Chapter 5: Concrete

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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.

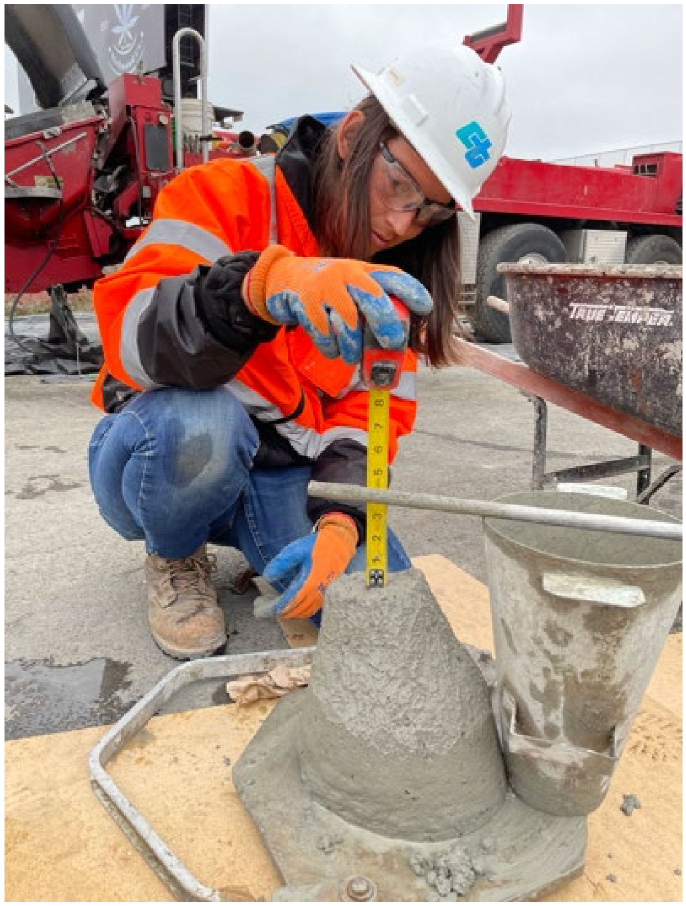

Figure 5-1. Slump Test

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.

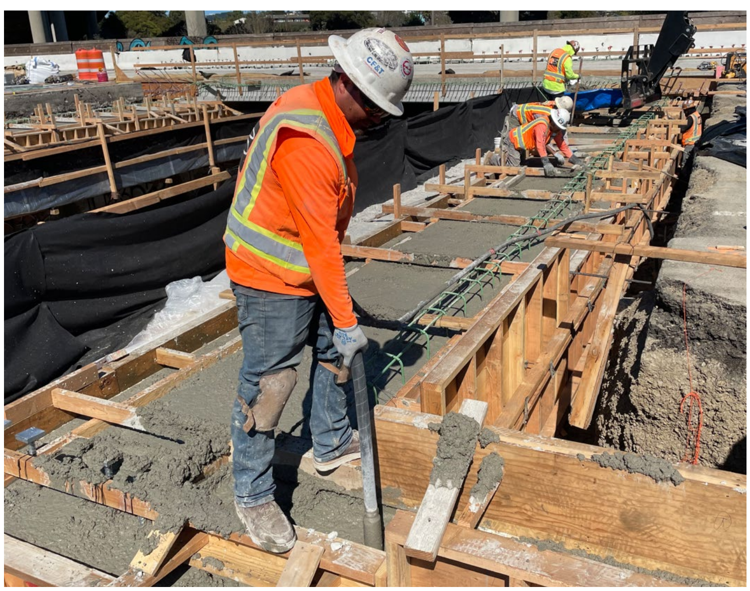

Figure 5-14. Vibrating Using Internal Vibrator

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.

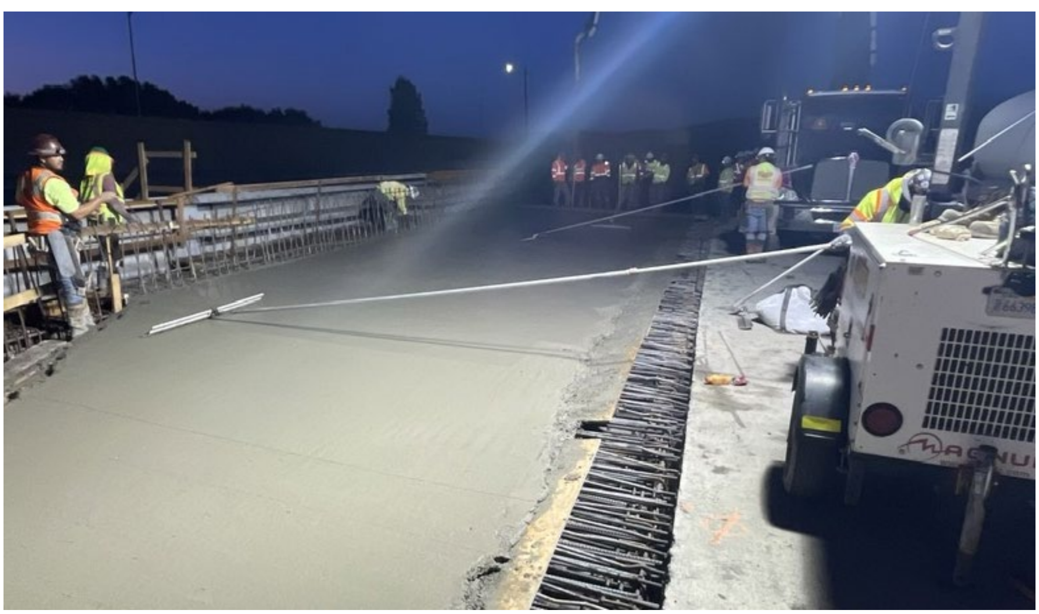

Figure 5-17. Bull Floats

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.

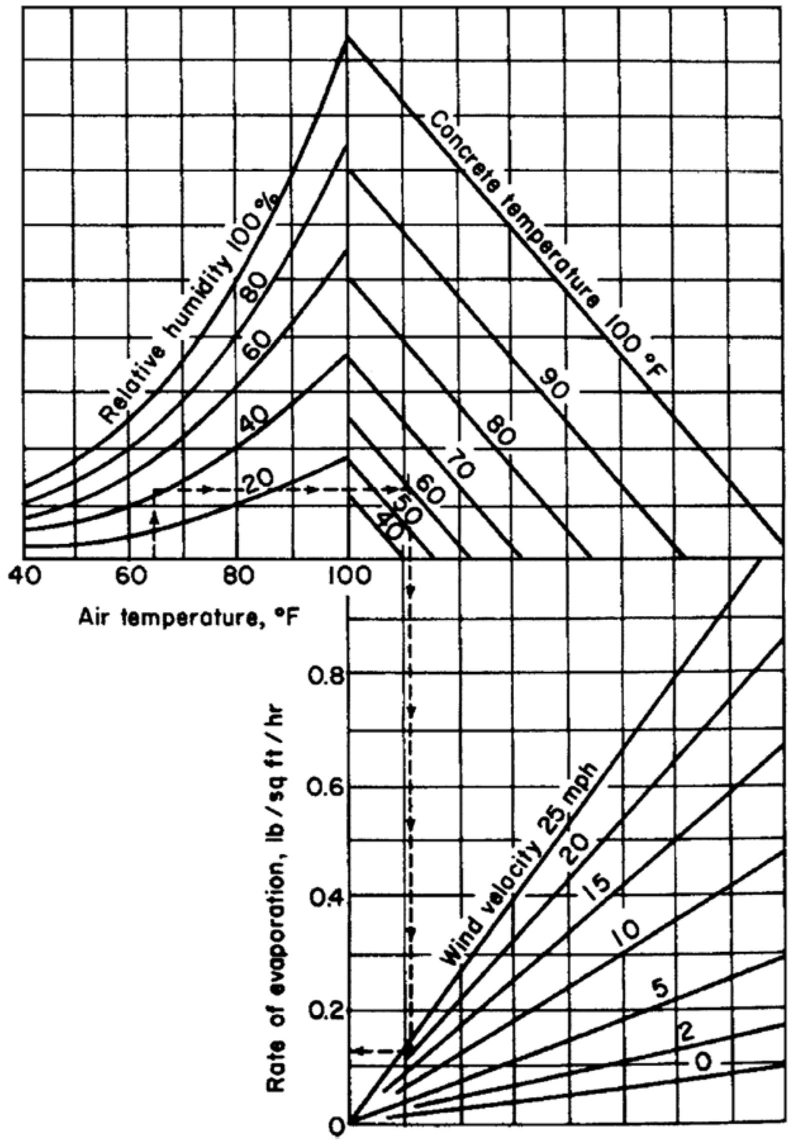

Figure 5-18. Evaporation Rate Nomograph (ACI 308, Standard Practice for Curing Concrete)

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.

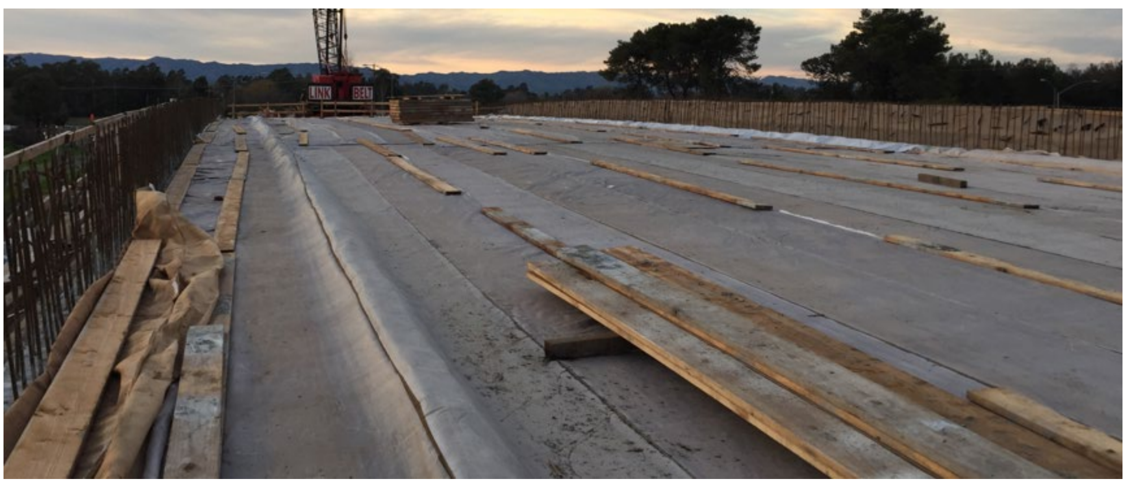

Figure 5-20. Curing with Burlene Curing Blankets

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.

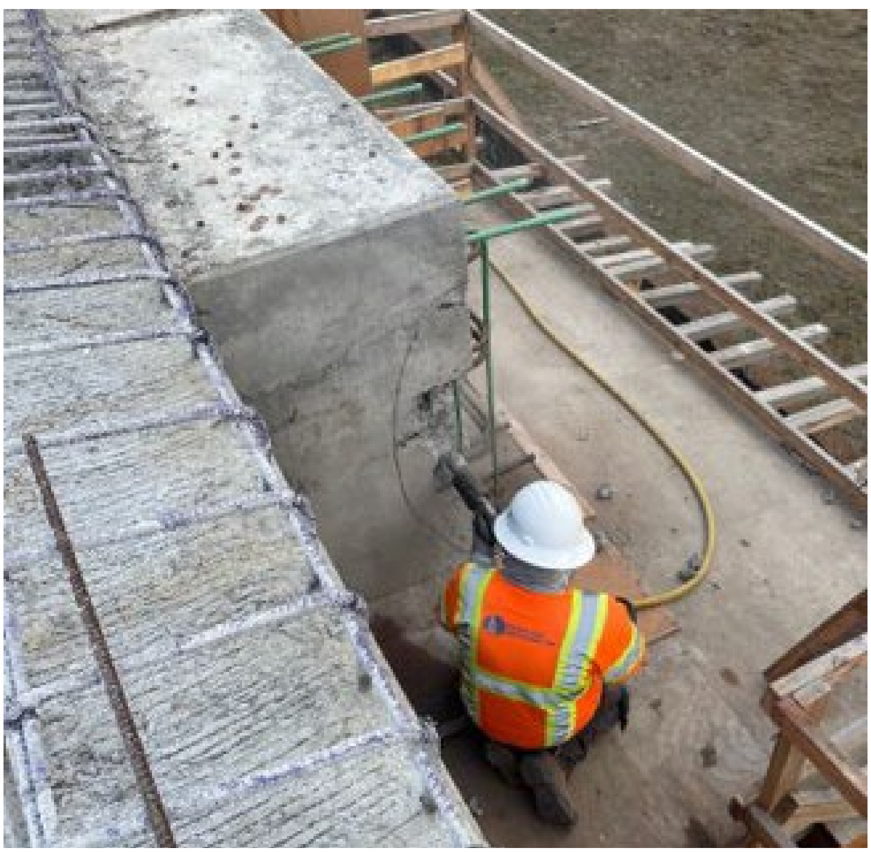

Figure 5-28. Concrete Removal for Repair

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.

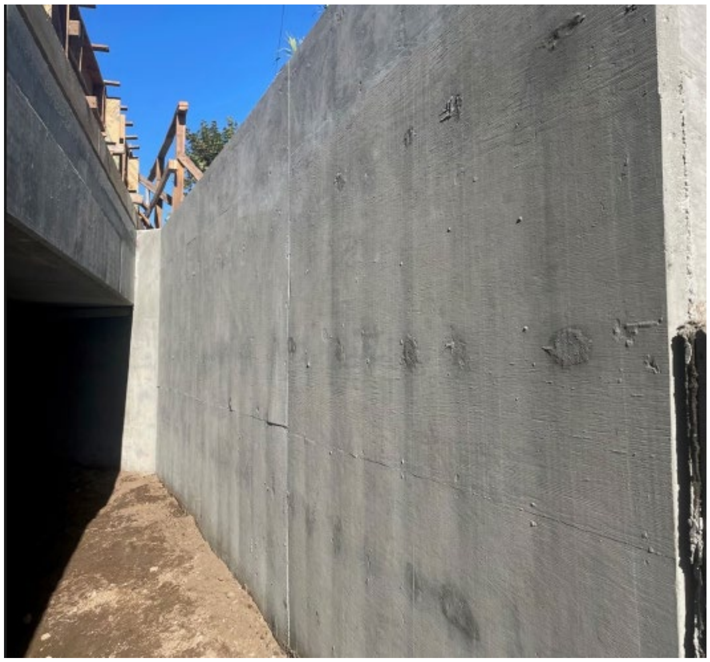

Figure 5-30. Ordinary Surface Finish

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.

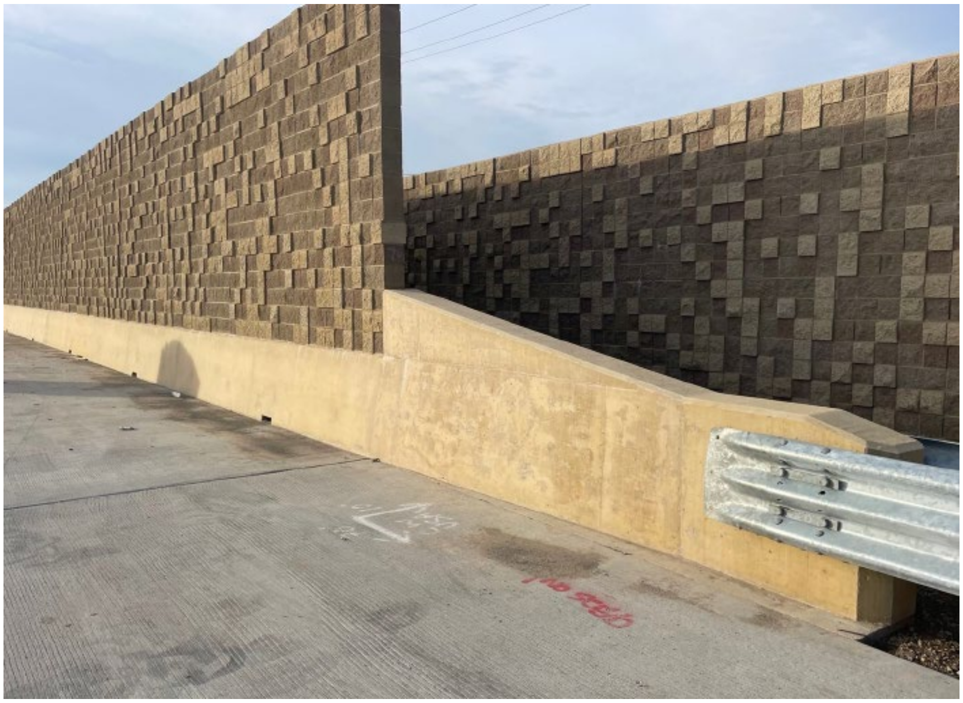

Figure 5-37. Barriers Constructed with Integrally Pigmented Concrete

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.

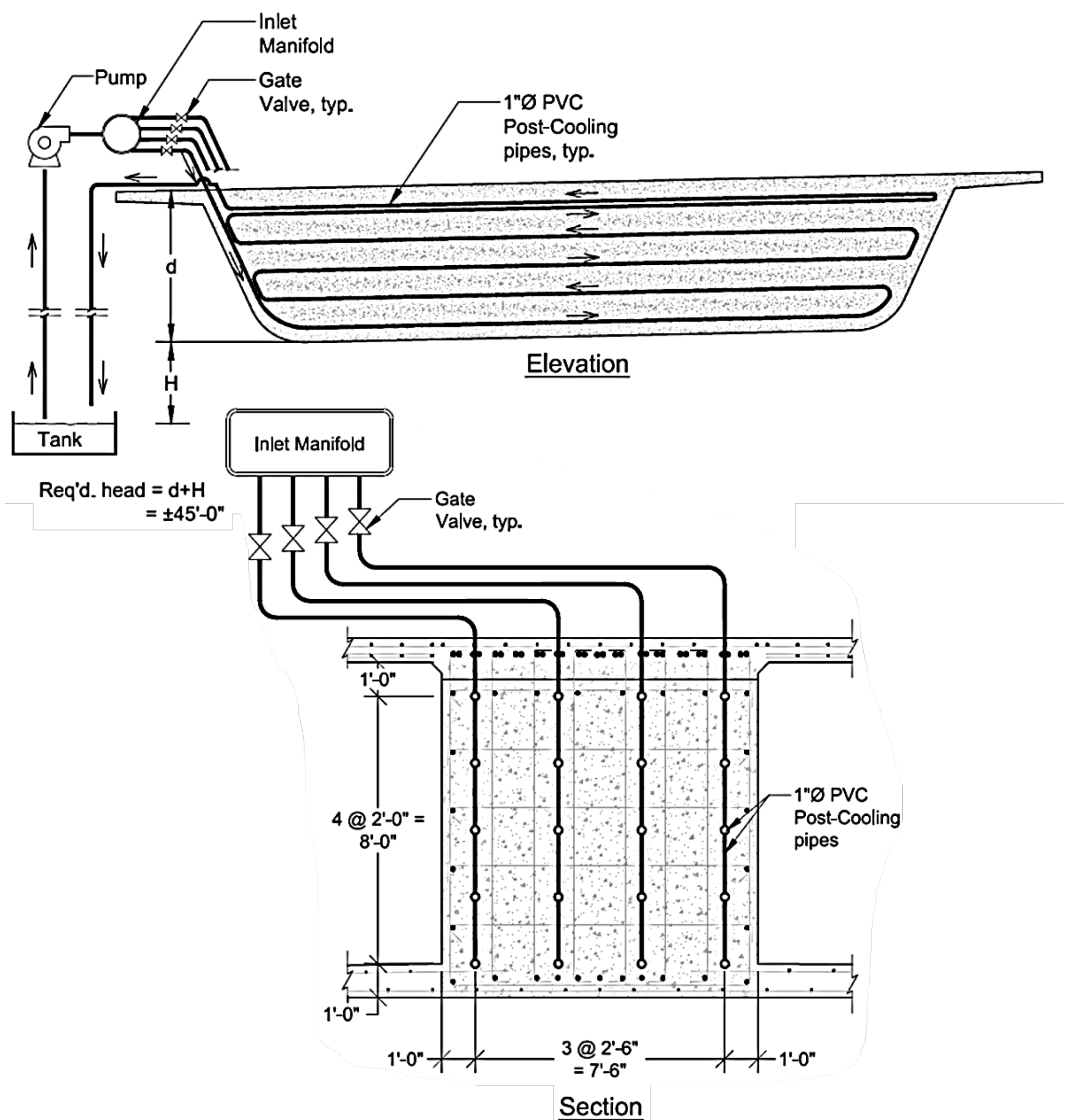

Figure 5-40. Schematic of Mass Concrete Cooling System

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 Foundations 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.