimum coefficient of friction must be ground or grooved.

7-11.03 Crack Intensity

Crack intensity is the visual measure of the amount of surface cracks that exceed the maximum allowable width. *Contract Specifications,* Section 51-1.01D(3)(b)(iv), *Concrete Structures – General – Quality Assurance – Department Acceptance – Testing Concrete Surfaces – Crack Intensity,* limits the cumulative length of cracks that exceed 0.02 inches within a specified area. The length and area depend on the type of bridge deck, as noted in the specifications.

A visual crack comparator shown in Figure 7-37 is commonly used for this purpose. A feeler gauge may also be used. A very close approximation to 0.02 inches is the 0.5-mm pencil lead of a common mechanical pencil. If any areas are found to be non-compliant, the bridge deck must be treated with methacrylate resin to address the issue.

Figure 7-37. Crack Width Measurement with a Crack Comparator

While performing crack intensity assessments, maintain concise records and mark the deck to readily identify any areas requiring mitigation or further evaluation.

7-12 Pedestrian Overcrossings

Pay special attention to the deck construction of POCs and similar pedestrian bridges and facilities. In addition to *Contract Specifications*, Section 51-1.03F(6), *Concrete Structures – General – Construction – Finishing Concrete – Finishing Pedestrian Overcrossing Surfaces*, POC walkways must also comply with American with Disabilities Act (ADA) requirements. ADA standards establish guidelines for pedestrian facilities, including minimum clear width, texture finish, running (or profile) slope, and cross slope. The latest Design Information Bulletin (DIB) 82*, Pedestrian Accessibility Guidelines for Highway Projects*, provides design guidance for permanent pedestrian facilities.

POCs must be designed so that the walking surface – namely the bridge deck – complies with ADA requirements. However, several factors may hinder compliance, and these potential issues may not always be accounted for by the BD Project Engineer. Review the contract documents during the early stages of the project, taking into consideration ADA compliance. This is best done during the project development stage, so that design oversights can be addressed before the project is finalized.

Discuss issues identified with the BD Project Engineer. Pay particular attention to factors that may negatively affect the profile slope, as the POC design may not have accounted for design features and other potential issues that could cause the constructed deck to exceed ADA limits for running slope. Obtain the maximum allowable running slope limit from the designer. Then consider the following when reviewing the contract documents:

1. Construction Allowances (Tolerances) and ADA Compliance – The design profile of the POC may be significantly close to the ADA limit when considering construction tolerance. Caltrans ADA Compliance Inspection Report forms consider 0.2 percent as the allowable construction tolerance for slopes. Note that the accuracy of specified measuring devices is accounted for in the allowable tolerances.
2. Bridge Camber Impact on Profile Slope – For a bridge span that slopes uphill, the long-term design bridge camber typically increases from the low end toward mid-span. The addition of the increasing design bridge camber causes the as-constructed profile slope to be steeper than the design profile slope for this portion of the span. This may result in portions of the deck exceeding the ADA running slope limit when constructed, as shown in Figure 7-38. Even after falsework removal, residual camber may still impact the profile at the time of bridge opening.

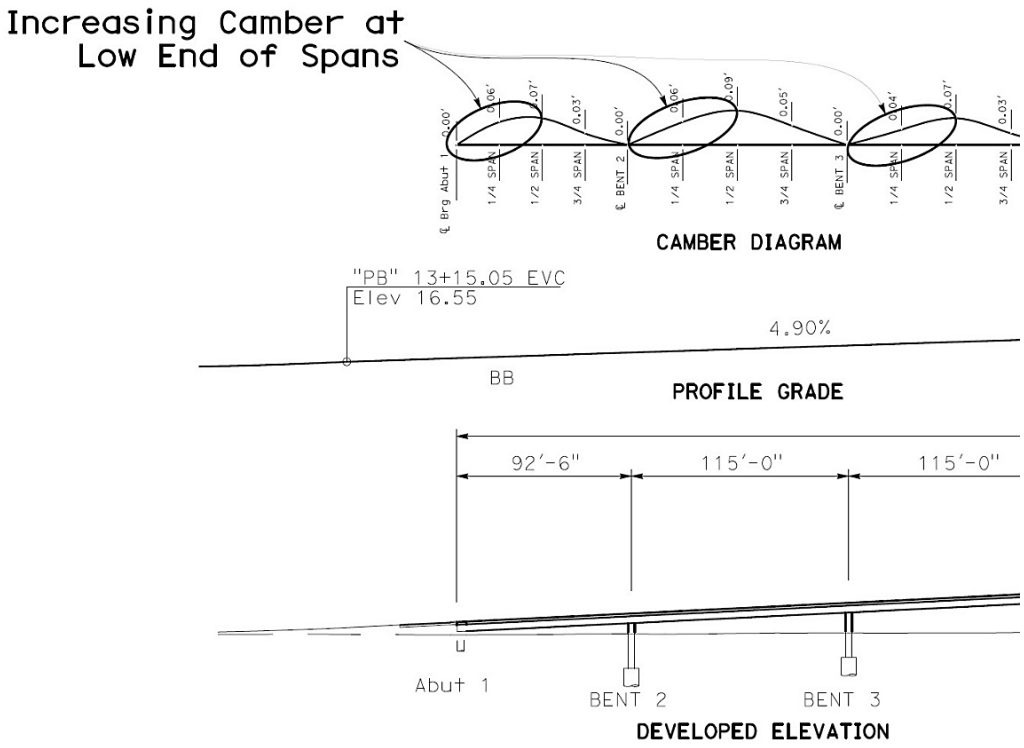

Figure 7-38. Increasing Long-Term Camber Increases Constructed Profile

3. The profile shown in the project plans is typically at the bridge centerline with the cross slope being consistent along horizontal curves. Due to the geometry of horizontal curves, the profile slope increases from bridge centerline moving transversely towards the inner curve. This is because the curve length decreases when moving towards the inner curve, while the elevation change stays consistent. Conversely, the profile slope decreases from bridge centerline to outer curve, as the curve length increases while the elevation change still stays consistent (see Figure 7-39).

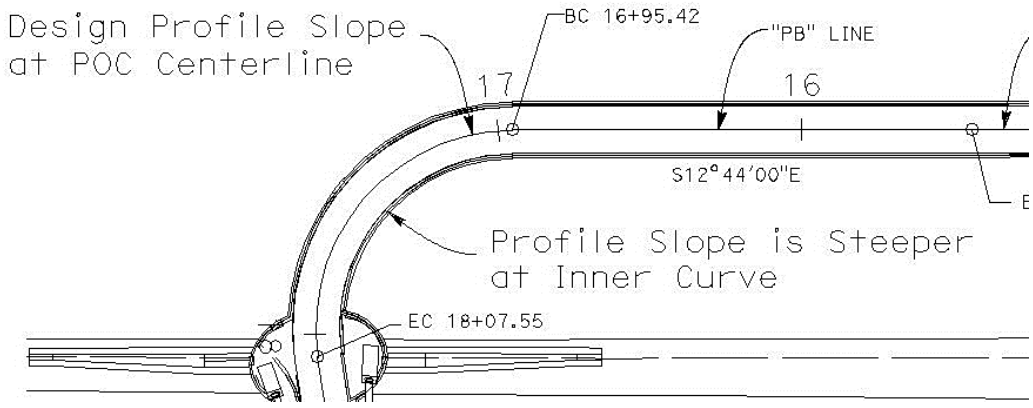

Figure 7-39. Profile Slope is Steeper at Inner Curve

Methods of deck construction and inspection for POC bridge decks are similar as those for concrete bridge decks. However, due to the stringent ADA requirements, consider incorporating the below additional practices for POC deck construction:

1. To maximize grade control, place elevation control points (deck dowels) as reasonably close to the minimum allowable transverse distance as possible (4 feet transversely to the POC centerline). *Contract Specifications*, Section 51-1.03F(6), *Concrete Structures – General – Construction – Finishing Concrete – Finishing Pedestrian Overcrossing Surfaces,* allows a closer transverse distance of control points for POCs compared with *Contract Specifications*, Section 51-1.03F(5)(a), *Concrete Structures – General – Construction – Finishing Concrete – Finishing Roadway Surfaces – General,* for roadway bridges (24 feet from centerline).
2. After the Contractor grades the screed rails, use a digital level to verify that the cross-slope and profile slope of the rails are close to the expected values (ensure that the digital level is calibrated per the manufacturer's instructions).
3. Verify that objects built into or on the bridge deck, such as drain gratings, cover plates, and railings, are installed such that they will be ADA compliant.

Contract Specifications, Section 51-1.01D(3)(b)(ii), *Concrete Structures – General – Quality Assurance – Department Acceptance – Testing Concrete Surfaces – Surface Smoothness,* provides separate requirements and testing methods for deck smoothness of POCs and bridge decks. The smoothness of POC bridge decks is tested with a 12-foot-long straightedge in the longitudinal direction and a 6-foot straightedge in the transverse direction.

POC bridge decks are not required to meet a specified coefficient of friction. According to *Contract Specifications*, Section 51-1.03F(6), a broom finish surface texture is required. However, DIB 82 advises using "engineering judgment" to evaluate the acceptability of the walking surface for pedestrians. Regarding crack intensity, the requirements for POC bridge decks are the same as those for decks for vehicular bridges.

Before contract acceptance, the Resident Engineer is responsible for documenting that permanent pedestrian facilities comply with ADA requirements, using the appropriate ADA Compliance Inspection Report form. These forms are organized in a table within the *Documentation and Certification* section of the ADA Handbook described and linked to below. Assist the Resident Engineer in performing the appropriate measurements and documentation. Directions for measuring and documenting, including what tools to use and how often to measure, are included in the form. The *Permanent Pedestrian Facilities ADA Compliance Handbook* contains more thorough inspection checklists. Use the checklist that is most applicable.

Chapter 8: Precast Concrete

Table of Contents

Chapter 8: Precast Concrete 1
Table of Contents 1
8-1 Introduction 2
8-2 Advantages of PC Concrete Members 2
8-3 Preparation and Fabrication 3
8-3.01 Quality Control 3
8-3.02 Submittals 7
8-3.03 Precast Concrete Quality Control Meeting 9
8-3.04 Quality Assurance 10
8-3.05 Pre-Installation Inspection 12
8-4 Precast Prestressed Concrete Girders and Slabs 13
8-4.01 Deflection/Camber 13
8-4.02 Bearing Pads 14
8-4.03 Girder Stability 14
8-4.04 Bar Reinforcement 17
8-4.05 Girder Splicing 20
8-4.06 Forms and Cast-In-Place Concrete 20
8-5 Accelerated Bridge Construction 23
8-5.01 Ultra-High Performance Concrete 24

8-1 Introduction

While most concrete structures are designed to be cast-in-place (CIP), some projects may require specific members to be fabricated off-site. These members are referred to as precast (PC) concrete members. PC concrete members are cast and cured at a precast facility in a controlled environment. Once fabrication is complete, the members are transported to the construction site, where they are installed in their permanent locations.

Contract Specifications, Section 90-4, *Concrete – Precast Concrete,* and Section 51-4*, Concrete Structures – Precast Concrete Members,* contain the requirements for fabricating, handling, and erecting precast concrete members. Precast prestressed (PC PS) concrete piles have additional requirements, including those for fabrication and construction, under Section 49-2.04, *Piling – Driven Piling – Precast Prestressed Concrete Piling*.

8-2 Advantages of PC Concrete Members

The use of PC concrete is chosen during the design phase for several reasons. The following are key advantages of utilizing PC concrete members:

1. Minimize or eliminate falsework – Most PC concrete members can be erected with minimal to no use of falsework. Falsework for CIP concrete construction may have unacceptable impacts to traffic and sensitive environments, or may be difficult to install due to obstructions or conflicts. These issues can be significantly minimized or avoided entirely by using PC members.
2. Parallel construction activities – Precasting allows the fabrication of concrete members to be partially or fully off the critical path, allowing these activities to occur simultaneously with other on-site activities. In contrast, CIP concrete construction is very linear, where one activity must be completed before the next begins. Precasting, however, facilitates the parallel progression of significant bridge work off-site, minimizing delays and improving overall project efficiency.

Other advantages to using PC concrete members include improved quality control, elimination of risk of weather-related impacts, and increased safety and efficiency.

Box culverts, drain inlets, piles, columns, deck panels (discussed in Chapter 7, *Bridge Deck Construction*), slabs, and girders are examples of common precast concrete members. PC PS concrete members are a specific type of precast concrete, as their fabrication includes prestressing steel. Figure 8-1 shows the fabrication of a PC PS concrete pile. PC PS concrete girders are the most frequently precast concrete members used in bridge construction.

Figure 8-1. PC PS Concrete Pile Fabrication

8-3 Preparation and Fabrication

8-3.01 Quality Control

Contract Specifications, Section 90-4.01D(1), *Concrete – Precast Concrete – General – Quality Assurance – General,* categorizes various types of PC concrete members into four tiers. In general, Tier 1 is designated for bridge members, Tier 2 for earth retaining systems and sound walls, Tier 3 for drainage, and Tier 4 for other members not included in the previous tiers. Refer to the aforementioned specification for complete tier classification of specific PC concrete members. Figures 8-2 through 8-7 show examples of various Tier 1 PC concrete members.

Figure 8-2. Round PC PS Concrete Piles

Figure 8-3. Square PC PS Concrete Piles

Figure 8-4. PC PS Concrete Panels

Figure 8-5. PC Concrete Abutment

Figure 8-6. PC Concrete Column

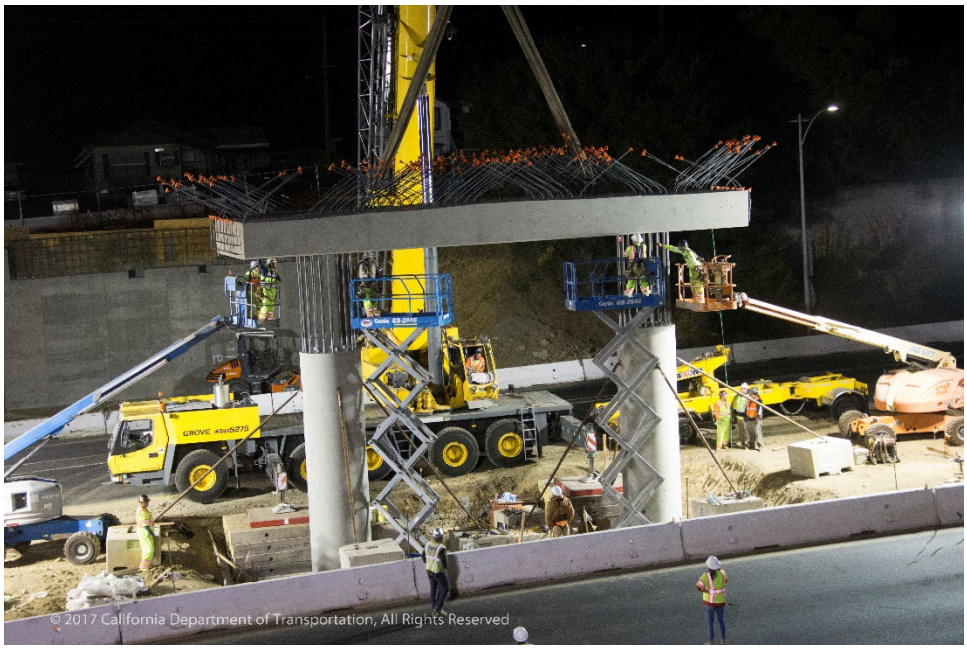

Figure 8-7. PC Concrete Bent

The level of the quality control (QC) required depends on the tier classification of the PC concrete members as detailed in *Contract Specifications,* Section 90-4.01D(2), *Concrete – Precast Concrete – General – Quality Assurance – Quality Control*. Tiers 1 and 2 have the most rigorous requirements. For example, PC concrete members in these tiers must be fabricated at a plant that is on the Department's Authorized Facility Audit List for Structural Precast Concrete. This ensures that the fabricator is capable of adhering to the required QC standards, and that Materials Engineering and Testing Services (METS) is familiar with the plant's processes. Should any issues arise during fabrication, they can be addressed before the members are transported to the jobsite.

Moreover, for Tier 1 and 2 members, the Contractor must submit a Precast Concrete Quality Control Plan (PCQCP) prior to the Quality Control Meeting, which the Quality Control Manager of the plant must attend. Consult with your METS Representative (METS Rep) to get the latest information on the facility where the precast members are being fabricated at and to request assistance in reviewing the PCQCP.

The efficiency of a casting yard relies on its ability to cycle work crews and casting beds quickly. To facilitate this, high-early-strength concrete mixes and steam curing are commonly used to accelerate the removal of PC concrete members from their casting beds. However, these methods can result in excessively high temperatures within the curing concrete, potentially compromising the integrity of the members. For this reason, there are limits on the temperatures that the concrete is allowed to reach, thus the requirement for a temperature monitoring and recording plan in the PCQCP.

Tiers 3 and 4 do not require METS involvement and can be released on site by the Resident Engineer (RE) or Structure Representative (SR) based on a signed certificate of compliance (COC).

Repairs to damaged PC concrete members must be authorized by Structure Construction (SC), the Bridge Design (BD) Project Engineer, and METS.

8-3.02 Submittals

For the fabrication and erection of PC concrete members, the Contractor must submit various submittals for the Department's review and authorization. The following is a list of required submittals, with necessary information and key considerations to be aware of while performing a review. These submittals must be authorized before the associated activity can begin:

1. Shop Drawings
    a. Include METS and the BD Project Engineer in the review process.
    b. Verify layout, dimensions, material, embeds, compliance with concrete specification requirements, and requirements for specific PC concrete members per *Contract Specifications*, Section 51-4.01C(2), *Concrete Structures – Precast Concrete Members – General – Submittals – Shop Drawings*.
    c. Confirm inclusion of epoxy-coated bar reinforcement or prestressing stands, if required.
    d. For PC PS girders, check inclusion of anticipated deflections and calculations per *Contract Specifications*, Section 51-4.01C(2)(b), *Concrete Structures – Precast Concrete Members – General – Submittals – Shop Drawings – Girders.*
2. Concrete Mix Design
    a. Review in accordance with applicable subsections of *Contract Specifications*, Section 90, *Concrete*, including Section 90-4.02, *Concrete – Precast Concrete – Materials.*
    b. Unless specified otherwise, self-consolidating concrete (SCC) may be used to cast PC concrete members in accordance with *Contract Specifications*, Section 90-5, *Concrete – Self-Consolidating Concrete*.
    c. For box culverts, *Contract Specifications*, Section 51-4.02D(5), *Concrete Structures – Precast Concrete Members – Materials – Fabricating Precast Concrete Members – Box Culverts,* allows dry cast methods for fabrication. Refer to ASTM C1837, *Standard Specification for Production of Dry Cast Concrete Used for Manufacturing Pipe, Box, and Precast Structures*, for guidance on dry cast concrete.
    d. Include METS in the review process.

3. Precast Concrete Quality Control Plan (PCQCP) (Tiers 1 and 2)
    a. Required for each PC concrete plant.
    b. Ensure all information required in *Contract Specifications*, Section 90-4.01C(3), *Concrete – Precast Concrete – General – Submittals – Precast Concrete Quality Control Plan,* is included.
    c. Include METS in the review process.
    d. Must be submitted prior to PC concrete QC meeting.
4. Erection Work Plan
    a. Required for PC PS concrete girders and deck panels.
    b. Verify plan is signed and sealed by a licensed engineer in the State of California.
    c. Review and analyze details for transporting, unloading, staging, lifting, erecting, and temporary bracing.

Provide copies of all submittals relevant to precasting, such as the PCQCP, mix designs, shop drawings, and schedules, to METS for their concurrent review. METS and SC should meet to review and resolve their comments together prior to discussing the comments with the Contractor and fabricator. Provide METS with copies of all authorized submittals to be used for inspection purposes.

In addition to the above, the below submittals may be required during and after fabrication:

1. QC Test Results (Tiers 1 and 2)
    a. Submitted by the Contractor via the Data Interchange for Materials Engineering (DIME) database.
2. Certificates of Compliance (all Tiers) for:
    a. Cementitious material – Signed by the PC concrete product manufacturer.
    b. Curing compound
    c. Each PC concrete member
        i. Tier 1 and 2 – signed by QC manager (QCM)
        ii. Tier 3 – signed by QC inspector
        iii. Tier 4 – prepared by manufacturer.
3. Daily Production Log (Tiers 1 and 2)
    a. Must include daily temperature data for Tier 1 PC concrete members.
4. PC Concrete Report (Tiers 1 and 2).

8-3.03 Precast Concrete Quality Control Meeting

Fabrication and delivery of PC Concrete members requires the coordination and cooperation of at least the following parties:

1. The Contractor and the PC concrete QCM
2. A representative from the PC fabricator plant
3. The RE and/or SR
4. METS.

All parties must collaborate to ensure the timely inspection, release, and delivery of PC concrete members to the project.

Contract Specification, Section 90-4.01D(2)(b), *Concrete – Precast Concrete – General – Quality Assurance – Quality Control – Quality Control Meeting,* requires a PC QC meeting to be held after the Contractor submits their PCQCP. The purpose of this meeting is to ensure all parties are aligned with the PC concrete scope of work and the contract requirements.

While the Contractor and RE/SR are primarily responsible for contract administration, the PC fabricator and METS handle most of the material inspections. For this reason, the METS Rep typically leads this meeting.

The METS Rep will likely address the following topics during the PC QC meeting:

1. Roles and Responsibilities – Clarify the expectations of the Contractor, QCM, QC inspector(s) (QCI), RE/SR, METS Rep, and the METS inspector.
2. PCQCP – Review the requirements of the plan and address deficiencies of the submitted PCQCP.
3. Reporting – Discuss the reporting requirements of the QCI and QCM.
4. Non-conforming Work – Discuss the process for reporting and handling non-conforming work.
5. Job-specific Details – Highlight design details and contract requirements unique to the project.

In addition to the fabrication-related items listed above, it is recommended to discuss the process of delivering the PC concrete members to the jobsite. Due to the size and weight of members that are typically transported, delivery can involve several logistical, technical, and safety-related challenges. Mitigation of these challenges may require extensive coordination with external project stakeholders including California Highway Patrol (CHP), adjacent municipalities, and the Department's Permitting Office.

Discuss the PC QC meeting with the METS Rep in advance so they can confirm their availability as well as prepare the relevant agenda and discussion topics.

8-3.04 Quality Assurance

As with most material fabricated off-site and shipped to the construction site, METS provides quality assurance inspection at the site of fabrication (PC concrete fabrication facility). Conforming material is tagged and released by METS, prior to being shipped to the jobsite.

Review the Contractor's submitted Form CEM-3101, *Notice of Material to be Used*, to see which facility will be producing PC concrete members and verify that they are on the Department's Authorized Facility Audit List for Structural Precast Concrete. Although facilities on the Authorized Facility Audit List have been authorized to fabricate PC concrete members on Caltrans projects, high personnel turnover or other factors may impact a fabricator's efficiency, consistency, and quality. Contact your METS Rep to discuss their level of confidence in the chosen facility. This will also open the lines of communication with METS before receiving any mandatory submittals which they will aid in reviewing.

The SR may request to schedule a PC fabricator site visit with the METS Rep. This will provide an opportunity to become familiar with the facility's operations and QC.

METS documents their source inspections of PC concrete member fabrication by recording relevant activities and observations on a Form TL-6033, *Precast Concrete Inspection Report*. The form includes checkboxes to document the status of the facility audit, authorized materials, submittals, and pouring activities the report covers. Figure 8-8 is a sample cover page of a TL-6033. METS provides copies of the TL-6033 to the RE and SR. Upon completion of final inspection, METS places release tags, TL-0624, *Inspection Release Tag* ("orange tag"), on each of the PC concrete members that are authorized for delivery.

If METS determines a PC concrete member does not comply with the contract requirements but still meets its intended function, METS may instead attach a TL-0625, *Materials Suitability Tag* ("blue tag"). In such cases, the METS Rep will have already informed the RE and SR of the non-compliance, and the SR should have coordinated with the BD Project Engineer to determine how to proceed with accommodating and incorporating the non-compliant member. An example of this situation is if a PC concrete member does not meet specified camber requirements.

Refer to METS Office of Quality Assurance and Source Inspection (QASI) Manual[1], Sections 51-F, *Concrete Structures – Precast Concrete Members*, through 51-J, *Concrete Structures – Precast Concrete Box Culverts,* for further clarification regarding METS' role and expectations in the inspection and release of PC concrete members and other materials incorporated into construction projects.

[1] Caltrans internal use only

STATE OF CALIFORNIA • CALIFORNIA STATE TRANSPORTATION AGENCY

DEPARTMENT OF TRANSPORTATION
DIVISION OF ENGINEERING SERVICES
MATERIALS ENGINEERING AND TESTING SERVICES
OFFICE OF QUALITY ASSURANCE AND SOURCE INSPECTION

Contract #: [redacted]
EFIS #: [redacted]
Vendor #: [redacted]

PRECAST CONCRETE INSPECTION REPORT

Resident Engineer: [redacted] **Date Inspected:** 10/10/2023
Project Name: [redacted] **OQASI Arrival Time:** 0630
Prime Contractor: [redacted] **OQASI Departure Time:** 1600
Precast Firm: [redacted] **Location:** [redacted], CA
Quality Control Contact: [redacted] **Quality Control Present:** ☒Yes ☐No

Bid Item: 103
Contract Quantity: 31
Type of PC Member: Precast Prestressed Concrete Box Girder (100'-110')

Caltrans PC Audit:	☒Yes ☐No	**Exp. Date:**	Expires 6/2024
Authorized Shop Drawings:	☒Yes ☐No	**Date:**	9/29/2023
Authorized Mix Design:	☒Yes ☐No	**Date:**	10/2/2023 (Mix Design # S9.8-25FA)
Authorized Strand:	☒Yes ☐No	**Date:**	6/29/2023*, 9/12/2023 (*EA# [redacted])
Authorized PCQCP:	☒Yes ☐No	**Date:**	6/28/2023

EPD has been authorized: ☐Yes ☒No ☐N/A **If Yes, mill name/location(s):**

☐ **Pre-Fabrication** ☒ **Pre-Pour** ☒ **Pour** ☒ **Post-Pour** ☐ **Final Release**

Summary of Items Observed: Caltrans Quality Assurance Inspector [redacted] (QA), arrived on site at [redacted] in response to a submitted Inspection Request to observe various fabrication operations on precast prestressed concrete box girders for the [redacted]. On arrival, QA with [redacted] (QCM), [redacted] (QC), and [redacted] (Plant Engineer).

Post-Pour Operations for Box Girder SB2.2 (2 of 11) (Cast 10-9-23):

QC reported to QA that overnight breaks for 10/9/2023 Casting averaged 5470 psi meeting stripping strength requirements (5000 psi stripping requirement per drawing 1.1 of the approved plans). QC dataloggers recorded a high internal temperature of 152.0 and 136.4 degrees. QA datalogger recorded a high internal temperature of 149.0. Data provided by QCM showed no rise in temperature above 40 degrees per hour and that bed enclosure was maintained above 60 degrees until cut down. QA performed random post-pour dimensional checks, finding no issues. QA visual inspection of bottom surface found surface to be smooth with no obvious irregularities. QC performed post pour dimensional inspection and found zero tolerance issues. QA witnessed QCM perform camber measurements with QCM recording 1" camber. Drawing 2.1 lists anticipated mid-span camber at 1". Box girder was moved to patching area with cleanup not underway as of yet. No other post-pour observations to report.

Strand Stressing and Pre-Pour Operations for Box Girder SB2.2 (3 OF 11) (Cast 10-10-23):

Stressing began at 0904 and was completed at 0930 hours. Ambient temperature at time of stressing was recorded as 64 degrees. QA/QC monitored initial and final tensioning thru completion and verified that the

TL-6033, Precast Concrete Inspection Report (06/01/2023 PH) Page 1 of 4

Routing: 1. Contract File 2. Branch Senior, Resident Engineer, MR 3. Structure Representative (if applicable)

Figure 8-8. Sample Form TL-6033, *Precast Concrete Inspection Report*

8-3.05 Pre-Installation Inspection

Although PC concrete members are released by METS before delivery, it is critical for SC staff to thoroughly inspect members as they arrive to the jobsite. Verify that the delivered members have been released by METS by collecting the TL-0624 orange tags and ensuring they correspond to the delivered material. Measure controlling dimensions and deflection (camber) to confirm they align with the project plans and calculations. Visually inspect damage-prone areas including the ends of girders, embed locations, dunnage supports, and adjacent any repairs made prior to release. Confirm that PC concrete members are handled exclusively at the designated pick points outlined in the authorized erection work plan, as seen in Figure 8-9. Inspect for any handling damage and check that members are properly stored on-site to prevent potential damage. If necessary, coordinate with the Contractor to add additional support at the bearing points.

Figure 8-9. PC Concrete Handled at Pick Points

Inspect the quality of the concrete surfaces for any cracks, spalls, honeycombing, or other defects. Note any areas requiring repair, as these should be addressed before PC concrete members are installed. All repairs made must be in accordance with the authorized repair procedures. Only patching material listed for its intended use on the Department's Authorized Materials List (AML), Precast Concrete Cementitious Based Repair Material is allowed for patching PC concrete members.

Exposed spacers and positioning reinforcement are typical defects for box culverts. Although these issues are not grounds for rejection per *Contract Specifications*, Section 51-4.02D(5), *Concrete Structures – Precast Concrete Members – Materials – Fabricating Precast Concrete Members – Box Culverts,* coordinate with the Contractor to implement appropriate repairs, as these may contribute to future corrosion issues.

8-4 Precast Prestressed Concrete Girders and Slabs

8-4.01 Deflection/Camber

As mentioned in Chapter 7, PC PS concrete girder and slabs exhibit time-dependent behavior after being stressed in the casting bed and before deck concrete placement. Prestressing is performed under an unbalanced condition, as the prestressing force is designed to account for the full weight of the structure. However, the deck, diaphragms, barrier rail, and deck furnishings (e.g., fencing, sidewalks, etc.) are not yet in place when girders are initially installed. As a result, the member experiences upward deflection after release of prestressing strands due to the eccentricity of the strand profile. This upward deflection is sometimes referred to as “camber” and intentionally designed to counteract the downward deflection induced by the design load demands. Do not confuse this with the bridge camber indicated in the project plans, which is the amount of downward deflection of the girders anticipated as a result of the additional dead load applied, along with long term creep, once bridge construction is complete.

The Contractor’s shop drawings must account for this time-dependent behavior, ensuring the girder or slab erection and deck concrete placement are scheduled appropriately. The BD Project Engineer must review the schedule and verify that the camber calculations noted in the shop drawings for the PC PS concrete member span are appropriate. If the anticipated time between fabrication and installation is changed significantly – such as early fabrication or construction delays – the amount of bridge camber may need to be reevaluated. Effects of prestressing loss, creep, and shrinkage should be considered when reevaluating. Discuss this with the BD Project Engineer if schedule delays become an issue.

If excessive camber is observed before girder or slab installation, collaborate with the BD Project Engineer to evaluate and address the impact of the camber on the final structure. It may be necessary to adjust bridge elements. *Contract Specifications*, Section 51-4.03B, *Concrete Structures – Precast Concrete Members – Construction – Girders, Box Girders, and Double T Girders,* outlines the restrictions for making adjustments to accommodate excessive camber.

Minimum permanent vertical clearances must be maintained, along with the final bridge deck profile characteristics. This is typically achieved by adjusting the height of the haunch, which is the concrete buildup between top of girder and bottom of deck. Project plans typically specify the minimum superstructure depth (measured from the top of deck to the bottom of girder), so the thickness of haunch should vary along the bridge length based on the vertical profile, cross slope, camber, and dead load deflection.

Unless otherwise specified on the project plans, set the minimum haunch thickness based on constructability considerations. For example, if the precast deck panels are used as deck forms, a minimum haunch thickness of ½ inch might be needed for bedding strips under the deck panel. In any case, the top flange of girder must not encroach into the bridge deck.

Avoid introducing an additional vertical curve, or "hump", to the final profile while planning adjustments. Consider factors such as bridge skew, orientation of the bridge deck finishing machine, and camber height to ensure proper bar reinforcement clearances.

Section 5.3.9, *Deflection and Camber*, of Bridge Design Memo, BDM 5.3, *Precast Prestressed Girders*, provides a detailed discussion on PC PS girder camber and explores potential methods to address camber related issues.

8-4.02 Bearing Pads

PC PS concrete girders and slabs installed on bridge spans are typically supported at their ends by permanent elastomeric bearing pads which are installed on abutment seats or bents. METS tests and releases elastomeric bearing pads by lot. When delivered to the jobsite, the pads must be accompanied by certified test results and COCs. Confirm that the lot number(s) of the pads matches the lot number(s) noted on the COC. Verify also that the type of elastomeric pad delivered – nearly always steel-reinforced – matches the type and dimensions specified in the project plans.

Bearing pads play a critical role in the stability of PC PS concrete members when installed in their final location. Confirm that they are at the correct orientation and slope when placed on abutment seats. Even a small misalignment can compromise the stability of the PC PS member. Bearing pads for PC PS girders are typically level. For voided slabs, bearing pads may need to match the bridge superelevation, as specified in the project plans.

The project plans may specify the placement of galvanized sheet metal on the bearing pads, with the top of pads coated with silicone grease. This can create potential issues for the installation of PC PS concrete girders, as it introduces a risk of girders sliding. Make the Contractor aware of this potential risk so that they can take precautions during girder installation. Additionally, verify that temporary bracing is installed promptly per the authorized erection work plan to minimize this risk.

8-4.03 Girder Stability

As previously noted, the Contractor must submit an erection work plan for the Department's review and authorization. This plan must detail the procedures for unloading, lifting, erecting, and temporarily bracing the girders. During girder picking

and installation, verify that the work complies with the authorized erection work plan to prevent any potential failures in the field. Be aware that even if it appears the Contractor is following their plan, there remains a risk for incidents and mishaps to occur.

It is important for the licensed engineer who developed the erection work plan to evaluate not only the in-place stability of girders but also for the stability during the picking and placement processes. For the incident in Figure 8-10, it was determined that the girder required longitudinal stabilizers to prevent lateral bending during picking.

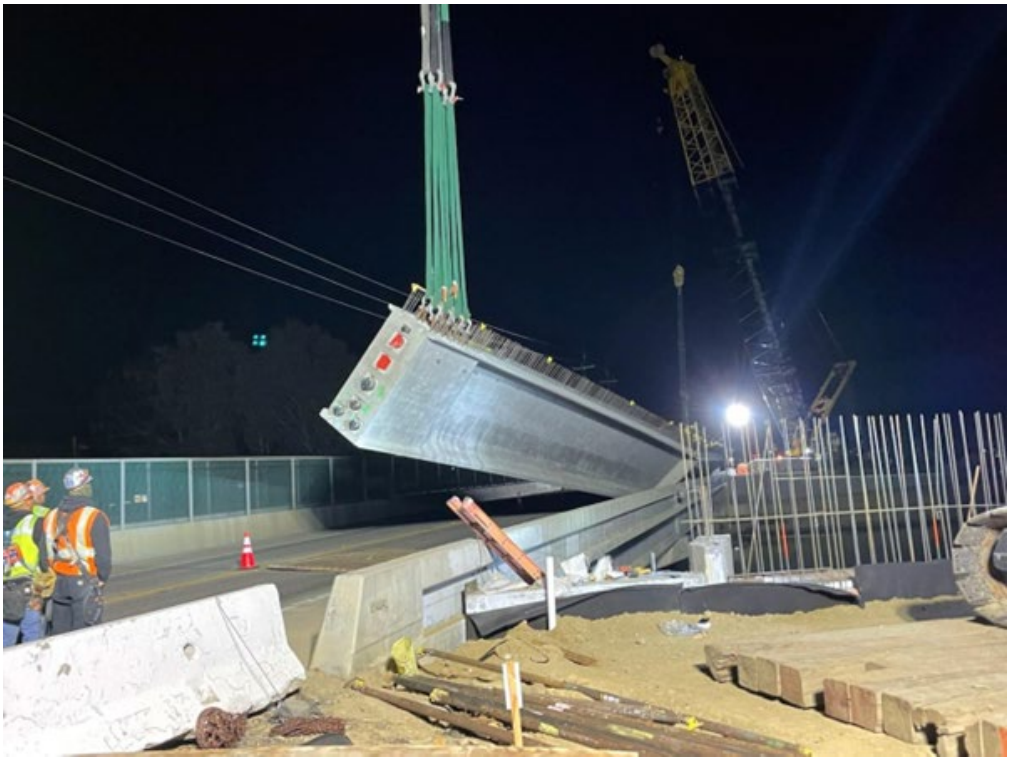

Figure 8-10. PC PS Girder Failure During Picking

Confirm girders are stable while each is being placed and when they are in their final position. Typically, girders are temporarily braced against each other to provide lateral support. Therefore, the erection work plan must specify how the Contractor intends to stabilize the first girder before installation of subsequent girders. Figures 8-11 and 8-12 are example details of PC PS concrete girder bracing, and Figure 8-13 is a picture illustrating temporary girder bracing that has been installed between girders. The Precast/Prestressed Concrete Institute (PCI) has published *Recommended Practice for Lateral Stability of Precast, Prestressed Concrete Bridge Girders*, which provides guidance for assessing the stability of precast members during various phases of installation, including during transport and seating; note that this publication is available for download from the "Free Resources" tab.

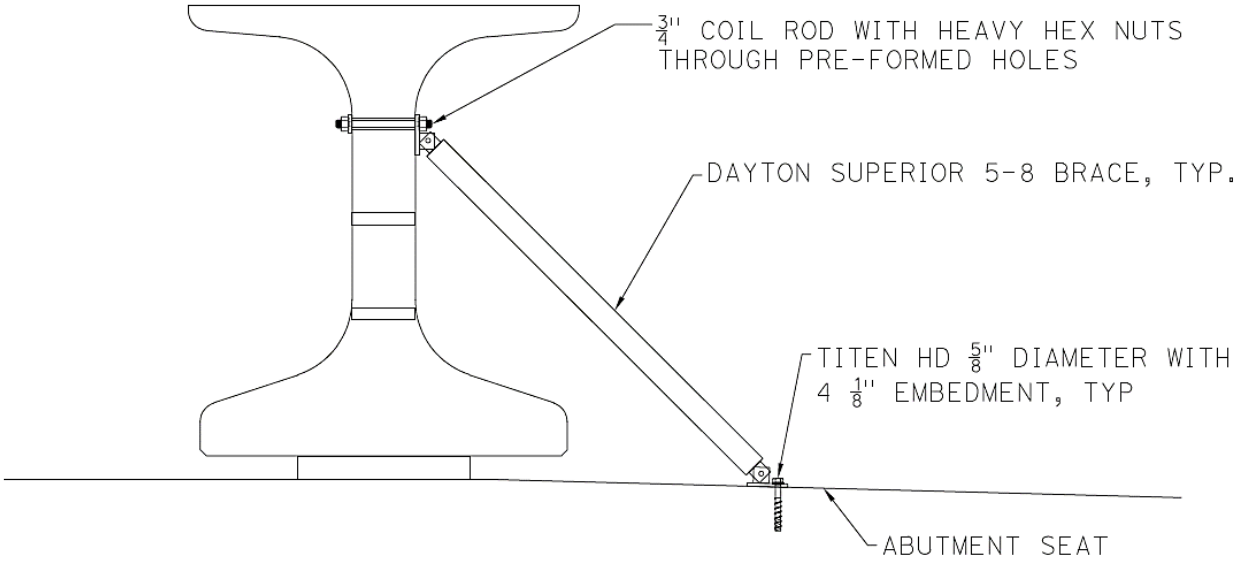

Figure 8-11. PC PS Concrete Girder Bracing Detail – 1st Girder

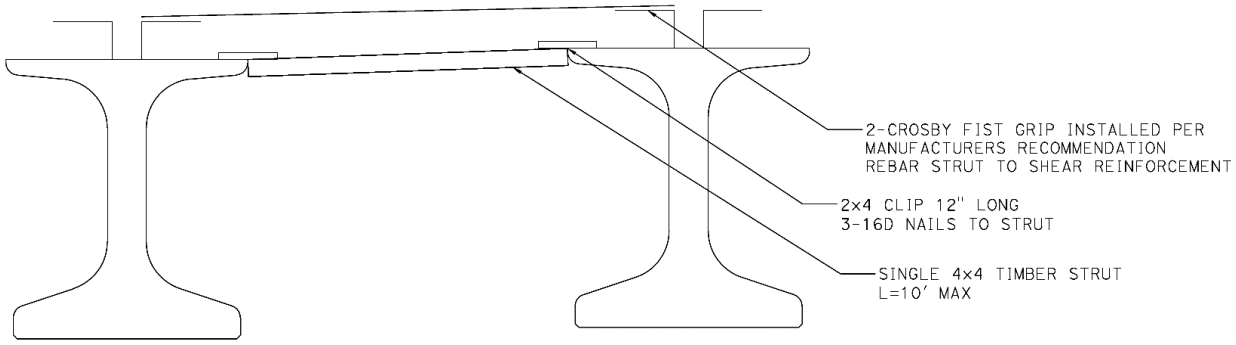

Figure 8-12. PC PS Concrete Girder Temporary Bracing Detail – Remaining Girders

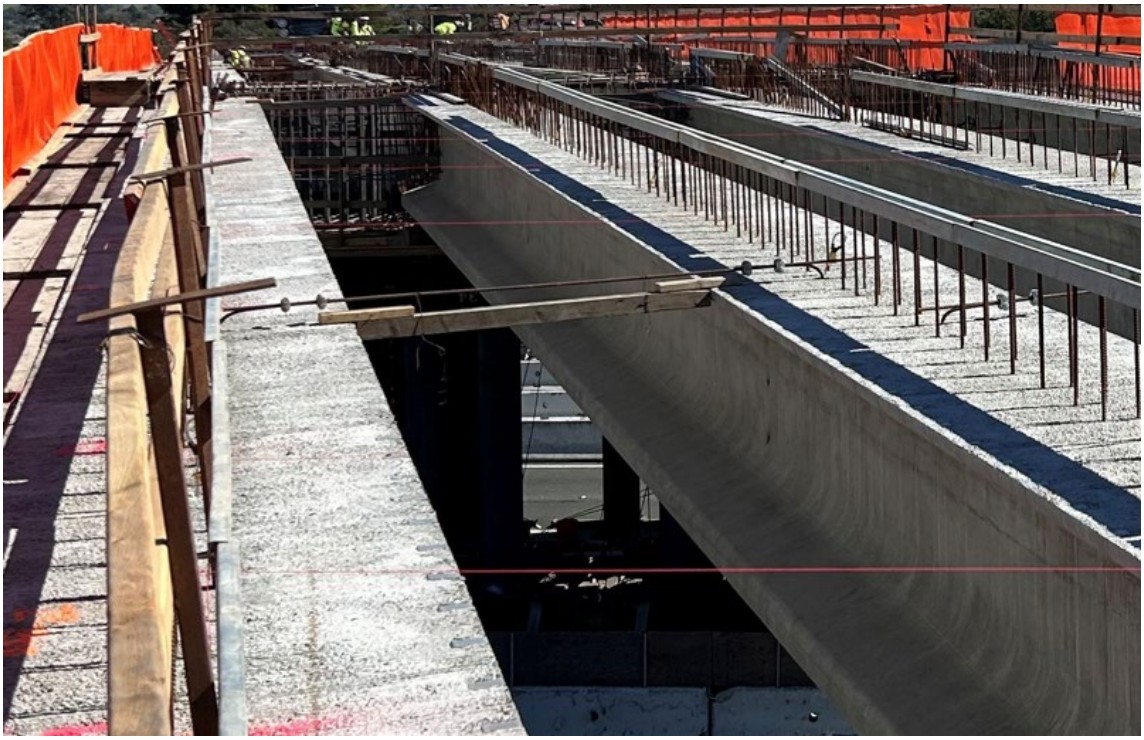

Figure 8-13. PC PS Girder Temporary Bracing Between Members

8-4.04 Bar Reinforcement

During source inspection, METS inspects bar reinforcement for PC concrete members at the PC facility before concrete placement. For PC concrete girders, project plans typically specify stirrups to be cast straight so that they can be bent in the field after the girder installation. Be aware that impalement protection, discussed in Chapter 7, must be in place once the girders are installed and access is in place. The PC concrete girders shown in Figure 8-14 had impalement protection in place prior to being installed.

Refer to Section 4-4.02, *Material and Fabrication Verification* of Chapter 4, *Reinforcement*, for guidance regarding field bending of bar reinforcement, including minimum required bend diameter and tail length as specified in the *Building Code Requirements for Structural Concrete* (ACI 318) published by American Concrete Institute (ACI). Bar reinforcement must not be damaged after being field bent.

Figure 8-14. Bar Reinforcement Impalement Protection

When reviewing the project plans and shop drawings, take note if the exposed reinforcement is to be epoxy-coated. Only epoxy-coated reinforcement complying with ASTM A775/A775M, *Standard Specification for Epoxy-Coated Steel Reinforcing Bars*, which is colored green, is permitted to be field bent. The Contractor must repair any damage to the epoxy coating in accordance with ASTM A775/A775M. Unbent epoxy-coated stirrups from installed PC concrete girders are shown in Figure 8-15. Figure 8-16 shows these stirrups after bending.

Figure 8-15. Unbent Epoxy-Coated Bar Reinforcement Stirrups

Figure 8-16. Bending of Epoxy-Coated Bar Reinforcement Stirrups

8-4.05 Girder Splicing

For bridges requiring very long full-length PC PS concrete girders or project sites with restrictive access routes, the project may specify fabrication of shorter PC concrete segments to be spliced together during installation. Post-tensioning the spliced segments may also be specified to achieve structural continuity. Adjoining surfaces of closure joints must have been fabricated with roughened vertical surfaces if shear keys were not specified. Check that post-tensioned ducts cast in the PC concrete segments extend sufficiently so that they can effectively connect to the ducts of the adjoining segment. Refer to Section 5.3.13, *Spliced Precast Prestressed Girders*, of previously referenced BDM 5.3 for additional information.

8-4.06 Forms and Cast-In-Place Concrete

The underside of PC concrete girder bridge decks are exposed, requiring that their forms be removed. The exception is if stay-in-place forms, such as precast concrete deck panels (PDP) or permanent steel deck forms (PSDF), are specified. PSDF may also be allowed if proposed by the Contractor and authorized by the Department. Refer to Chapter 7 for further details regarding bridge deck forms for PC concrete girder bridges.

The Contractor may choose to install deck overhang formwork brackets onto the exterior girders before girders are placed in their final location, as seen on the girder in Figure 8-17. This work is easy to accomplish while girders are still on the ground. Verify that formwork brackets are installed per all authorized shop drawings before girder placement. The authorized shop drawings for the PC concrete member will indicate any required inserts cast into the member for attaching formwork brackets. These inserts must correspond with details provided in the authorized shop drawings for the overhang formwork brackets and meet manufacturer requirements for spacing, depth, and edge distance.

Figure 8-17. Overhang Formwork Brackets Before Girder Installation

Project plans typically indicate the superstructure depth at girder supports (such as abutment and/or bent cap), and, in some cases, at mid-span. The mid-span depth would be based on the anticipated girder camber/deflection. Deck thickness is also shown on project plans. Figure 8-18 is an example detail showing deck thickness and structure depth at the bearing centerline, which aligns with the centerline of the girder. While the haunch thickness can be calculated using this information, it varies along its width due to the deck cross slope. As mentioned in Section 8-4.01, the superstructure depth may be adjusted from the plan dimension to account for deviations in the anticipated girder camber, provided that the changes comply with *Contract Specifications*, Section 51-4.03B with abutment or bent cap seat elevations adjusted accordingly.

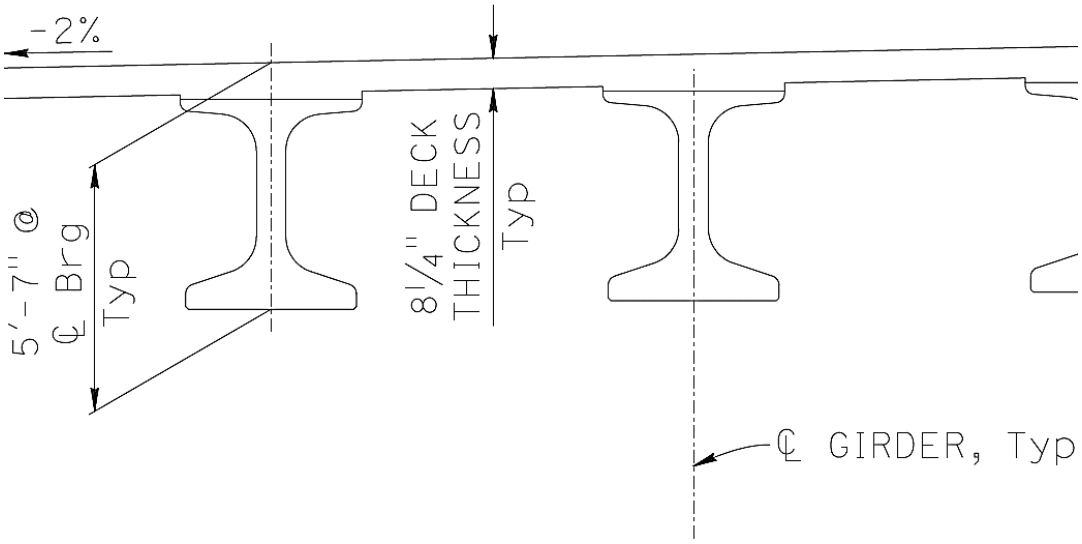

Figure 8-18. Structure Depth and Deck Thickness Detail

Contract Specifications, Section 51-1.03D(2), *Concrete Structures – General – Construction – Placing Concrete – Concrete Bridge Decks and Diaphragms,* requires intermediate diaphragms be cast prior to the deck for bridges with simple span PC concrete girders. Check that the project plans show a construction joint at the intermediate diaphragm/deck interface to reflect this requirement. If no joint is shown, consult with the BD Project Engineer to clarify the intent. Verify also that connection hardware from PC concrete girder to intermediate diaphragm, typically sets of bolts inserted into the PC concrete girder, are properly installed. Figure 8-19 provides an example detail of an intermediate diaphragm showing callouts for both the construction joint and the connection bolts.

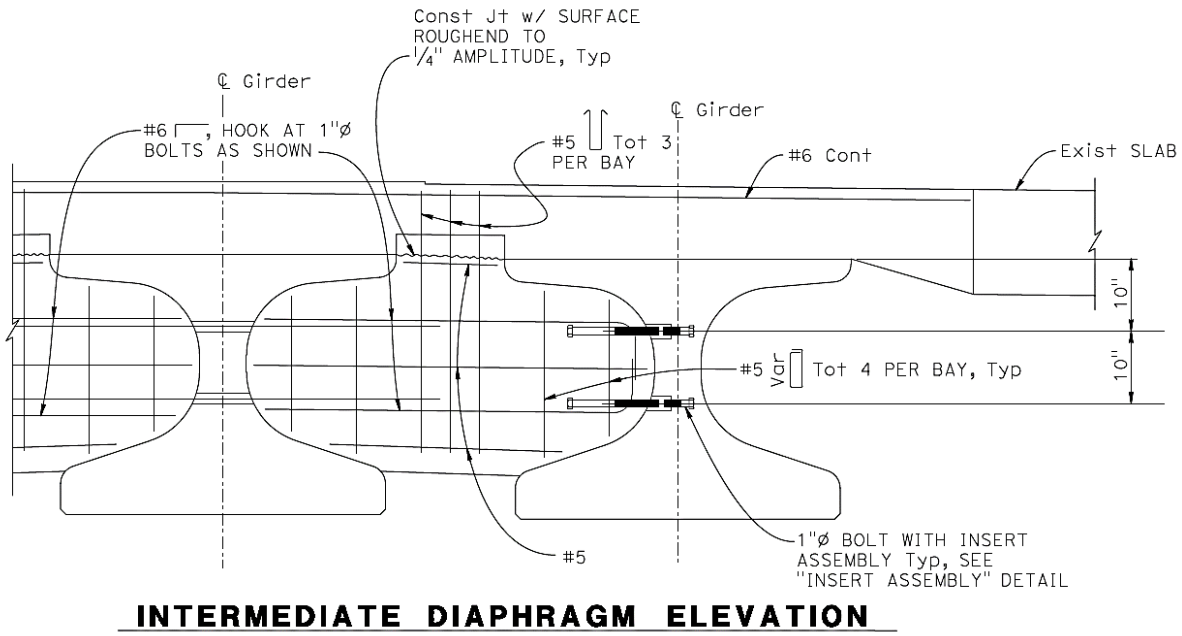

Figure 8-19. Intermediate Diaphragm Detail

8-5 Accelerated Bridge Construction

The need to reduce construction related impacts contributed to the development of Accelerated Bridge Construction (ABC). ABC is a project delivery method that utilizes innovative bridge design and construction techniques, which may deviate from traditional methods, to reduce construction schedule, minimize traffic disruptions, and lessen other potential impacts. One advantage of using PC concrete members, as discussed in Section 8-2, is the ability to fabricate concrete members off-site while on-site activities progress simultaneously. This benefit aligns closely with the ABC concept, and thus the reason why PC concrete members are commonly incorporated in ABC projects.

The use of PC concrete members alone does not necessarily qualify a project as an ABC project if it also incorporates more traditional bridge design and construction techniques. Review the contract specifications and project plan sheets to verify the project you are working on is an official ABC project by locating the logo shown in Figure 8-20:

Caltrans®
ACCELERATED BRIDGE CONSTRUCTION

Figure 8-20. Caltrans ABC Logo

If the project is an ABC project, review the Department's Accelerated Bridge Construction (ABC) Manual[1] (note that the ABC Manual uses the term "precast element" instead of "precast member"). The manual contains various checklists that SC staff should utilize when administering ABC projects.

In addition to consulting the BD Project Engineer, contact the SC Falsework Engineer[1] for ABC-related project questions and issues. The SC Falsework Engineer serves as the ABC specialist for SC. For any sampling and testing requirements, coordinate with the METS Rep as needed.

While PC PS concrete girders and piles have long been common PC concrete applications in bridge construction, ABC projects use a more extensive range of PC concrete members, such as columns, pier caps, abutments, deck panels, and wing walls. The ABC Manual refers to these items as Prefabricated Bridge Elements (PBEs).

8-5.01 Ultra-High Performance Concrete

ABC may incorporate the use of specialty material like Ultra-High Performance Concrete (UHPC) to shorten on-site bridge construction time. UHPC is a cementitious composite of finely ground constituents combined with a superplasticizer and approximately 2 percent steel fibers. It can be designed to achieve concrete strengths in excess of 9,000 psi in just 10 hours, making it ideal for creating strong structural connections between PC members in the tight work windows typical of ABC projects. However, UHPC is more temperamental than regular concrete. Work closely with the METS Rep to ensure the work is compliant with contract requirements. The Department maintains an AML for UHPC products that are authorized for use on Caltrans' projects.

UHPC is not commonly required and, as such, is not included in the current *Standard Specifications*. If it is required for a particular project, the relevant requirements will be provided in the project-specific *Special Provisions*.

UHPC may be specified for various bridge elements, including the following:

1. PC Member Connections
    a. Closure joints
    b. Grouted keyways (see Figures 8-21 and 8-22)
    c. Grouted duct splices
    d. Pocket connections
    e. Socket connections
2. Link Slabs
3. Bridge Deck Overlays.

[1] Caltrans internal use only

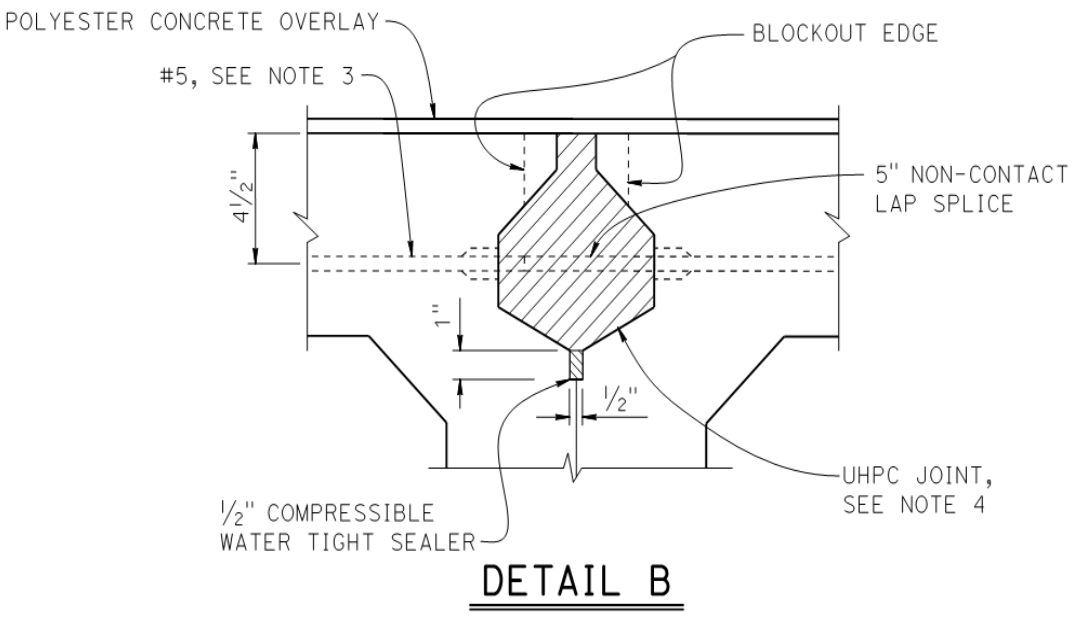

Figure 8-21. UHPC Grouted Keyway Detail

Figure 8-22. Grouted Keyway Filled With UHPC

The Contractor is typically required to submit a UHPC work plan for the Department to review and authorize, perform a full-scale mockup of UHPC placement (a mockup workplan may be required), and in some cases perform a full-scale preassembly of the completed PC PS girders at the fabricator's facility to verify fit. Mockups should be performed under the same conditions that the actual UHPC placement will be performed in, including atmospheric conditions, and carried out by the Contractor's field staff who will be performing the work on-site. This ensures that the Contractor is familiar with construction of UHPC, understands UHPC material requirements and limitations, and can properly complete the work. Note that wooden mockups may not accurately replicate surface temperatures.

Although the Contractor may request the UHPC mockup requirement be waived, it is not recommended. Exceptions may be taken if the Contractor has recently and successfully performed a similar UHPC pour using the same UHPC material in a comparable environment, and with the same crew.

The below is a list of lessons learned and critical items for SC staff to be aware of when working with UHPC:

1. Material quantity and expiration – Confirm the Contractor has the correct amount of material ordered and available for the project, including the amounts associated with required mock-ups, samples, head-cups, joint tolerances, construction losses and required over-pour, and that the material on site is not expired.
2. UHPC manufacturer's representative – A representative from UHPC material supplier must attend the UHPC preconstruction meeting and be on site during UHPC pours. The representative will be responsible for any required adjustments during the batching process to achieve the required material properties.
3. Testing facility preparation – The testing facility, whether mobile or at a permanent location, must be prepared to process QC samples promptly. In some cases, QC cylinder breaks may need to be performed within 1-3 hours of preparation.
4. Transportation to testing facility – Transportation of samples must be performed carefully. Verify that samples are securely handled by a designated person and delivered to the testing facility.
5. Pre-wet saturated surface dry (SSD) condition – Typical UHPC specifications require the joint be pre-wet for at least 2 hours, with the surfaces interfacing with UHPC being dry immediately prior to UHPC placement. Obtaining and maintaining SSD condition until the pour is one of the most important factors for achieving a good bond at the interface (see Figure 8-23).

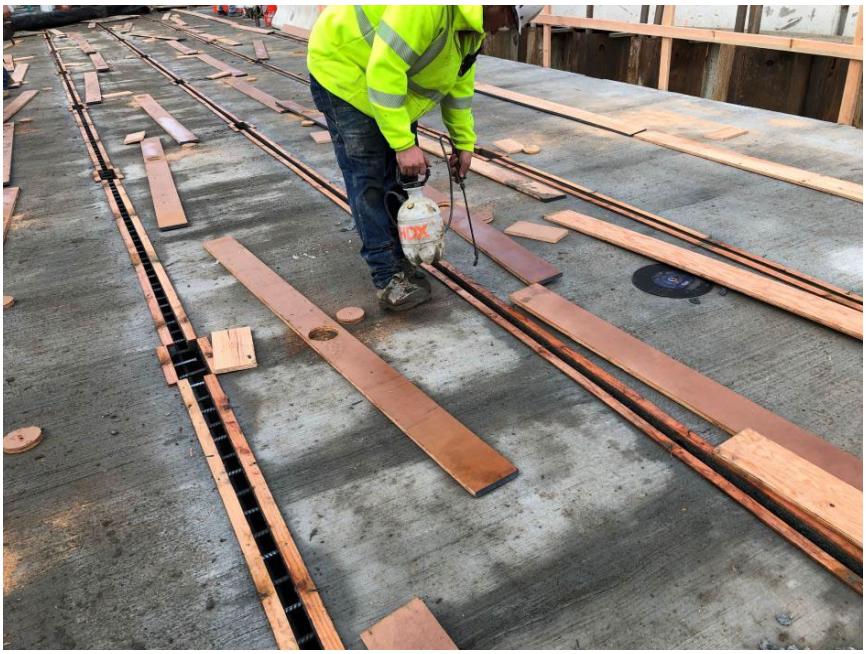

Figure 8-23. Laborer Maintaining Saturated Surface Dry Conditions

6. Material conveyance – The Contractor should develop a method to transport UHPC from the mixer to the pour location. Manual transport, such as laborers carrying 5-gallon buckets across a job site, can be physically demanding and dangerous. The Contractor's plan should include back-up measures appropriate for the selected method of placement, whether they be additional labor or standby buggies/carts.
7. Creating and maintaining head – Structures with a cross slope or longitudinal slope require tight, sealed joints at top and bottom to prevent leakage. Also, it is essential to maintain proper head – keep the level of the UHPC pour high – at intermittent locations. The Contractor's selected method of maintaining constant positive head throughout the placing operation will dictate how much additional material should be ordered and accounted for.
8. Curing –The Contractor uses time-temperature prequalification, to establish the theoretical compressive strength based on heat input over time, otherwise known as strength-maturity relationship. In the case of an ABC project, proper heat curing is very important, particularly if the specifications require an applied curing temperature to achieve rapid cure. This also includes the cylinders being cured in the same fashion as the bridge to produce accurate opening age breaks.
9. Redundancy – Due to the nature of UHPC as a material, along with the rigid time constraints associated with ABC construction, it is critical that all elements of the proposed UHPC placement and curing plans are assessed for potential failure modes and the appropriate back-up plans developed and agreed upon ahead of the production operation.