CHAPTER 5
CONCRETE CONSTRUCTION

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5 CONCRETE CONSTRUCTION

Even though the concrete produced by the batch plant has all the attributes of a quality structure material, as described in the foregoing chapters, and may also be of excellent quality and capable of producing a strong, durable concrete product, the quality of the concrete will be only as good as the handling, placing, finishing, and curing methods employed.

With the delivery of the mixed concrete to the job site, the production phase ends and the construction phase begins. During the construction phase, the primary responsibility of ensuring the quality of the concrete and the resultant concrete structure rest almost exclusively with the field engineering staff. The quality assurance requirements of concrete construction constitute far and away the bulk of the inspection work associated with the predominant bridge construction project in Caltrans – concrete box girder bridges.

This chapter is devoted to the concreting practices during the construction phase, with emphasis on methods and procedures that will ensure a high quality finished product. This chapter is intended to provide field engineering staff with guidance on the various aspects of concrete construction operations on a typical bridge project; starting with the delivery of the concrete to the jobsite and then moving onwards, covering fundamental concrete construction operations like transporting and handling concrete, depositing, consolidating and curing concrete. While best practices are described, the chapter is not intended to serve as a how-to reference.

Formwork, which precedes the actual concrete delivery in a typical bridge construction project, is included in this chapter because not only is it integral in rendering the form, shape, and appearance of the final concrete product, but it also to a large extent, influences the quality of concrete. Additionally, discussion of hot and cold weather concrete construction and underwater concrete placement, etc., is also included.

The content of this chapter is by design narrow in scope to emphasize the predominant work encountered in Caltrans structure construction projects, cast-in-place box girder structures, and retaining walls. A brief introductory overview of precast concrete construction, slip-form concreting, shotcrete, building construction, and segmental bridge construction is included for the purpose of context and to provide direction toward detailed treatment elsewhere, either in the appendix or in a separate manual.

Caltrans

Quality Assurance: Pre-Construction Review

Care and a rigorous quality control process employed by the contractor and a diligent observance of established quality assurance standards by inspectors responsible for the concrete work are key elements in ensuring a quality concrete structure. Diligent preparation on the part of the contractor and on the field engineering staff is also a key factor in achieving a superior concrete structure.

Specifications

To ensure that the concrete inspector is capable of enforcing the contract specifications and implementing the quality assurance standards in concrete placement, the concrete inspector must have a thorough knowledge of the work to be done as well as the proper method or methods by which it may be accomplished. A key component of such preparation is the review of the contract plans and specifications. The inspector should have a working knowledge of the core concrete specifications and a thorough understanding of the contract Special Provisions because, as a supplement to the Standard Specifications, the "Specials" contain job specific requirements that may be unique to particular circumstances on the project.

Standard Plans

In addition to a comprehensive understanding of the contract plans, a thorough review of the Standard Plans, which are contractual supplements to the contract plans, is also essential to make sure that the details and plan notes thereon, which may not be shown or included on the contract plans, are duly incorporated during construction. Due to the density of information on a typical plan sheet, careful review is necessary to ensure that the details and requirements in the plan notes are not overlooked. For example, the "wall offset value" for Type I walls, reinforcement of openings in concrete, and detailing on prestressing, among others are details found in the standard plans, which could easily be missed without the extra effort and care in reviewing the appropriate plan sheet.

Other Reference Documents

Additional concrete construction guidance can be found in the Bridge Construction Memo (BCM) found in the Bridge Construction Records and Procedures Manual. Inspectors should take the time to review applicable memos and, if appropriate in the context of the contract administration procedures, integrate their guidance with the contract plans and specifi ations. The Caltrans Construction Manual provides construction administration procedures and defines quality control test requirements. The local Structure Materials Representative from

Caltrans Materials Engineering and Testing Services can provide documentation when required for both California Test Methods (CTM) and ASTM tests.

Technical Resources

While every effort was made to produce a comprehensive set of guidance on concrete placement in this manual, it is recognized that other technical resources are available, including those online that may be useful in the furtherance of an inspector's knowledge and expertise in concrete and concrete placement such as but not limited to:

- The Portland Cement Association's publication, "Concrete Construction Practices"
- American Concrete Institute
- APA – The Engineered Wood Association

However it should be noted that if the information found in these external sources contravenes Caltrans specifications, policies, or standing practices and procedures, the Caltrans standards prevail, especially in contract administration. As an example, the Department uses proprietary test procedures, the CTM, in lieu of the widely available ASTM test methods and as such the ASTM test methods or other externally sourced procedures should not be used when a CTM has been specified.

Specific Pre-Construction Practices

Before work begins, an inspector should review the contractor's proposed concrete construction methods. For example, while it is not required, it is advisable to have a "pre-pour" meeting to discuss the issues that may delay placing the concrete, such as not having all reinforcement in place and secure with sufficient clearance. It is best to work closely with the contractor and to advise them as soon as possible of conditions that would prevent the timely start and completion of the concrete placement.

Bridge Construction Surveying

The location, position, and grades of a bridge, wall, or structure, are controlled by survey stakes provided by the District survey crew. In addition, Structure Construction has made it a practice to provide line and grade sufficiently close to the working area to enable the contractor to layout the work using tools which are normally associated with the work of a bridge construction crew, such as string or wire lines, plumb bobs, carpenter's levels, and tapes. At this time, the practice of providing line and grade relieves the contractor of the need to use survey instruments to layout bridge location.

As such, in addition to the pre-construction review of concrete material quality assurance requirements, field engineers also review the surveying requirements of the job. The field engineer has dual surveying duties. The first duty is to verify that the staking provided by the District survey crew is correct. And the second, is to provide "Structure Construction Control Surveying," which is the staking performed by the bridge inspection staff to set the bridge lines and grades sufficiently close to the working area, typically using the control stakes, called the "Original Structure Stakeout" that was provided by the District survey crew.

For State-administered bridge construction projects, the District survey crew will typically provide "control stakes" for the bridge foundation. These control stakes serve as the fundamental control for location, position and elevation of the bridge being constructed. As such, it is incumbent upon the field engineer to ensure that these stakes are correct by exercising prudent, mostly basic, coordinate calculations and checking the stakes in the field, a task that has been made easier with the introduction of Total Stations and surveying software such as COGO. Technical support is available from Structure Construction.

In addition to verifying the survey stakes, the engineer must also review the bridge deck contour sheet (also called "four scale") for accuracy. Deck contour sheets are scaled topographic plans showing the elevation of the bridge deck. The deck contour sheet defines the upper limit of the bridge elevations and is used to determine the grades of various components of the bridge. Given its importance in controlling the vertical geometry of the bridge, it is vital that field engineers ensure that the grades generated are accurate.

One of the best practices to ensure that the bridge deck contour sheet is accurate is to match it with the road contours. Plotting and matching the lines and grades not only of the bridges but also of walls and other structures against the roadway plans, general topography, as-built jobsite condition, etc., will not only ensure a structure cohesive with its surroundings but could also forestall possible conflicts early in the project to minimize possible impacts on the project. One example is to plot the top of retaining walls and match the plot to the topography, smoothing out any unwanted dips or bumps, ensuring an aesthetically pleasing structure. It is also considered a good practice to plot elements of walls, such as weep holes to ensure that they will be above grade per the plans and in a nice alignment.

Concrete Forms

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

The term formwork can be defined in the broadest sense to include the total system of support for freshly placed concrete – from sheathing to all supporting members, hardware and necessary bracing. Concrete forms are more than just mere molds that give the hardened concrete its final shape, dimension and position. It is also the system that renders texture and surface characteristics to the formed concrete surface. As such, the quality of workmanship taken in building the form often determines the amount of subsequent work needed to obtain the required finished surface.

Specifications

Aside from the basic requirement in the specifications that all concrete forms shall be mortar tight, true to the dimensions, lines, and grades of the structure, and of sufficient strength to prevent appreciable deflection during the placing of concrete, the specifications place particular emphasis on the quality and workmanship of forms that are used for exposed concrete surface.

Fundamentally, forms for concrete surfaces exposed to view shall produce a smooth surface of uniform color and texture. Due to its importance in achieving a uniform concrete surface, the specifications require that forms for exposed surfaces shall be faced with form panels and that each element shall be formed with the same forming material or with materials that produce similar concrete surface textures, color, and appearance. The specifications define form panels as a continuous section of form facing material, unbroken by joint marks. The form panels for exposed surface shall be in good condition, free of defects, such as scars, dents, or delaminated areas.

The specifications explicitly require that form panels for exposed surfaces shall be plywood conforming to or exceeding the requirements of U.S. Product Standard PS 1 for Exterior B-B (Concrete Form) Class I Plywood, or any material which will produce a smooth uniform concrete surface substantially equal to that which would result from the use of that plywood. Figure 5-1 is a typical grade stamp.

Figure 5-1. Typical PS-1 Grade Stamp.

Form panels for exposed concrete surfaces shall be arranged in symmetrical patterns conforming to the general lines of the structure with uniform widths of not less than 3 feet and in uniform lengths of not less than 6 feet, except at the end of continuously formed surfaces where the final panel length is less than 3 feet[1] or where the width of the member formed is less than 3 feet. Furthermore, it is required that the forms for exposed surfaces shall be constructed with chamfers at all sharp edges of the concrete to prevent mortar runs.

For exposed vertical surfaces, the specifications also require that panels shall be placed with the long dimension horizontal and with its joints level and continuous. There are also specific requirements for form panels for curved surfaces of columns and walls with sloping footings.

[1] 2006 Standard Specification , Section 51-1.05, or 6 feet in 2010 Standard Specifications, Section 51-1.03C(2)(a).

Forming System

For most structure concrete work, the forming system will consist of a form surface material or sheathing, studs, wales, and kickers; all adequately braced to retain the concrete within the required line, grade and dimensions. In addition to the basic form components of sheathing, studs and wales, a complete forming system also includes forming accessories such as ties, anchors and spreaders.

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

Other sheathing material may be used in forms for exposed concrete surfaces as long as it produces a smooth uniform concrete surface substantially equal to that which would result from the use of specified plywood, such as metal forms. Increasingly form liners are being specified as a sheathing material for exposed concrete surface as a means to render architectural treatment to the formed concrete surface.

The form sheathing is reinforced by a system of studs and wales in order to allow it to withstand the load imposed by the concrete during placement. For jobsite-built plywood forms common in bridge construction for such custom-built bridge elements as abutments, retaining walls and box girder superstructure, studs are vertical form elements, usually made of dimensional lumber, to which the sheathing is nailed. Essentially, studs serve as sheathing reinforcing that allows the sheathing to confine the freshly placed concrete. The studs are spaced close enough to limit the deflection of the sheathing between the studs. Wales are horizontal form components that support the vertical studs. Wales are usually installed in pairs into which concrete ties are inserted to keep the form from separating. The actual stud and wale spacing is governed by deflection criteria, lateral concrete load, and allowable stresses. Figure 5-2 is a typical wall-forming system.

Figure 5-2. Typical Concrete Wall Forms.

Vertical concrete forms must be braced to resist lateral loads such as wind and construction loads. Kickers are usually installed diagonally between the form and the ground or stable platform to keep vertical forms plumb and provide a measure of stability to the whole system. Kickers are important because if the forms are not properly braced they may deflect, in which case remedial work may be necessary to obtain the required lines and grades.

Chamfers are wooden triangular shaped fillets used in bridge construction to prevent mortar runs and bevel the corners of various bridge elements. Forms for exposed surfaces shall be constructed with triangular fillets not less than 3/4″× 3/4″ attached to produce smooth straight chamfers at all sharp edges of the concrete. They are also used as a “grade strip” to control the grades of various bridge components.

Form Fasteners

Form fasteners are form bolts, clamps or other devices used as necessary to prevent spreading of the forms during concrete placement. Form fasteners and anchors shall be of those types that can be removed as required for form bolts per ordinary surface finish specifications without chipping, spalling, heating, or otherwise damaging the concrete surface. No metal shall be left closer than 1-1/2 inches to the surface of concrete.

Note: Using twisted wire loops to hold forms in position is not permitted.

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

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

The internal disconnecting member in which the tensile unit has an inner part with threaded connections to removable external members (bolts), completes the tensile unit, and have varied devices for holding them against the outside of the form. The internal member generally remains in the concrete. This type of tie is available for light or medium loads but finds its greatest application under heavier construction loads.

Tie wedges are metal plates used in conjunction with concrete ties to distribute the load from the concrete tie to a bigger area on the formwork element, usually the form wales. Wedge shaped in profile, the tie wedge slips over the head of a snap tie and is used to tighten the snap tie against the form by driving the wedge until there is no slack in the concrete tie. After the tie is tight, the tie wedge is nailed to the form to ensure that it will not move and loosen during concrete placement.

Spreaders are devices that maintain the correct spacing between the opposite faces of a form, such as those of walls or bridge box girder stems. They may be integral or fabricated with the concrete ties or custom made, usually from dimensional (typically 2″ × 4″) lumber, cut in the field to the exact width of the formed element. Contractors may sometimes employ both a concrete tie with an integral spacer with a custom made wood spacer to ensure that the correct width is maintained, especially as the ties are tightened. Wood spreaders are never embedded in the concrete.

Form anchors are devices that are cast into the concrete for later use in supporting forms or for lifting pre-cast members. There are two basic parts: the embedded anchoring device, whose design varies with the load to be carried and the strength of concrete in the structure; and the bolt or other external fastener which is removed after use, leaving a set-back hole that must be patched. Driven type of anchorages, such as powder-actuated nails driven by "nail guns", shall not be used for fastening forms or form supports to concrete, except as provided for in the specifications.

Form Liners

The term "form liner" refers to any sheet, plate, or layer of material attached directly to the inside face of forms to improve or alter the surface texture and quality of the finished concrete. While plywood, hardboard, and steel, have application as form liners, the term is commonly associated with form liners made out of synthetic or plastic materials. The principal types of plastic liners in current use are: elastomeric, rigid, and fiberglass reinforced.

Elastomeric liners are made of rubber-like plastic formulations that are flexible enough to be peeled away from cast concrete surfaces with slightly undercut areas. They require good support and usually are adhered to form sheathing. Tough, wear resistant; 100 to 200 uses are reported possible with reasonable care. Peeling capability is rarely lost if the liner remains attached to a rigid backing. A typical form liner panel is shown in Figure 5-3.

Rigid type form liner formulations, including ABS and poly-vinyl chloride sheets, are stiff enough to be considered self-supporting. They are attached to sheathing by nails, staples, or screws and are available in standard sheets up to 10 feet long, or on special order up to 30 feet lengths. Some manufacturers provide interlocking joints at the edges of the sheets to maintain continuity of pattern. The panels are particularly suited to ribbed or fluted wall surfaces.

Similar in appearance and function to other rigid plastics, but much stronger, fiberglass reinforced form liners have longer potential service life. Better quality glass fiber reinforced plastic liners have an extra gel coat of the plastic resin at the contact surface to keep glass fibers from blooming through the resin skin.

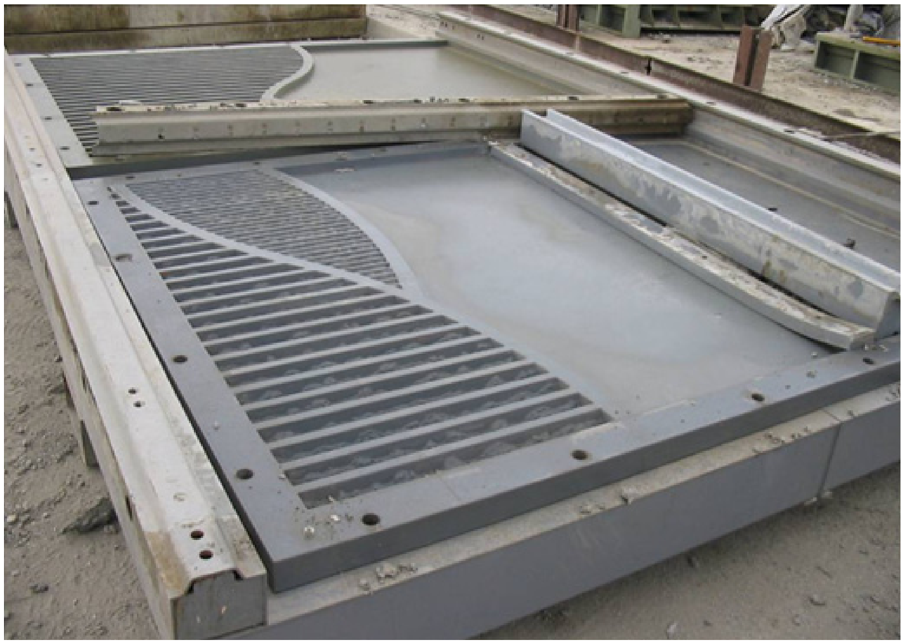

Figure 5-3. Form Liner Panel.

Figure 5-4. ABS Panel Liner and Resulting Wall.

Miscellaneous Form Types

While plywood is the predominant material used for jobsite-built forms for such custom-built bridge elements as abutments, retaining walls, and box girder superstructure, other form systems using different materials are usually used for bridge members with standardized shape and size, such as columns and barrier rails.

Steel Forms

The most common steel forms used in bridge construction are for columns (Figure 5-5) and barrier rails. These elements have a fairly standardized shape and size, which lends itself to the use of prefabricated forms. The durable nature of steel forms makes them economical for repeated use. Similar to wooden forms, steel forms consist of the form surface, studs, wales and kickers, all made out of steel. Steel forms are heavy and rigid, which while less prone to failure, are also limited in ability to follow certain dimensional requirements. For example, the steel forms for barrier rails come in straight 10-foot sections and cannot be placed to form barrier rails of tight radii. Steel forms are also commonly used in pre-casting yards where repeated use of a standard form is the norm.

Figure 5-5. Steel Column Forms.

Fiber Form Tubes

Fiber tube forms are typically used in bridge construction to form the exposed portion of "pile-extension" columns in slab bridges. Fiber tube forms are complete units with no extra fastenings and require only a minimum of external bracing to keep them plumb. This tube form, which consists of laminated fiber plies that are spirally constructed and are available with wax-impregnated inner and outer surface for weather and moisture protection, are considered single use items. Where the columns are to be exposed, the inner surface is coated with polyethylene. Fiber forms can be cut by saw to the exact length desired, and cut sections can be adapted to forming half-round, quarter-round, and round columns. They are also used to form the voids in voided-slab bridges. Sonotube is a proprietary trademark for the most widely available cylindrical fiber form.

Figure 5-6. Fiber Forms Used for Forming Voided Slab Structure.

Metal Decking

Metal decking (Figure 5-7) is a type of form that is left permanently in place and may become an integral part of the completed structure. When allowed by the contract, at the contractor's option and at no cost to the State, galvanized metal decking, which are ribbed or corrugated steel sheets, may be used in lieu of the typical forming system. If allowed, the specification requires that the steel deck forms conform to the requirements in ASTM Designation: A653/A653M (Designation SS, Grades 33 through 80) having a coating designation G165.

The specifications require that detailed shop drawings shall be submitted to the engineer for authorization. Metal decking is assumed not to provide additional support or reinforcement; hence, the deck reinforcement shown on the plans shall not be altered. The deck thickness shall not be reduced and must be measured from the surface of the bridge deck to the top of the metal decking ribs or flutes. Metal decking shall be galvanized and shall not be used in freeze-thaw areas[2].

Figure 5-7. Metal Deck Forms.

[2] Memo To Designers 8-7 and Standard Special Provisions 51-1.03.

Pre-Fabricated Forms

Specifications now allow the use of pre-fabricated plywood panels for the bridge superstructure soffit forms provided that when pre-fabricated panels are used, the form filler panels joining the pre-fabricated panels shall have a uniform minimum width of 1 foot and shall produce a smooth uniform surface with consistent longitudinal joint lines between the pre-fabricated panels. See BCM 125-3.0 “Prefabricated soffit forming panels” for further guidance.

Form Workmanship

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

The appearance of a finished concrete structure depends to a great extent on formwork quality, particularly the adequacy of the formwork to withstand, without appreciable settlement or deflection, the loads imposed by the concrete while it is in a plastic state. In turn, the behavior of the formwork under load depends on several factors, including the character of the foundation material, the support system used, and the quality of its construction, the quality of the form materials and workmanship, the forming method employed, and the rate and method of concrete placement. The formwork must remain in place until the concrete has hardened enough to maintain its cast shape, or the finished structure may be damaged.

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

With regard to compliance with the specification, keep in mind that the intent of the specification is to assure good workmanship in form construction. Compliance should be as important to the contractor as to the State, since the degree of care taken by the contractor when building forms will determine the amount of subsequent work needed to obtain the required finished product. For example, if panel joints are not tight, the resulting grout leakage will increase the surface finishing required. Dirty form surfaces and form panels having worn or ragged edges will also increase surface finishing costs. Improperly braced forms will deflect, in which case remedial work may be necessary to obtain the required line and grade.

Wherever the concrete surface is to be visible and appearance is important, the proper type of form tie or hanger that will not leave exposed metal at the concrete surface is essential. Specifications often require that no metal be left closer than 1 inch to the surface of the concrete. If any moisture gets to the tie end, rust stains will gradually appear on the surface of the concrete. Greater depth of break-back or threaded ends of internally disconnected tie units allow a better chance of bonding the patch which covers the tie, and also a greater factor of safety in case of spalling of the patch. Although the patch remains in place, it may shrink and leave fine cracks through which moisture and rust gradually seep. Because it is non-corroding, a glass fiber-reinforced plastic tie, commonly referred to as a fiberglass tie, is cut off flush with the concrete surface, leaving no hole to patch.

Structural Adequacy of Formwork

Concrete forms are more than just a mold that shape concrete into its desired size and shape. The forms are also temporary structures that maintain the shape while resisting fluid pressure loads imposed by the freshly placed concrete, plus those due to construction loading during its placement, including the effects of vibrating the concrete.

There are two distinct loading conditions of a complete formwork system, if broadly defined as a total system to include its supporting elements, that must be considered in evaluating the adequacy of the formwork:

- Lateral loading on the vertical surfaces of the concrete form due to the hydrostatic pressure of freshly placed concrete.
- Vertical loading on the formwork supporting elements due to, until it becomes self-supporting, the weight of the concrete. In Caltrans bridge construction practice, the system that supports the elevated vertical load is considered falsework and is subject to the stringent requirements in the falsework specifications.

Another design parameter required in the specifications is the limit on the allowable deflection of formwork and its various components, individually or as a system.

Formwork Design

For typical bridge construction, the formwork generally will be constructed in accordance with standard industry practice for concrete work. In most cases, a formwork design submittal is not required and inspection of bridge formwork is generally a routine procedure.

It should be noted, however, that temporary support systems supporting an elevated vertical load, mostly concreting loading, such as those for box girder superstructures, slab bridges, bent caps, etc., are considered falsework. The specification requires the contractor to submit falsework plans for authorization by the engineer.

Formwork Design Review

While formwork plans are not generally required, the specification, however, grants the engineer the option of requiring the contractor to submit formwork design plans, including supporting calculations and documentation, when deemed necessary. This may be required if the best general practices of the construction industry standards are absent. For example, a design submittal and a review by the engineer may be warranted for unique situations, unusual, possibly unsafe installations, or where a non-typical forming system will be used.

Form design and formwork plans, if requested by the engineer, are reviewed pursuant to the provisions in Section 4-1.01[3], "Intent of Plans and Specifications", Section 5-1.02, "Plans and Working Drawings," and Section 51-1.05[4], "Forms," of the Standard Specifications. Review and authorization protocols, while not specified, are generally similar to those established for falsework review.

Deflection

The specificat ons require that forms for exposed concrete surfaces shall be designed and constructed so that the formed surface of the concrete does not undulate more than either 3/32″ or 1/270 of the center to center distance between supports - studs, joists, form stiffeners, form fasteners or wales. This deflection criteria can serve as a parameter in the design of concrete forms.

Lateral Loading

The vertical surfaces of concrete forms are designed to resist the fluid pressure of concrete plus additional pressure generated by vibrating the concrete. While concrete is not a perfect fluid, if poured quickly, it will develop significant hydrostatic forces on the vertical surfaces of the forms that support the new concrete.

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[3] 2006 Standard Specifications, or 2010 Standard Specifications, Section 4-1.02,"Intent".
[4] 2006 Standard Specifications, or 2010 Standard Specifications, Section 51-1.03C(2).

Since concrete is typically deposited in a purposeful manner, it will not act as a true fluid, determining the appropriate lateral loading to be used in form design becomes a subjective exercise. This lack of precision is due to the fact that the basic component of lateral loading, the fluid pressure of fresh concrete, is not only governed by the unit weight of concrete but is also affected by a number of variables, such as the type of cement, concrete temperature, concrete penetration (slump) and rate of concrete placement.

Unit Weight of Concrete

The basic component of the lateral loading on the forms is the unit weight of concrete. Freshly placed concrete behaves temporarily like a fluid imparting a hydrostatic pressure that acts laterally on the vertical surfaces of the forms. As a fluid, the concrete's hydrostatic pressure at any point in the fluid is created by the weight of the superimposed fluid. Consequently, the pressure on the form during concrete placement, if concrete is considered in a state of idealized fluid, follows the standard fluid pressure formula

$$P = wh$$

Where "w" is the unit weight of concrete in pounds per cubic foot (pcf) and "h" the height in feet of the superimposed concrete over a given point. Although it also includes the weight of the reinforcing bars, which is not a factor in lateral loading, 150 pcf is the commonly assumed unit weight of concrete for sake of convenience. It is considered conservative for most form design applications.

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

Rate of Placement

One of the significant factors that affect lateral pressure on concrete forms is the average rate of concrete placement, known colloquially, as the "pour rate." During concrete placement, the lateral pressure on the vertical surfaces of the concrete form at any given point is a product of the height of the concrete above it and the unit weight of concrete in its plastic state. In its plastic state, the lateral pressure at a given point increases as concrete depth above it increases.

However, as soon as concrete becomes less fluid it starts to lose its capacity to impose lateral pressure on the vertical surfaces of the form. Moreover, as concrete starts to set it will also lose its capability to translate the weight of subsequent concrete layers as additional lateral pressure on the forms. As concrete stiffens inside the form, it not only will support its own weight and no longer exert lateral pressure but will be able to carry the weight of the subsequent layer of concrete. This reduces the hydrostatic head only to those layers where concrete is still fluid thereby decreasing the effective fluid pressure on the form. With slower rates of placing, concrete at the bottom of the form begins to harden and the lateral pressure is reduced to less than full fluid pressure by the time concreting is completed in the upper parts of the form.

Other Factors

In addition to the pour rate, other factors such as temperature of the concrete, admixtures, have an effect on the lateral pressure imparted by the concrete on the forms.

Temperature of the concrete during its placement also influences effective pressure on concrete forms because it affects the setting time of concrete. At low temperatures, the concrete takes longer to stiffen and therefore a greater depth can be placed before the lower portion becomes firm enough to be self-supporting. The greater liquid head thus developed results in higher lateral pressures. It is particularly important to keep this in mind when designing forms for concrete to be placed not only during cold weather but also if fly ash or retarding admixtures are used in any weather.

The method of consolidating concrete inside the forms is also a factor that affects the magnitude of the effective fluid pressure. Consolidating concrete using internal vibrators results in temporary lateral pressures, because it causes concrete to behave as a fluid for the full depth of vibration (locally to the area of vibration), generating up to at least 10 - 20% greater pressure. If external vibrators are used, the loads it exerts on the forms must also be taken into consideration in form design as it essentially hammers the form against the concrete.

Admixtures

Chemical admixtures and supplementary cementitious materials have significant effect on lateral pressure, which must not be overlooked. The chemistry coefficient introduced in ACI 347-01 and continued in ACI 347-04 provides a way to quantify the effect of a number of these variables on lateral pressure.

Lateral Pressure Values (ACI 347-04)

The continuing advancement in concrete placement methods and, specifically the rapid progress in admixture technology resulted in significant revisions to American Concrete

Institute's recommended concrete fluid formulas used in form design. As admixtures and cement replacements proliferated, the American Concrete Institute (ACI) recognized that, given current construction practices, the previous form pressure recommendation might have had too small a margin of safety, which could potentially result in form failures. In ACI 347-04, ACI used the accumulating data on lateral pressures to revise the concrete pressure formulas, introducing two new coefficients to cover a variety of concrete mixes:

Cc : Chemistry coefficient
Cw : Unit weight coefficient

For normal Portland cement concrete weighing 150 pcf , having about 2-inch penetration reading, and with normal internal vibration, the ACI recommends use of the following formulas to determine the form design pressure:

For Columns: With a minimum of $600C_w$ psf; but less than $150h$

$$P = C_w C_c [150 + 9000(R/T)]$$

For Walls: With a minimum of $600C_w$ psf; but less than $150h$

If rate of concrete placement is 7 feet per hour or less:

Where: $h \leq 14$ feet:

$$P = C_w C_c [150 + 9000(R/T)]$$

Where: $h \geq 15$ feet:

$$P = C_w C_c [150 + 43{,}400/T + 2800(R/T)]$$

If rate (R) of concrete placement is 7 feet to 15 feet per hour and $h \geq 15$ feet

$$P = C_w C_c [150 + 43{,}400/T + 2800(R/T)]$$

Where: C_c is the chemistry coefficient
C_w is the unit weight coefficient
P is the design pressure, in psf
R is the rate of concrete placement, in feet per hour
T is the concrete temperature, in degrees Fahrenheit
h is the height of plastic concrete above the point under consideration
W is the unit weight of concrete

Table 5-1. Coefficient to be Used in Pressure Equations.

Chemistry Coefficients, C_c	
Types I, II, and III cement without a retarder*	1.0
Types I, II, and III cement with a retarder*	1.2
Other types or blends without retarders*, containing less than 70% slag or less than 40% fly ash	1.2
Other types or blends with retarders*, containing less than 70% slag or less than 40% fly ash	1.4
Blends containing more than 70% slag or 40% fly ash	1.4
Unit Weight Coefficient, C_w	
Concrete weighing less than 140 pcf: C_w=0.5(1+W/145) but not less than 0.80	
Concrete weighing 140 to 150 pcf C_w=1.0	
Concrete weighing more than 150 pcf C_w= W/145	
* Retarders include any admixtures such as a retarder, retarding water reducer, retarding mid-range water reducing admixtures, or retarding high-range water reducing admixture (superplasticizer) that delays setting of concrete.	

Form Release Agent

The specifications require that forms that will later be removed shall be thoroughly coated with a releasing agent prior to use. Release agents, colloquially known as form oil, are applied to form sheathings to prevent concrete from bonding to the form, permit its ready release, and keep the formwork clean. Although not specified, with the increasing use of non-lumber sheathing materials, such as form liners, application-specific form release agents warrant consideration, as different types of release agents affect the resulting formed concrete surface, including discoloration or staining. The specifications stipulate that the form release agent shall not discolor the concrete.

While the specifications only require a commercial quality form release agent that will permit the ready release of the forms, there are products that are specifically formulated as form release agents. In general, there are two broad categories of form release agents: barrier type and chemically active. Barrier types are water-insoluble materials that include neat oils, paraffin wax and silicone oil. The Environmental Protection Agency prohibits the use of uncut or straight diesel oil as a release agent. Chemically active agents are those that have fatty acids that chemically react with the basic materials in concrete and, essentially, produce soap. The formation of the soap film from the ingredients in the cement paste and the chemically active release agent prevents the concrete from bonding to the form surface. ACI 303R-04 is an excellent source of technical information on form release agents.

When used, form release agent should be applied uniformly over all form surfaces in the manner recommended by the manufacturer. Without “form release agents”, the forms will invariably adhere to the surface of the concrete when the forms are stripped creating, in some cases, rough, irregular, spalled surfaces. The resulting effect necessitates costly, countless hours to refinish the exposed, concrete surface. A well-prepared contractor will take pains to ensure that the forms are saturated with form oil. During application, the specifications require that the form release agent cannot come in contact with the rebar.

There has been increasing concern on the use of form release agents in applications over bodies of water; check with the Storm Water Prevention Plan or regulations of the local Regional Water Quality Control Boards. There are also local and federal regulations on the volatile organic compounds (VOCs) that have to be considered.

Formwork Removal

Although from a casting standpoint forms may be removed as soon as the concrete has hardened, formwork must remain in place long enough to make sure the concrete is self-supporting and stiff enough to carry its own weight and construction loads without undue deflection or damage. Forms should be removed without damage to the concrete.

The specifications require that all forms be removed. The removal of forms that do not support the dead load of concrete members, other than railings and barriers, shall not begin until at least 24 hours after the concrete for the member has been placed. Note, however, that the specifications also require forms to remain in place until the concrete has gained sufficient strength to prevent surface damage. During periods of cold weather, this provision may require extending the 24-hour period. And in any case, the contractor should not be permitted to begin form removal until preparations have been made to begin curing as soon as the forms are removed.

To achieve the necessary strength, either the forms will be left in place for a specified period of time, or the time of removal will be determined by strength of test specimens. Improper stripping and shoring of bridge members may cause sagging of partially hardened concrete. Falsework, on the other hand, must remain in place until the supported concrete members have attained sufficient strength to support themselves.

Forms for railings or barriers may be removed at the convenience of the contractor after the concrete has hardened. The concrete surfaces exposed by removing forms shall be protected from damage. When the contractor elects to cure railings and barriers by a method other than the forms-in-place method, the forms must remain in place for a minimum of 12 hours. Forms for other concrete members, exclusive of forms supporting the dead load of a member, must remain in place for at least 24 hours after concrete has been placed for that member.

However, the specifications allow the forms to remain in place where the forms are inaccessible or where no permanent access is available. This may occur where there is no permanent access after construction, like, the forms for deck slabs of cast-in-place box girders, the forms for the interior voids of precast members, and the forms in hollow abutments or piers. When formwork will remain after construction, the inside of the cells or voids shall be cleared of all loose material prior to placing concrete.

Concrete Placement

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 though the concrete as delivered is of excellent quality and capable of producing a strong, durable structure, the actual quality of the finished concrete will only be as good as the handling, placing, finishing, and curing methods employed.

Of the many operations involved in concrete construction, handling and placing concrete are the most critical. While proper placing procedure will not in itself ensure a quality concrete product, improper procedures will almost certainly guarantee a poor one. Therefore, the importance of knowing and following correct concrete placement procedures cannot be overemphasized. The basic requirement in the handling of concrete is that the concrete quality and uniformity, such as the water-cement ratio, concrete penetration, homogeneity, and air content have to be maintained throughout the concrete placement process if optimum concrete qualities are to be attained.

Prior to Placing Concrete

The specifications require that concrete shall not be deposited in forms until the work connected with constructing the forms has been completed, all materials required to be embedded in the concrete have been placed, and the engineer has inspected the forms and materials. Work to prepare for concrete placement includes the removal of all dirt, chips, sawdust, water, and other foreign materials from the forms.

Before work begins, the contractor's proposed placing procedure as well as applicable specification requirements should be reviewed. If there is doubt or uncertainty as to whether the contractor's proposed placing methods and procedures will achieve the desired results, the contractor should not be permitted to start the concrete pour. It is considered good practice that, not only all equipment intended to be used during the placement of the concrete must be clean and in good working condition, standby equipment should be available in the event of a breakdown.

The inspector must also ensure that all the requirements per the Storm Water Pollution Prevention Program (SWPPP) and any other requirements by environmental and regulatory agencies that are pertinent to concrete construction, such as concrete wash outs, etc., are adhered to faithfully and rigorously by the contractor.

Advance planning is essential when placing concrete because of the short time concrete remains in the plastic state. Once work is underway, there is no time for experimentation, and little or no time to correct mistakes. Once started, concrete placement should continue uninterrupted until the application of concrete cure. The specifications clearly stipulate that the concrete in each integral part of the structure shall be placed continuously and the contractor will not be allowed to commence work on any integral part unless sufficient material for the concrete is on hand and the contractor's forces and equipment are sufficient to complete the part without interruption in placing the concrete.

Concrete Delivery

Concrete is usually delivered to the job site via truck transit-mixers. However, the Standard Specifications, in effect, allow the contractor to transport concrete by any means of conveyance, providing the consistency and workability of the mixed concrete upon discharge at the delivery point is suitable for adequate placement and consolidation, and providing the mixed concrete, after hauling, conforms to the requirements of Section 90-6.01[5] "General" of the Standard Specifications. The other modes of transporting concrete, such as truck agitators, open top vehicles, barges, etc., are seldom used in a typical Caltrans box girder bridge construction project. However, some have been employed in special cases, and their use should be considered individually in view of the peculiar demands of the project.

[5] 2006 Standard Specifications, or 2010 Standard Specifications, Section 9-1.02G, "Mixing and Transporting".

Quality Assurance

When concrete is delivered to the jobsite, it is the inspector's responsibility to ensure that the concrete being delivered complies with the contract specifications. As the concrete is delivered, the construction phase of concrete production begins. Being in the construction phase, the quality assurance becomes the primary responsibility of the inspectors. Therefore, field engineers responsible for concrete inspection must have a complete understanding of the work to be done as well as the proper method or methods by which it may be accomplished.

Forms

Immediately before placing the concrete, the inside of the surface of the forms and subgrade should be thoroughly moistened with water.

Mix Consistency and Uniformity

The Standard Specifications require that all concrete be homogeneous and thoroughly mixed, and there shall be no lumps or evidence of undispersed cement. Field engineers in charge of concrete inspection should monitor the concrete stream as it is discharged from transit mixers or deposited into the work, not only for the aforementioned specified properties of fresh concrete, but also for evidence of deleterious materials, such as debris, broken bricks, or recycled concrete that may be unknowingly or unscrupulously incorporated into the concrete mix.

Variations in consistency of the mix should be avoided. Changes in penetration, grading, etc., have a cumulative effect on the ease of finishing, and are reflected in the finished surface. Variations in the consistency of the concrete may also be an indication of improper mixing, use of deleterious materials or unacceptable concrete mixing practices and may warrant rejection of the material and/or further investigation of the entire concrete production operation.

Concrete Tickets

The Standard Specifications require that each load of ready-mixed concrete delivered at the jobsite be accompanied by a weighmaster certifi ate, commonly known as "concrete tickets." Concrete tickets should be checked for conformance with specification requirements.

This certificate shall be provided in printed form and must show the mix identification number, non-repeating load number, date and time at which the materials were batched, the total amount of water added to the load, the reading of the revolution counter at the time the truck mixer is charged with cement, and the actual scale weights (pounds) for the ingredients batched. It should be pointed out that the specifi ation expressly prohibits the use of theoretical or target batch weights as a substitute for actual scale weights. BCM 100-3.0 “Transit Mixed Concrete” outlines the procedure to be used for checking concrete tickets.

Concrete Placement Time

Concrete begins to harden as soon as the cementitious materials and water are mixed, but the degree of stiffening that occurs in the first few minutes is not usually a problem. The specification requires that the concrete be placed within 90 minutes or before 250 revolutions of the drum, whichever occurs first, after the introduction of the cement to the aggregates. However, under conditions contributing to quick stiffening of the concrete, or when the temperature of the concrete is 85°F or above, the time allowed may be less than 1.5 hours.

Transit Mixer Drum Revolution

Concrete shall be placed before 250 revolutions of the drum or within 90 minutes, after the introduction of the cement to the aggregates. The minimum number of drum revolutions for transit mixers shall not be less than 70[6], at the mixing speed recommended by the transit mixer manufacturer – or not less than that recommended by the manufacturer of the equipment.

Transit mixers shall be equipped with electrically or mechanically actuated revolution counters by which the number of revolutions of the drum or blades may readily be verified. Mixed concrete may be transported to the delivery point in truck mixers operating at the speed designated by the manufacturer of the equipment as agitating speed, provided the consistency and workability of the mixed concrete upon discharge at the delivery point is suitable for adequate placement and consolidation in place.

Concrete Temperature

The inspector must ensure that the temperature of mixed concrete, immediately before placing, shall be not less than 50°F or more than 90°F. Aggregates and water shall be heated or cooled as necessary to produce concrete within these temperature limits. Neither aggregates nor mixing water shall be heated to exceed 150°F. If ice is used to cool the concrete, discharge of the mixer will not be permitted until all ice is melted.

Certificates of Compliance

The specifications require that the contractor furnish a Certificate of Compliance for each lot of material delivered to the work. For each batch concrete delivered to the jobsite, the

[6] National Ready Mixed Concrete Association (NRMCA). Ready Mixed Concrete, "How is it produced?"

certificate of compliance shall have the concrete batch being certified clearly identified in the certificate, shall state that the materials involved comply in all respects with the requirements of the specifications, and shall be signed by the concrete supplier. The specifications state that the form of the Certificate of Compliance and its disposition shall be as directed by the engineer.

Materials used on the basis of a Certificate of Compliance may be sampled and tested at any time. The fact that material is used on the basis of a Certificate of Compliance shall not relieve the contractor of responsibility for incorporating material in the work which conforms to the requirements of the plans and specifications, and any material not conforming to the requirements will be subject to rejection whether in place or not. The Department reserves the right to refuse to permit the use of material on the basis of a Certificate of Compliance.

Weight Limits

Concrete trucks traveling on the highway with full loads generally need to use booster axles to meet the axle weight requirements of the California Vehicle Code. When discharging concrete, the booster wheels need to be raised, which increases the loads on the remaining axles resulting in axle loads that exceed the legal load allowed by the Permit Policy. Standard Specifications Section 7-1.02[7], "Load Limitations," allow trucks over legal (exceeding CVC weight limitations) limit on bridges with up to 28,000 pounds for single axles and 48,000 pounds for the tandem axles. This limits most trucks to hauling a maximum 7 1/2 to 8 cubic yards. These trucks should be weighed to confirm allowable specification loading

Adding Water to Concrete

CPD 10-5, "Adding Water to Concrete in the Field" allows water to be added to remix the concrete when the truck arrives on the jobsite and the concrete penetration is less than specified providing the following conditions are met:

- The maximum allowable water-cement ratio is not exceeded as calculated including surface water on aggregates as well as batch water and water added on site.
- Maximum allowable slump is not exceeded.
- Maximum allowable mixing and agitating time (or drum revolutions) are not exceeded.

After the additional water is introduced, the concrete must be remixed at mixing speed for a minimum of 30 revolutions or until the uniformity of the concrete is within the limits described in ASTM C94 (AASHTO M 157).

[7] 2006 Standard Specifications, or 2010 Standard Specifications, Section 5-1.37B, "Load Limits".

Water should be added before the truck discharges the first 1/4 cubic yard. After discharge is started, the contractor usually doesn't know the quantity of concrete with sufficient accuracy to add water with the assurance that the maximum water content will not be exceeded. Water should not be added to a partial load.

Indiscriminate addition of water to make concrete more fluid should not be allowed because it lowers the quality of concrete. The specification requires that concrete be placed while fresh and before it has taken an initial set. Retempering 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 high-cement-content mixes.

Delivery Rate

Although not specified, the contractor's expected concrete delivery rate warrants attention. An often overlooked consideration during concrete placement, the concrete delivery rate can have an impact, not only to the productivity of concrete placement, but potentially to the quality of the concrete, if, for example, delays result in cold joints or unplanned construction joints. The specifications are explicit in requiring that concrete in each integral part of the structure must be placed continuously, and the contractor should not be allowed to begin work unless there is sufficient inspected and approved material on hand, and his forces and equipment are sufficient, to complete the contemplated pour without interruption.

The secret of a successful pour is getting a good start and maintaining a constant delivery rate. If the concrete placement is too slow relative to the delivery rate, or if there is a breakdown in placing the concrete, the transit mixers arriving at the jobsite will begin to stack up, causing a delay in discharging their load and, often times, cause the concrete to exceed the specified 90 minutes mixing time. Also, if the delivery rate is too slow to assure a continuous supply of fresh concrete, the resulting interruptions in delivery will exacerbate any concrete placement problem that may develop during the pour, such as cold joints, and will extend the placement period as well, all with undesirable consequences. As a best practice, the interval between concrete delivery should not exceed 20 minutes and shall be adequate to prevent formation of cold joints.

Planning should eliminate or minimize any variables that would allow the concrete to stiffen to the extent that full consolidation is not achieved and finishing becomes difficult. Less time is available during conditions that hasten the stiffening process, such as hot and dry weather or use of accelerators.

Conveyance of Concrete

The method of concrete placement depends on such factors as the size, location, and accessibility of the concrete pour, and to a certain extent on the type of equipment available to do the work. The methods of delivering and handling concrete should be such that it will facilitate concrete placement with a minimum of handling or re-handling, and without damage to the structure or the concrete. The pumping system shown in Figure 5-8 was required to lift concrete almost 200 vertical feet for placement in the Benicia-Martinez Bridge.

There has been rapid improvement in the ability of concrete placing equipment, and particularly pumping systems, to deliver concrete to any desired location in the structure, at a uniform rate and without segregation. Keep in mind, however, that the use of state-of-the-art equipment will not necessarily ensure satisfactory results. A workable mixture of proper consistency along with care and attention to detail on the part of the placing crew are still the essential ingredients of satisfactory concrete placement.

The intent of this section is to give an inspector an insight into the advantages and disadvantages of each type of the commonly used concrete placement equipment in order to ensure that either the right equipment is used by the contractor or the inherent shortcoming of each system does not in any way become detrimental to the concrete being placed on structures.

Figure 5-8. Benicia-Martinez Concrete Pumping.

Chutes

Chutes are trough-shaped pieces of equipment set in an inclined position between the concrete delivery point and point of concrete placement. Chutes should be lined with smooth watertight materials and, to facilitate the flow of concrete, chutes should be rounded on the bottom and large enough to prevent overflow. When in use, the concrete is conveyed along the chute by the action of gravity.

When chutes are used, they must be placed at the inclination required to permit concrete of the specified consistency to flow easily down the chute. When the elevation of the forms is below the delivery point, chutes provide a cost-effective means of concrete placement.

Transit-mixers are equipped with delivery chutes (Figure 5-9) that could be conveniently used to place concrete directly into footings, abutments, or other locations where the truck can be positioned above the placement location.

The greatest objection to the use of chutes is the tendency for the concrete to segregate. To prevent segregation, chutes are often provided with baffle boards or a reversed section at the discharge end. The use of a small hopper at the discharge end is also effective in reducing segregation.

If delivery chutes are used as the sole means of conveying concrete, the inspector must ensure that the concrete is not deposited at just the location nearest to the transit mixers and then moved using vibrators, as this is also a cause for segregation. Also to prevent segregation, ensure that concrete does not fall more than 8 feet or as specified.

When using chutes, adding water or using vibrators to promote the free flow of concrete must not be allowed.

Figure 5-9. Concrete Transit Mixer Truck with Built-In Delivery Chute.

Concrete Buckets

Concrete buckets are still used in bridge construction where the pour volume is small or at remote locations where concrete pumps are not readily available. Although in a typical bridge construction project concrete buckets are usually lifted into position using cranes, hence the term “crane and bucket method”, they 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 or to a secondary discharge point.

A typical crane-and-bucket operation (Figure 5-10) 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 placing rate of 20 to 30 cubic yards per hour per crane is typical for most operations, although higher rates of about 50 cubic yards per hour, or more are possible with heavier equipment under ideal conditions.

Figure 5-10. Crane and Bucket Method.

Concrete buckets are available in various sizes. Large buckets with capacities of 8 cubic yards and higher have rectangular cross-sections (Figure 5-11), but most buckets in general use on construction work are circular. 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.

The crane-and-bucket method is still used in bridge construction, even on a limited basis, because a crane is usually on site already for other phases of work, therefore, concrete placements do not require special equipment and setup. The crane has a high degree of mobility, which allows concrete placement under difficult conditions. Clean up of the concrete bucket is minimal. An advantage in the crane-and-bucket method is that, due to a minimal amount of concrete movement during its handling thereby reducing the risk of segregation, a homogeneous concrete mix is assured in most cases.

Figure 5-11. Concrete Bucket Used on the Benicia-Martinez Bridge Project.

The inspector must be aware of some disadvantages of the crane-and-bucket method. When the crane-and-bucket method is used, care should be taken so that while the bucket is being filled with concrete it is positioned on a sheet of plywood in order to catch the spills and to keep the bottom of the bucket frame and boot out of the dirt. Also the crane's radii must encompass the pour front and often there are areas that are inaccessible. High pour rates require the use of additional cranes, which leads to a safety problem with swinging booms. Overhead wires are a serious hazard. Impact due to concrete dropping from a high bucket can cause form failure.

Drop Chutes

Drop chutes are lengths of pipe or tubing that are used to facilitate placing of concrete in walls and columns, typically as a means of ensuring that the concrete does not fall beyond the specified drop limits. 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, also known as elephant trunks.

Drop chutes direct concrete inside forms and deliver the concrete to the bottom of the forms as a means of avoiding segregating the concrete. Using drop chutes greatly minimizes the contact between concrete and the bar reinforcing steel during concrete placement, which is important in avoiding segregation of the concrete.

Figure 5-12. Depositing Concrete Using a Drop Chute.

Drop chutes should be used in conjunction with a funnel-like device into which concrete can be introduced without spillage. The size of the drop chute should match the size of the form opening to ensure that it can be inserted without interfering with reinforcing steel. Drop chutes should be of sufficient length to ensure that concrete does not fall more than the specified drop limit of 8 feet or make concrete strike the reinforcing steel inside the forms.

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 distant. The belts are supported by light steel framing which is set on the forms.

Belt conveyors have been used on concrete placement operations where there is a need for a continuous concrete placement but it is impractical or impossible to use concrete pumps. Conveyor belt systems have a relatively high capacity as compared to other systems in general use and delivery of concrete may be quite rapid. Conveyor belt systems offer the advantage of rapid delivery of concrete to relatively inaccessible locations. However, the use of conveyor belts on bridge construction is limited by economic considerations to situations where a large volume of concrete (several hundred cubic yards or more) is to be placed, or where the placement location cannot be reached by other types of placing equipment, such as pumps or cranes. 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 that are equipped with belt conveyors, which can be advantageous because the concrete mixer arrives complete with concrete conveying equipment. These mixer-mounted belt conveyors have adjustable reach and variable speeds. Similar to stand-alone belt conveyor systems, end discharge arrangements are necessary to prevent segregation and leave no mortar on the return belt.

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

In addition, concrete belt conveyors often require special supports or must be located along girder stems. Cleanup due to spillage is often a problem and care must be taken to place rugs or plastic sheathing at terminal points. Safety of the workers in the area of the terminal section requires special consideration. The chance of segregation is always present. Uneven pour fronts may result from removing support rail sections as the pour progresses, which could later make some areas inaccessible. Often unbalanced falsework loadings are encountered. Since the concrete while it is being conveyed on the belt is uncovered, it is exposed to the risk of rain on one hand, and the drying conditions such as high temperature and high winds on the other.

Because conveyor belts deliver concrete rapidly, it is important that there are enough people 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. Also, since the concrete must be placed on both sides of the conveyor rail before it is moved back and the rail removed, the operator may fill one side completely before moving to the other. Rate of placement and placing sequence requires careful monitoring to assure proper vibration. Some belts must complete an entire 10-foot section before the finishing machine can move forward.

Concrete Pumps

Currently, concrete pumps are the most popular method for placing concrete. Truck-mounted pumps are more versatile and have higher pour rates than any other previously used method of conveyance. Present day pumps are expected to deliver up to 100 cubic yards per hour without any major breakdowns or malfunctions. More favorable consideration is given to pumps due to this greatly increased reliability. In the past, pumps could be expected to malfunction at least once during a pour. This increased reliability and higher pour rate can be attributed to improvements in pump design and the increased use of admixtures.

The typical mobile pumping system in use today consists of a pump mounted on a truck equipped with an adjustable boom. The concrete, which is deposited directly from the transit mixer into the pump hopper, is pumped through a system of pipes and hoses mounted on the boom to a 5-inch diameter delivery hose, also attached to the boom, which permits the concrete to be deposited at the exact location desired. Pumping rates of 100 cubic yards per hour and vertical lifts of 190 feet or more are easily attainable with today's mobile pumping equipment (the Benicia-Martinez Bridge Project pumped concrete at these rates. The pump truck used a four-segment reticulated arm to deliver the concrete).

Concrete pumps are very mobile and can change locations very quickly unlike cranes with buckets and other previously used methods of conveyance which are generally limited to a single or perhaps two locations for receiving ready-mix concrete. This is very important in keeping a fresh pour front-for-deck concrete placement. In areas where overhead airspace is congested with utility lines, etc., pumping is more advantageous because pumps normally require less headroom. Pumps also offer a less disruptive, ominous presence and are consequently less hazardous since the absence of swinging buckets or belts eliminates evasive maneuvering by the crew.

Aluminum pipe is not allowed 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.

Slick Line

Slick line is a term used in the concrete pumping industry to describe a pumping system consisting of a portable concrete pump and a rigid conduit delivery system that may be used where concrete must be moved horizontally over a long distance, or where access limitations or other considerations preclude the use of mobile pumping equipment.

Figure 5-13. Slick Line Used to Deliver Concrete.

In a typical installation, the concrete is pumped through sections of 6-inch diameter steel pipe 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. However, according to the American Concrete Pumping Association, the term “slick-line” refers to a pump primer as well as a concrete admixture to allow ease of flow of concrete through the pump and piping. At this time Caltrans Materials Engineering and Testing Services (METS) has not approved the slick line admixture.

Placing Concrete

Proper concrete placing techniques will prevent segregation, eliminate voids, and provide adequate bond strength between successive layers as the concrete is placed, and thereby achieve the "dense homogeneous concrete" intended by the specifications. It is important to note, however, that while proper placing procedures will not necessarily ensure a satisfactory result, improper procedures will almost certainly guarantee an unsatisfactory one. Therefore, the importance of knowing and following correct placing procedures cannot be overemphasized.

Depositing Concrete

Concrete should be deposited continuously as near as possible to its final position without objectionable segregation. The specification requires that the 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 because such practices result in segregation as mortar tends to flow ahead of the coarser material. In most bridge applications, such as the bridge deck or footings, concrete should be placed starting along the perimeter at one end of the work with each batch discharged against previously placed concrete.

For concrete to be placed in retaining walls, abutments, footings, columns or bents, or thick slabs it is considered good practice to place the concrete in horizontal layers of uniform thickness with each layer 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 layer of concrete is placed upon it. Timely placement and adequate consolidation will prevent flow lines, seams, and planes of weakness (cold joints) that result from placing freshly mixed concrete on concrete past initial set. Layers should be about 6 to 20 inches thick for reinforced members and 15 to 20 inches thick for “mass concrete” work; the thickness will depend on the width between forms and the amount of reinforcement.

To avoid segregation, concrete should not be moved horizontally over too long a distance as it is being placed in forms or slabs. 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, but this should be kept to a minimum.

Where standing water is present, such as at the bottom of footings or drilled piles, as much of the water should be removed as possible, typically using sump pumps. If water is expected at the bottom of the excavation, it has been considered best practice 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 will not cause it to segregate. In general, 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; to do so will reduce the quality of the concrete. 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, care should be taken to avoid disturbing subgrade soils so they maintain sufficient bearing capacity to support structural loads. During concrete placement, reinforcing steel clearances should be continuously checked, displaced reinforcing steel should be repositioned, blocked and tied, broken dobies should be replaced and the position of waterstops, deck drains, conduit, and prestressing hardware and appurtenances should be checked and repositioned if displaced.

When concrete is placed in tall forms at a fairly rapid rate, some bleed water may collect on the top surface, especially with non air-entrained concrete. Bleeding can be reduced by placing more slowly and by using concrete of a stiffer consistency, particularly in the lower portion of the form.

When practical, concrete should be placed to a level about a foot below the top of tall forms and 1 hour or so allowed for the concrete to partially set. Placing should resume before the surface hardens to avoid formation of a cold joint. If practical to work around vertical reinforcing steel, it is good practice to overfill the form by 1 inch or so and cut off the excess concrete after it has stiffened and bleeding has ceased.

Fresh concrete should be placed against previously placed concrete rather than away from it. When it is necessary to place concrete on a slope, placement should begin at the lower end of the slope and progress upward. These practices allow vibration to follow immediately behind placement, thereby minimizing segregation. For bridge decks, the placing rate and location should be controlled to facilitate timely vibration. Uniform consistency of concrete and a uniform pour front parallel to the finishing machine should be maintained.

Concrete is sometimes placed through openings, called windows, in the sides of tall, narrow forms. When a chute discharges directly through the opening without controlling concrete flow at the end of the chute there is danger of segregation. A collecting hopper should be used outside the opening to permit the concrete to flow more smoothly through the opening; this will decrease the tendency to segregate.

Segregation

The specifications require that concrete be placed and consolidated by methods that will not cause segregation of the aggregates.

Segregation is the term used to describe non-uniform separation of the coarse-aggregate particles from the sand-cement components of the concrete mixture. 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 not 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, because it has relatively higher water and mortar content, shrink and crack more and have poorer resistance to abrasion. On the other hand, the portion of the segregated concrete with more coarse aggregate tends to be, because of the lack of cement paste, relatively speaking, less susceptible to consolidation, harder to finish, and prone to having concrete defects such as honeycombing.

Preventing segregation is the major consideration in handling and placing of concrete. The methods and equipment used in transporting, conveying, depositing, and consolidating the concrete must not result in the segregation of the concrete components. The two most important factors in preventing segregation are placing the concrete as closely as possible to its intended final location and keeping the drop of the concrete in a vertical direction to a minimum. Accordingly, once placed, concrete should not be moved laterally in the forms by vibrators, and concrete should not be placed by pushing or pulling a drop chute at an angle to the vertical.

The free fall distance is also a segregation factor. The free fall distance is limited by the specifications to 8 feet, but this should be viewed as the absolute maximum. Ideally, the fall-distance should be decreased to the extent possible to reduce the segregation that occurs when concrete strikes reinforcing steel or the sides of the forms above the placement level.

Prevention of Concrete Defects

Although concrete defects are occasionally attributable to an improper batching or mixing procedure, experience reveals that most concrete defects are the direct result of a failure or breakdown in the concrete placing operation. In view of this, it is evident that proper placing methods and procedures along with continuous inspection as the work progresses are the keys to obtaining a defect-free concrete structure. Accordingly, field personnel who have concrete inspection responsibilities will be expected to take affirmative action as necessary to ensure that recommended construction practice is followed at all times.

The most frequently occurring defect in concrete construction is the rock pocket. The term "rock pocket" is used informally to describe anything from a slight surface defect to a hole large enough for a man to crawl through; however, as used herein a "rock pocket" is understood to mean either (1) a portion of the hardened concrete in which the materials have segregated, thus resulting in the formation of a cluster of coarse aggregate particles that are unbonded or only slightly bonded to the surrounding matrix of fine aggregate and cement, or (2) a void within a larger concrete mass in which no concrete is present.

Most rock pockets are the result of improper placing procedures, usually insufficient vibration. When compared to the typical commercial product, concrete used on State highway work has a much lower slump; hence it is stiffer and more difficult to place and consolidate. Thorough vibration is a must if rock pockets are to be avoided.

When deposited into the forms, 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, lifts should be shallow and the vibrator should penetrate through the fresh concrete into the concrete in the previously placed lift. The more reinforcing steel there is in the forms, and the narrower the forms, the more care is required to ensure adequate vibration and thus avoid the formation of rock pockets.

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 to leak out, causing a rock pocket. This type of pocket is usually quite shallow and of the "popcorn" type. The only cure is mortar tight forms. 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.

Cold joints are often accompanied by rock pockets. When fresh concrete is placed on the old layer, the vibrator head should penetrate the older layer sufficiently to ensure adequate blending of the new and old concrete.

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 structure construction in California, which is fortunate since it is a defect that is virtually impossible to repair.

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 in accordance with specification requirements. 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.

Soft or powdery surfaces may result from several causes, but inadequate curing is the major cause of this type of defect. Once the concrete dries out, the hardening process stops. Proper curing is essential to ensure a sound, powder-free surface.

Protecting Concrete

Unless precautions are taken, adverse weather conditions during and immediately after concrete placement can contribute to undesirable properties in the finished product. For example, while light rain is not always harmful, concrete should not be placed when it is exposed to heavy rain. Rain will dilute the mortar at the concrete surface, and if an appreciable amount of rain falls, it may increase the water-cement ratio sufficiently to decrease both strength and durability at the surface.

The Standard Specifications provide that under rainy conditions, placing of concrete shall be stopped before the quantity of surface water is sufficient to damage surface mortar or cause a flow or wash of the concrete surface, unless the contractor provides adequate protection against damage. Admittedly, administering this particular requirement will require the use of subjective judgment, but the point to keep in mind is that if more than a light rainfall occurs while a pour is in progress, consideration should be given to ordering a suspension until the rain stops, unless the contractor is willing to shelter the work area or otherwise mitigate the potentially adverse effect of moisture contamination.

Prior to the start of the concrete placement operation, plans should be in place that will be followed in the event of rain during the concrete placing operation, especially for concreting operation involving significant areas of concrete that could be exposed to the rain, such as bridge deck. Protective coverings such as polyethylene sheets or tarpaulins should be available and onsite at all times.

The specifications also require that concrete shall not be placed on frozen or ice-coated ground or subgrade or on ice-coated forms, reinforcing steel, structural steel, conduits, precast members, or construction joints. Concrete that has been frozen or damaged by other causes, as determined by the engineer, shall be removed and replaced by the contractor at the contractor's expense. Structure concrete and shotcrete used as structure concrete shall be maintained at a temperature of not less than 45°F for 72 hours after placing and at not less than 40°F for an additional 4 days. When required by the engineer, the contractor shall submit a written plan of the proposed methods for protecting the concrete.

Consolidating Concrete

Consolidation is the process of compacting fresh concrete, to mold it within the forms and the reinforcement and embedded items, and to eliminate rock pockets, honeycomb, and entrapped air. Consolidation can be accomplished by hand or by mechanical methods. The Standard Specifications require 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.

Vibrating Concrete

Vibrating the concrete, using either internal or external vibrators, is the most common method of consolidating concrete. The purpose of vibration is to consolidate the concrete into a dense uniform mass free of voids and entrapped air. 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. In air-entrained concrete, it should not remove significant amounts of entrained air in the concrete mix.

Prior to vibration concrete presents a dry, irregular surface, while vibrated concrete presents a distinctively different appearance. When concrete is vibrated, the internal friction between the aggregate particles is temporarily destroyed and the concrete behaves like a liquid; it settles in the forms under the action of gravity and the large entrapped air voids rise more easily to the surface. A vibrated concrete takes on a moist appearance as the fines move to the top and the large aggregates settle. Internal friction is re-established as soon as vibration stops.

The high frequency vibrators required for concrete consolidation by the Standard Specifications vibrate in an approximate range of 80 to 250 cycles per second. Cycles per second are also referred to as Hertz (Hz). Vibrators may be classified by vibration rate or vibration amplitude, which are inversely related. If the vibration rate appears inadequate, the rate can be measured using a vibrating reed tachometer.

Internal Vibrators

The specifications require all structure concrete to be consolidated with high frequency internal vibrators within 15 minutes after it is placed in the form, with the exception of concrete for certain minor structures and concrete placed under water.

The vibrator type required by the specifications is known in the construction industry as an immersion or internal vibrator, since in use it is "immersed" into the concrete. 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 motor can be powered by electricity, gasoline, or air. The vibrating head is usually cylindrical with a diameter ranging from 3/4 to 7 inches. The smaller diameter heads have the highest vibration rates, possibly exceeding 250 Hz and the smallest amplitude, less than 0.02 inches. Vibration rate and head diameter are also inversely related, vibration rate decreases as diameter increases. As head diameter increases, vibration amplitude also increases. Larger diameter vibrators consolidate larger areas of concrete; the consolidation of a 2-inch vibrator might be 6 inches in radius while a 3-inch vibrator could have an effective radius of 14 inches.

Some vibrators have an electric motor built right into the head, which is generally at least 2 inches in diameter. The dimensions of the vibrator head as well as its frequency and amplitude in conjunction with the workability of the mixture affect the performance of a vibrator.

Proper use of an internal vibrator is important in order to obtain the optimum benefit of concrete consolidation.

Where possible, the vibrator (Figure 5-14) should be inserted vertically and allowed to descend through the concrete by the action of gravity. The points of vibration should be evenly spaced about 24 inches apart; however, the actual spacing should be adjusted so there is some overlapping of the vibrated areas. It should penetrate the layer being placed and at least 6 inches into any previously placed layer to ensure a thorough combining of the two lifts and to prevent “cold joints”. The distance between insertions should be about 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 Box Girder Stem Concrete.

Once the vibrator has been inserted, it should be held steady as consolidation occurs and then withdrawn slowly. Vibrators consolidate concrete by pushing the coarse aggregate down and away from the point of vibration. This action induces 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 layer of concrete and will mark a point along the vibrator hose a distance of the depth of the recent pour plus 1 foot. By dipping the hose into the fresh concrete up to the marked point, the operator of the vibrator will minimize the existence of “cold joints”. Experience has shown that concrete is not adversely affected when the lower lifts are revibrated, or by vibration transmitted by embedded reinforcing steel, provided the concrete is still plastic or again becomes plastic under revibration. The height of each layer or lift should be about the length of the vibrator head or generally a maximum of 20 inches in regular formwork.

In thin slabs, the vibrator should be inserted at an angle or horizontally in order to keep the vibrator head completely immersed. In bridge decks and similar thin sections where vertical insertion is not feasible, the concrete may be consolidated with the vibrator in a sloping position.

For a given consistency of concrete there is an optimum amount of vibration that will result in maximum consolidation without appreciable segregation. The length of time a vibrator should be left in the concrete is a function of slump. 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 on withdrawal. If the hole does not refill, reinsertion of 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.

Although it appears easy to follow the vibrator manufacturer’s use instructions, proper operation requires experience. There are visible changes that occur in concrete as it undergoes consolidation. Larger aggregate settles toward the bottom surface and the upper surface becomes smoother as mortar rises and entrapped air is released. Excessive vibration may reduce the benefits of air entrainment. An experienced vibrator will recognize the changes that occur as consolidation progresses and move the vibrator to the next consolidation location as needed.

The technique of the operator should vary with the depths and complexity of the section. In deep sections where it is possible to get full penetration of the vibrator, it is imperative that the person operating the vibrator hit the concrete approximately every 2 feet and the head of the vibrator enter almost vertically. In thin deck sections the 2 feet separations must also be observed but it is not as important to enter the concrete vertically.

Vibrators should not be used to move concrete horizontally since this will cause segregation. Allowing a vibrator to remain immersed in concrete after paste accumulates over the head is bad practice and can result in non-uniformity. The length of time that a vibrator should be left in the concrete will depend on the workability of the concrete, power of the vibrator, and the nature of the section being consolidated. The vibrator should not be dragged horizontally over the top of the concrete surface. Neither should the vibrator be allowed to run continuously while the operator is occupied with other things. Special care must be taken in vibrating areas where there is a high concentration of reinforcing steel. The vibrator should not be dragged around randomly in the slab. For slabs on grade the vibrator should not make contact with the subgrade.

It is considered best practice that a standby vibrator and generator should be on hand at all times in the event of mechanical breakdown.

Where epoxy-coated rebar or epoxy-coated prestressing steel are used, rubber tipped or resilient-coated vibrator heads should be employed to prevent damage to the epoxy coating on the rebar.

External Vibrators

At locations where the concrete placement configuration precludes the use of internal vibrators, the specification requires the use of external vibrators. When the use of an external vibrator is necessary, the specification requires that the vibrator be attached to the form. As such, the forms must be sufficiently rigid to resist movement and to withstand the forces induced by the external vibrators. Form vibrators, designed to be securely attached to the outside of the forms, are especially useful for consolidating concrete in members that are very thin or congested with reinforcement, to supplement internal vibration, and for stiff mixes where internal vibrators may not be effective. Form vibrators can be either electrically or pneumatically operated.

External vibrators should be positioned about 18 inches below the top surface of the concrete, and they must be moved as necessary to maintain this relative position. They should be spaced to distribute the intensity of vibration uniformly over the form; optimum spacing is best found by experimentation. They are ineffective when operating on empty forms or when positioned more than about 2 feet below the concrete surface. Form vibrators should not be applied within the top yard of vertical forms. Vibration of the top of the form, particularly if the form is thin or inadequately stiffened, causes an in-and-out movement that can create a gap between the concrete and the form. Internal vibrators are recommended for use in this area of vertical forms.

Sometimes it may be necessary to operate some of the form vibrators at a different frequency for better results; therefore, it is recommended that form vibrators be equipped with controls to regulate their frequency and amplitude. Duration of external vibration is considerably longer than for internal vibration, generally between 1 and 2 minutes.

External vibration is not always effective. Best results are attained when the vibrators are securely fastened to the exterior surface at points where form bracing will transmit the vibrations to the nearby concrete.

In heavily reinforced sections where an internal vibrator cannot be inserted, it is sometimes helpful to vibrate the reinforcing bars by attaching a form vibrator to the exposed portions of rebars. This practice eliminates air and water trapped under the reinforcing bars and increases the bond between the bars and surrounding concrete. It is recommended that this technique be used only if the concrete is still workable under the action of vibration. Internal vibrators should not be attached to reinforcing bars for this purpose because the vibrators may be damaged.

Consequences of Improper Vibration

Insufficient vibration may result in voids and rock pockets remaining in the concrete, whereas excessive vibration will cause segregation, increase the amount of surface water, and leave a layer of mortar at the surface. However, for the concrete specified for structure work on State projects, unsatisfactory results are much more likely to occur as the result of too little vibration than from too much. This should be kept in mind when vibrating heavily reinforced sections where special care is required to assure proper consolidation.

Under vibrating concrete causes serious concrete defects that could be detrimental to the quality of concrete and to the integrity of the concrete structural member. Some of the worst defects caused by poorly consolidated concrete include honeycombs, excessive amounts of entrapped air voids sand streaks, cold joints, placement lines, and subsidence cracking.

Honeycomb results when the spaces between coarse aggregate particles do not become filled with mortar. Faulty equipment, improper placement procedures, a concrete mix containing too much coarse aggregate, or congested reinforcement can cause honeycomb.

Excessive entrapped air voids, often called bug holes, are similar to, but not as severe as honeycomb. Bug holes are small or irregular cavities found on the surface of hardened concrete, usually less than 0.6 inch in diameter, that are air voids formed by the entrapment of air bubbles against the forms, especially impervious forms such as steel or plastic form liners. Vibratory equipment and operating procedures are the primary causes of excessive entrapped air voids, but the other causes of honeycomb apply too. If they become a problem, the amount of bug holes can be mitigated by assiduous utilization of proper vibrating techniques. Revibration may be employed to reduce the size and intensity of bug holes. Other mitigation measures such as higher slump, using high range water reducers, and using smaller aggregates to improve workability have often been successful.

Sand streaks result when heavy bleeding washes mortar out from along the form. A wet, harsh mixture that lacks workability because of an insufficient amount of mortar or fine aggregate may cause sand streaking. Segregation from striking reinforcing steel without adequate vibration may also contribute to streaking.

Cold joints are a discontinuity resulting from a delay in placement that allowed one layer to harden before the adjacent concrete was placed. The discontinuity can reduce the structural integrity of a concrete member if the successive lifts did not properly bond together. The concrete can be kept alive by revibration every 15 minutes or less depending on job conditions. However, once the time of initial setting approaches, vibration should be discontinued and the surface should be suitably prepared for the additional concrete.

Placement lines or "pour" lines are dark lines between adjacent placements of concrete batches. They may occur if, while vibrating the overlying layer, the vibrator did not penetrate the underlying layer enough to knit the layers together.

Subsidence cracking may occur at or near the initial setting time as concrete settles over reinforcing steel in relatively deep elements that have not been adequately vibrated. Revibration at the latest time that the vibrator will sink into the concrete under its own weight may eliminate these cracks.

On the other hand, overvibration can also cause concrete defects such as segregation as vibration and gravity causes heavier aggregates to settle while lighter aggregates rise, sand streaks, loss of entrained air in air-entrained concrete, excessive form deflections or form damage and form failure caused by excessive pressure from vibrating the same location too long, and/or placing concrete more quickly than the designed rate of pour.

For a given consistency of concrete there is an optimum amount of vibration that will result in maximum consolidation without appreciable segregation. The length of time a vibrator should be left in the concrete is a function of slump. To obtain the same degree of consolidation, low slump concrete requires more vibration than concrete having a higher slump. In general, with everything being equal, it is considered that under vibrating the concrete is more often a problem than over vibrating the concrete. This should be kept in mind when vibrating heavily reinforced sections where special care is required to assure proper consolidation.

Revibration

The specifications require that after placing, consolidating and initial screeding of concrete for structure footings, more than 2-1/2 feet in vertical dimension and with a top layer of reinforcement, the concrete shall be reconsolidated by the use of internal vibrators for a depth of 1 foot from the top of the footing and then finished. Revibration shall be accomplished as late as the concrete will again respond to vibration, but not less than 15 minutes after the initial screeding has been completed.

Revibration of previously compacted concrete can be done to both fresh concrete as well as any underlying layer that has partially hardened. Revibration can be used to improve bond between concrete and reinforcing steel, release water trapped under horizontal reinforcing bars, and remove additional entrapped air voids. In general, if concrete becomes workable under revibration the practice is not harmful and may be beneficial.

Finishing Plastic Concrete

Unless otherwise specified, after concrete has been consolidated but before application of the curing medium, surfaces of bridge concrete that are not in contact with the forms receive an initial concrete finish, which consists of striking off the top of the concrete to the planned level, grade, or slope and the surface is then finished by floating to seal the concrete surface. All concrete finishing work at this stage shall be performed while the concrete is still in a workable stage.

Bleed Water

Even after concrete has been vibrated as specified, additional consolidation takes place as the heavier materials slowly settle through the mixture. In this process, which is commonly called subsidence or settlement, 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”. Ideally, the initial finishing should be completed 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.

Finishing while bleed water is on the surface is one of the principal causes of defects on concrete surfaces. If bleed water is worked into the surface, the water-cement ratio is significantly increased which reduces strength, entrained-air content, and water tightness of the concrete surface. Also any finishing operation performed on the concrete surfaces while water is present can cause crazing, dusting, or scaling. Floating and troweling the concrete before the bleeding process is completed may also trap bleed water under the finished surface producing a weakened zone or void under the finished surface, occasionally resulting in delamination. The use of low-penetration concrete, provided it has sufficient cement content and a properly graded fine aggregate, will minimize bleeding. Air entrainment also reduces bleeding.

Strike Off

After concrete is vibrated, the exposed concrete surface must be brought to the final level. Strike off, also called screeding, is the process of cutting excess concrete to bring the top surface of the concrete to proper grade. The most common device used in manually striking off concrete is the use of a straight edge, which in most instances in bridge construction, aside from bridge deck, is normally accomplished by using a piece of lumber, usually a 2×4 cut to a convenient length (Figure 5-15), to bring the concrete surface to the proper level as indicated by grade strips, screed rails or by top of forms.

In the manual method of striking off the concrete, the concrete is brought to the proper level by moving a straight edge across the concrete with a sawing motion while advancing forward a short distance with each straightedge to fill in low areas as the straightedge advances. The 2×4 straight edge is moved across the surface with a sawing motion at right angles to the direction of travel. If screed rails are used, any interior supports are removed after the grade is established and any voids left by the removal of the support then filled with concrete.

Figure 5-15. Striking Off Bridge Deck Concrete.

Initial Finishing

In bridge construction, initial finishing is usually accomplished using hand floats, except on bridge decks where mechanical finishing machines are the norm. 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 and pulls cream (water and fine concrete materials) 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 pores.

Floats can be made from wood, metal or fiberglass (Figure 5-16). Concrete without air entrainment would tend to have more water in the concrete and a wood float would leave the roughest smooth 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 floats to become rougher. Air entrained concrete typically arrives with less water in the mix design and produces less bleed water than concrete without air entrainment. A metal float (Figure 5-17) would be more durable than either a wooden or fiberglass float and produce a slightly smoother finish, that would still be rough enough to allow bleed water to escape.

The floating action, which is performed with a scrubbing motion, slightly depresses the larger aggregate particles, leaving a thin layer of surface mortar suitable for final finishing.

When floating concrete, the hand float should be held flat on the concrete surface and moved 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 most bridge concrete surfaces. Where a float finish is the desired final finish, it may be necessary to float the surface a second time after it has hardened a little more.

Floating must be completed before bleed water accumulates on the surface. Care must be taken not to overwork the concrete as this could result in a less durable surface. The preceding operations should level, shape, and smooth the surface and work up a slight amount of cement paste. Although sometimes no further finishing is required on most bridge construction finishing, in floor slabs for buildings floating is followed by one or more of the following finishing operations: edging, jointing, floating, troweling, and brooming. A slight hardening of the concrete is necessary before the start of any of these follow-up finishing operations. When the bleed-water sheen has evaporated and the concrete will sustain foot pressure with only about 4-inch indentation, the surface is ready for continued finishing operations.

Figure 5-18 is a photo taken in 1960 showing work on the San Francisco–Oakland Bay Bridge. Concrete was delivered to the pour location in a buggy, placed by shovel and consolidated with a jitterbug. The jitterbug was once a commonly used tool for initial finishing. Jitterbugs are no longer approved for use; internal and external vibration techniques have superseded the jitterbugs usefulness.

Figure 5-16. Hand Floating a Bridge Deck.

Figure 5-17. Metal Bull Float.

Figure 5-18. Jitterbugs are Not Permitted.

To facilitate finish ng some concrete finishers are accustomed to compacting concrete surface with a hand tamp with steel mesh stretched over a frame commonly called a "jitterbug". Jitterbugging wet concrete forces the coarse aggregate particles down, and brings excessive cement and fine aggregate to the surface, which results in soft surface that leads to crazing and cracking and, for exposed surfaces, dusting and scaling. Jitterbugging is not considered good practice for concrete work, and it should never be used in Caltrans bridge construction projects.

Machine Finishing: Bridge Deck

For bridge decks, the concrete surface is typically struck and finished using power driven finishing equipment, commonly called Bidwell Concrete Finisher (Figure 5-19) in honor of its inventor, Tex Bidwell. When configured for bridge deck finishing, these versatile machines spread, compact, and finish bridge deck concrete one pass at a time.

The basic bridge deck finishing machine consists of a carriage, fitted with concrete finishing equipment, that is suspended from and travels on carrier rails attached under an open welded-steel truss frame. The frame is supported by adjustable legs and wheeled bogies that ride on screed rails. Drive wheels on pipe screed rails move the finishing machine along the length of the bridge. The carriage is equipped with concrete finishing equipment consisting of augers, finishing drums, float pans, and texturing devices that are arranged sequentially to spread, finish, and texture the concrete surface with each pass. The truss assembly can be adjusted to provide the designed bridge grade, profile, and cross section.

Figure 5-19. Bidwell Concrete Finisher.

During bridge deck construction, the augers strike off the concrete to a rough grade and move excess concrete forward. Next, the drums trim and finish the concrete surface to the final grade. While the finishing drums do compact the concrete, they are not solely relied upon to consolidate the deck concrete. Separate vibrators are usually used to properly consolidate the bridge deck concrete. After the drum, a float pan or a series of float pans fills in small voids still remaining on the surface of the concrete. A texturing device, such as burlap or synthetic turf, is typically attached behind the float pan to texture the finished surface

Although one or more vibrators can be attached to the carriage, consolidation of bridge deck concrete is usually done by hand ahead of the finish ng machine. The deck concrete fin shing machine advances from as little as 4 to 6 inches to as much as 18 inches per carriage pass. A work bridge may also be used behind the finishing machine, riding on the same screed rails, to provide access to the freshly placed concrete to allow supplemental work such as additional finishing, fogging, or application of curing compound. For additional information, see the Bridge Deck Construction Manual.

Other Concrete Finishing Equipment

The specifications do not prescribe a particular means and method of finishing the bridge deck or similar riding surface. The "end product specification" only requires that the smoothness of completed roadway surfaces of structures, approach slabs and the adjacent 50 feet of roadway and approach paving, will be tested by the engineer with a bridge profilograph, in conformance with the requirements in California Test 547.

For approach slabs and bridge surfaces of similar size, the concrete surface is sometimes finished using power finishing equipment other than a Bidwell Concrete Finisher, such as the vibrating screed, also known as the Texas screed, shown in Figure 5-20.

Figure 5-20. Texas Screed.

On some segmental bridge projects, such as the Benicia-Martinez Bridge, where the specifications either require the bridge deck to have an overlay or grinding the deck surface, other concrete finishing has been used, such as the rolling screed shown in Figure 5-21.

Figure 5-21. Rolling Screed.

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.

As previously noted, air-entrained concrete contains microscopic air bubbles that tend to hold all the materials in the concrete, including water, in suspension. 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 need not be delayed while waiting for free water to evaporate from the surface.

If floating and finishing is done by hand, the use of an aluminum or magnesium float is essential. A wood float drags and greatly increases the amount of work necessary to accomplish the same result. For deck finishing with a finishing machine, there will be no difference between finishing procedures for air-entrained and non air-entrained concrete, except that the finishing operation may be started sooner on the air-entrained concrete.

Curing Concrete

Curing concrete is the process of keeping an optimum level of moisture and temperature within the concrete for a period of time immediately following its placement, as the concrete hardens, either by preventing or substantially reducing the rate of evaporation of the water from within the concrete mass. Proper curing of concrete is a key element in concrete construction because the effectiveness of the curing process is a significant determinant in achieving the desired superior concrete properties. With proper curing, concrete becomes stronger, more impermeable, and more resistant to stress, abrasion, and freezing and thawing.

For a given concrete, both strength and durability will continue to improve with the passage of time as long as conditions remain favorable for the continued hydration of the cement. It is the first few days following concrete placement that are the most critical, as it is during this initial period that rapid improvement in strength and durability is possible under favorable conditions. If curing conditions are unfavorable or even marginal, improvement in concrete strength will be slow and the intended properties may never be attained.

To ensure proper curing of concrete, two conditions are essential and must be maintained. First, the concrete must be kept moist to prevent the evaporation of water from within the concrete mass, and second, the temperature of the newly placed concrete must be kept within an optimum range of about 50 to 90°F. If these stresses develop before the concrete has attained adequate tensile strength, surface cracking can result. Since the rate of hydration is directly proportional to temperature of the curing concrete, it follows that the ideal curing method will also prevent significant loss of either moisture or temperature during the curing period.

While there is no ideal curing method, there are a number of relatively effective methods by which concrete can be kept in a moist condition, and, depending on exposure, at a favorable temperature as well, such as those specified in the Standard Specifications

For cast-in-place concrete construction, curing methods can be divided into two categories depending on the manner in which moisture loss is prevented:

- Methods that supply additional moisture to the surface of the concrete, such as the continuous application of water or the use of a moisture retaining fabric or blanket, and
- Methods that prevent moisture loss by sealing exposed surfaces of the concrete, as for example, the application of a membrane curing compound.

In cases of curing in hot or cold weather, special care, such as employing precautionary measures to counter the effects of extreme temperatures, may be necessary. 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; and at or below freezing temperatures, down to 14°F, little or no strength develops.

Plastic Shrinkage Cracking

The term "Plastic shrinkage cracking" is used to describe the formation of cracks in a horizontal surface of fresh concrete after it has been placed and finished but while it is still in the plastic state. Plastic shrinkage cracking is caused by rapid evaporation of moisture from the concrete surface, and occurs when 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 5-22 which provides a graphic method of estimating the loss of surface moisture for various weather conditions. To use the chart, follow the four steps shown on the chart. If the rate of evaporation approaches 0.2 lb/ft^2/hr (1.0 kg/m^2/hr), precautions against plastic shrinkage are necessary. For the example shown by dotted line, air temperature at 65°F, relative humidity at 35%, concrete temperature at 60°F and wind velocity at 20 mph: the evaporation rate is approximately 0.12 lb/ft^2/hr.

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 unless mitigating measures are employed.

Note: With increased use of supplementary cementitious materials and liquid admixtures, particularly high range water reducers, it is possible to produce a concrete with an extended set time. Additional precautions, such as fogging may be necessary to retard the development of plastic shrinkage cracks.

Preventing plastic shrinkage cracking is more a matter of common sense than concrete technology, since the most important factor is keeping the concrete surface moist until curing begins. This becomes increasingly more important as the predicted rate of evaporation increases due to adverse ambient conditions.

There are two methods by which a concrete surface may be kept in a moist condition. The first is reducing the rate of evaporation and the second is applying moisture to the surface to offset the evaporation loss. While applying moisture to the surface is an obvious solution, it must be done carefully to avoid dilution of the cement paste at the surface, with a consequent lessening of the concrete quality. A better approach is to employ measures that will reduce the evaporation rate directly. Since little can be done to improve ambient conditions, aside from misting and lowering temperature, reducing the evaporation rate can best be accomplished by reducing the temperature of the concrete mixture.

Factors affecting concrete temperature, and methods by which the temperature may be reduced, are discussed in the Hot Weather Construction section later in this chapter.

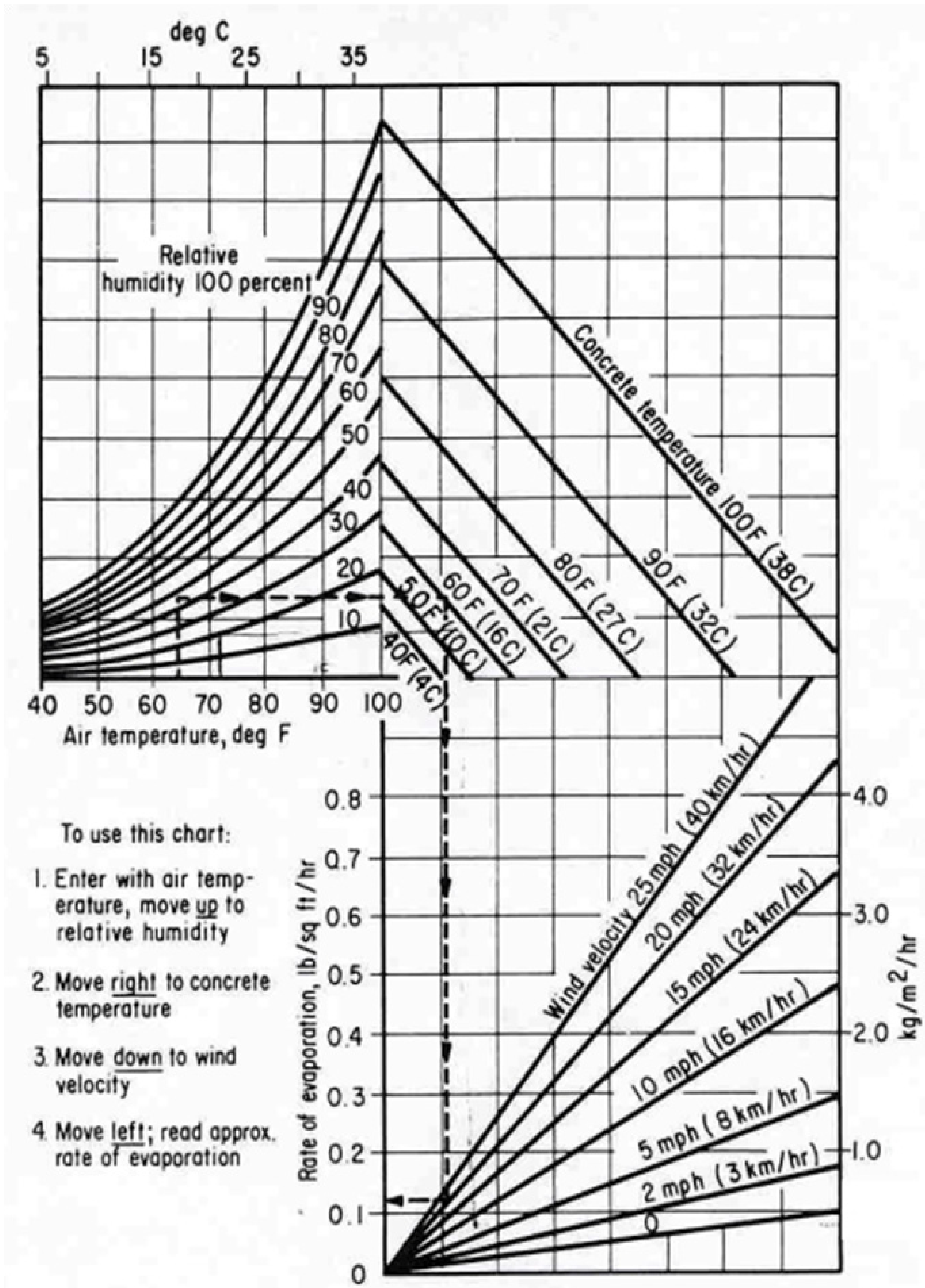

Figure 5-22. Evaporation Rate Nomograph (ACI 308, Standard Practice for Curing Concrete).

Specified Concrete Curing Methods

The specifications require all newly placed concrete for cast-in-place structures, other than highway bridge decks, to be cured by the water method, the forms-in-place method, or when specifically permitted, by the curing compound method. The top surface of highway bridge decks are cured by both the curing compound method and the water method. Note that regardless of the method used, curing begins while the concrete is still plastic and continues for the specified curing period.

Water Method

Under this curing method, the specification requires that concrete surfaces are kept continuously wet by the application of water for a period of 7 days after the concrete has been placed. There are several means by which the intent of the specifications can be met, including continuously spraying the surface, ponding water on the surface, or covering the surface with an absorbent material such as sand, burlap, rugs, or straw, and then keeping the moisture retaining medium saturated.

Water should be applied on exposed surfaces of newly placed concrete as soon as the concrete has hardened sufficiently to prevent any washing away of the cement or damage to the finish. Water should be applied to formed surfaces immediately after the forms are removed, and the exposed surfaces should be kept continuously wet for the remainder of the curing period, or until some other curing medium is applied. When the water method is used, the most important point to keep in mind is that, once the curing period begins, the surface of the concrete must remain moist for the duration of the curing period.

When a curing medium consisting of cotton mats, rugs, carpets, or earth or sand blankets is to be used to retain the moisture, the entire surface of the concrete shall be kept damp by applying water with a nozzle that so atomizes the flow that a mist and not a spray is formed, until the surface of the concrete is covered with the curing medium. The moisture from the nozzle shall not be applied under pressure directly upon the concrete and shall not be allowed to accumulate on the concrete in a quantity sufficient to cause a flow or wash the surface. At the expiration of the curing period, the concrete surfaces shall be cleared of all curing mediums.

As a rule, earth or sand blankets are less effective than other curing mediums because of the tendency of the curing water to wash or spread the material (thus developing thin spots) and because sand, in particular, may be too coarse to retain enough moisture to ensure that the surface remains damp.

When concrete bridge decks and flat slabs are to be cured without the use of a curing medium, the entire surface of the bridge deck or slab shall be kept damp by the application of water with an atomizing nozzle as specified in the preceding paragraph, until the concrete has set, after which the entire surface of the concrete shall be sprinkled continuously with water for a period of not less than 7 days.

Plastic Sheets

The specifications allow the contractor the option of using a curing medium consisting of polyethylene sheeting to cure concrete columns. The specifications limit the use of this curing method solely to columns. Polyethylene film is a lightweight moisture-retarding medium and it is an effective curing method if used with the application of water and the concrete is not allowed to dry out. The sheeting merely retards the evaporation of water from the concrete and a periodic application of water is necessary in order to maintain the optimum level of moisture during the curing process. As an allowed alternative under the water method of curing concrete, the surface of the concrete shall remain moist throughout the curing period.

Specifications require that polyethylene sheeting be 1.0 mm (10 mils) or thicker. When using polyethylene sheeting (Visqueen®) curing medium for concrete columns (Figure 5-23), the sheeting must be new or in near new condition, without tears or holes. The minimum thickness of 10 mils shall be achieved in one layer of materials. The polyethylene must be adequately secured at the top, bottom, discontinuous edges, and at mid-height or no more than 20 feet on the center for columns over 40 feet in height. Joints shall be folded and secured by tape, clamps, or stitching as necessary to ensure a moisture-proof seal. The sheeting shall be fastened such that it will remain within 3 inches of the concrete surface at all times. The use of polyethylene sheeting shall be in conjunction with the application of water. Cure water is to be applied between the sheeting and the concrete surface of the column by means of a soaker hose or a comparable device that provides an even water distribution completely around the perimeter of the column and shall be installed for the entire length of the cure period. Cure water should be applied at least twice daily and as required to keep the column surface moist at all times.

In regions or periods of extreme high temperatures, if the surface temperature of the column concrete under the sheeting cannot be maintained below 140°F, the use of Visqueen shall be discontinued and one of the other specified curing methods shall be used.

White polyethylene sheeting should be used for curing exterior concrete during hot weather to reflect the sun s rays. Black film may be used during cool weathe .

Figure 5-23. Curing Concrete Columns Using Polyethylene Plastic Sheets.

Burlene®

The specifications allow, at the option of the contractor, a curing medium consisting of white opaque polyethylene sheeting extruded onto burlap to cure concrete structures. The polyethylene sheeting shall have a minimum thickness of 4 mils and shall be extruded onto 10-ounce burlap. Furthermore, the medium and any joints therein shall be secured as necessary to provide moisture retention and shall be within 3 inches of the concrete at all points along the surface being cured.

The most common curing fabric allowed under this specification is a commercial curing fabric consisting of polyethylene film bonded to burlap, and trademarked Burlene®. There are no restrictions on which structure elements can be water cured with the use of Burlene, including concrete columns and retaining walls, provided that moisture is maintained throughout the curing period.

Because the burlap water-retaining medium is bonded to a polyethylene layer that averts rapid evaporation, the use of this curing medium will eliminate the need for continuous watering of the covering. However, Burlene will not totally prevent evaporation of water and the fabric should be periodically rewetted-under the plastic-before it dries out. It is important that moisture is maintained throughout the curing period, because alternate cycles of wetting and drying during the early curing period may cause crazing of the surface.

BCM 105-5.0 outlines the requirement on the use of a commercial curing fabric, such as Burlene. The burlap side of the material is to be placed next to the concrete. On decks, the fabric shall be secured by weighing it down or by other methods that ensure a proper seal and protection against the wind (Figure 5-24). On columns and retaining walls, the Burlene shall be secured at the top, bottom, discontinuous edges, and loosely secured at mid-height or at no more than 20 feet on center for columns over 40 feet in height. In addition, on flared or unusually shaped columns or walls the material shall be secured in such a fashion that the Burlene is within 3 inches of the surface of the concrete at all points along the surface being cured. Joints shall be folded and secured by ties, staples, or stitching as necessary to ensure a tight seal when curing columns and walls. Weighted lap splices are acceptable on decks and other similar surfaces.

Figure 5-24. Curing with Burlene Curing Blankets.

If Burlene is used as a curing medium, the cure water is to be applied under the Burlene (between the sheeting and the concrete). The burlap side of the material should be moist at all times. On columns and retaining walls a continuous application of cure water may be required. A soaker hose, or comparable device, that will provide an even water distribution completely around the perimeter of the surface being cured shall be permanently installed for the entire length of the cure period. Water shall be applied as necessary to keep the Burlene and concrete surface moist at all times.

The temperature of the concrete should be monitored during hot weather applications of Burlene curing. Concrete surface temperatures of 140°F or greater must be prevented. If the temperature of the concrete cannot be maintained below 140°F, this method of curing shall be discontinued, and one of the other curing methods allowed for the concrete shall be used.

Burlap must be free of any substance that is harmful to concrete or causes discoloration. New burlap should be thoroughly rinsed in water to remove soluble substances and to make the burlap more absorbent.

Wet, moisture-retaining fabric coverings should be placed as soon as the concrete has hardened sufficiently to prevent surface damage. During the waiting period other curing methods are used, such as fogging or the use of membrane forming finishing aids. Care should be taken to cover the entire surface with wet fabric, including the edges of slabs. The coverings should be kept continuously moist so that a film of water remains on the concrete surface throughout the curing period.

Forms-In-Place Method

Although forms are usually removed as soon as possible to permit their re-use, occasionally a contractor will choose to leave them in place for all or a significant portion of the curing period. The specifications allow that the formed surfaces of concrete may be cured by retaining the forms in place (Figure 5-25). Leaving the forms in place is an effective curing method, provided the forms do not dry out and exposed concrete is kept wet. The forms shall remain in place for a minimum period of 7 days after the concrete has been placed, except that for members over 20 inches in least dimension the forms shall remain in place for a minimum period of 5 days.

Figure 5-25. Forms-In-Place Curing Method.

The specifications require joints between form panels and areas between forms and concrete surfaces be kept moisture tight during the curing period. Additionally, any cracks in the forms or between the forms and the concrete that develop during the curing period must be sealed by methods approved by the engineer. The forms should be inspected periodically during the curing period, and this specification rigidly enforced if necessary; otherwise, the forms-in-place method will not provide an effective cure.

Curing Compound Method

The curing compound method consists of applying one of the membrane-forming curing compounds listed in the specifications 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 retard or reduce 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 completion of surface finishing, but not before 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.

Curing compounds are the most practical and most widely used method for curing not only freshly placed concrete but also for extending curing of concrete after removal of forms or after initial moist curing. While the most effective methods of curing concrete are wet coverings or water spraying that keeps the concrete continually damp, curing compounds should be able to maintain the relative humidity of the concrete surface above 80% for 7 days to sustain the hydration of the concrete.

The Standard Specifications allow two types of curing compounds, pigmented or nonpigmented. Pigmented curing compound is typically white, which makes it easy to determine if curing compound has been adequately sprayed over newly placed concrete. Nonpigmented curing compounds are clear when applied and remain clear when dry. An option with clear curing compound is inclusion of a fugitive dye that gives a red tint to newly applied curing compound but fades to clear as the compound dries. The fugitive dye allows the inspector to verify complete curing compound coverage and could be specified for concrete floor slabs in buildings.

The specifications require that if curing compounds are used on structures, only pigmented curing compounds shall be used, except for barrier rails. For structures, the curing compound method may not be used on any surface that requires a Class 1 Surface Finish, or on any other surface that is visible from a public traveled way. On hot, sunny days, white-pigmented compounds reduce solar-heat gain, thus reducing the concrete temperature.

Per the specifications, concrete barrier rails are cured using a non-pigmented curing compound. The specifications also allow the contractor the option of forms-in-place method for curing barrier rail. If the contractor elects the forms-in-place method, the forms must remain in place a minimum of 12 hours, and no further curing is required after the forms are removed.

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 specification requirements are detailed and explicit, and unless they are followed precisely, the curing compounds will not perform as intended. To ensure a satisfactory cure, field engineers who are responsible for inspection of structure concrete construction should review the applicable Standard Specifications, and any pertinent special provision requirements as well, and then discuss the requirements with appropriate contractor personnel before any work that will involve the use of curing compounds is started.

When the curing-compound method is specified or allowed, the specifications require that the curing compound be applied uniformly to the surface of the concrete. It is imperative that the curing compound be applied uniformly, without skips, sags, or holidays, because the intent in the use of the curing compound is to form a moisture-retaining membrane on the surface of the concrete. Failure to form this moisture-retaining membrane on the surface of the concrete will result in the rapid evaporation of water from the concrete, which could adversely affect the concrete strength, durability, and other desired concrete properties. Complete coverage of the surface must be attained because even small pinholes in the membrane will increase the evaporation of moisture from the concrete.

The curing compound shall be applied to the concrete immediately after the surface finishing operation, immediately before the moisture sheen disappears from the surface, but before any drying shrinkage or craze cracks begin to appear. The concrete surface should be damp when the curing compound is applied. On dry, windy days, or during periods when adverse weather conditions could result in plastic shrinkage cracking, application of a curing compound immediately after final finishing and before all free water on the surface has evaporated will help prevent the formation of cracks.

Fogging

In the event of any drying or cracking of the concrete surface, the specifications require the application of water using an atomizing nozzle - fogging - be started immediately. Fogging the concrete is applying water with a nozzle (Figure 5-26) that so atomizes the flow that a mist not a spray is formed. The moisture from the nozzle shall not be applied under pressure directly upon the concrete and shall not be allowed to accumulate on the concrete in quantity sufficient to cause a flow or wash the surface of the newly placed concrete. Fogging shall be maintained until the specified curing medium is applied. Curing compound shall not be applied over any freestanding water.

Figure 5-26. Fogging Bridge Deck to Minimize Plastic Cracking.

Application

Curing compound shall be applied at a nominal rate of 1 gallon per 150 square feet, unless otherwise specified. At any point, the application rate shall be within ±50 square feet per gallon of the nominal rate specified, and the average application rate shall be within ±25 square feet per gallon of the nominal rate specified when tested in conformance with the requirements in California Test 535. Runs, sags, thin areas, skips, or holidays in the applied curing compound shall be evidence that the application is not satisfactory. Normally only one smooth, even coat is applied at the recommended application rate. However, if two coats are necessary to ensure complete coverage, it is recommended that the second coat should be applied at right angles to the first, to ensure effective coverage.

The specifications require that curing compounds be applied using power-operated spray equipment. The power-driven spray equipment (Figure 5-27) must have the capability to apply the curing compound as a uniform membrane on the surface of the concrete, similar in appearance to uniform application found in painted surfaces. The power-operated spraying equipment shall be equipped with an operational pressure gauge and a means of controlling the pressure. Spray nozzles and windshields on such equipment should be arranged to prevent wind-blown loss of the curing compound.

Figure 5-27. Applying Curing Compound Using Power-Operated Spray Equipment.

While hand spraying of small and irregular areas that are not reasonably accessible to mechanical spraying equipment could be permitted by the engineer, the use of hand-operated sprayers (i.e., Hunt's can) should be extremely rare and only in applications that are truly unachievable with power sprayers. It should not be considered a routine alternative to the specified power sprayers. If used, spraying with Hunt's cans should achieve a uniform coverage of the concrete to form a moisture-retaining medium. 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 are prone to clogging, the amount of curing compound needed to achieve the required uniform coverage is considerably higher. If properly enforced, the contractor will realize that it would be economical to use power sprayers as specified.

When applied, curing compounds should not sag, run off peaks, or collect in grooves. They should form a tough film to withstand early construction traffic without damage, be non-yellowing, and have good moisture-retention properties.

The specifications stipulate that should the film of compound be damaged from any cause before the expiration of 7 days after the concrete is placed in the case of structures and 72 hours in the case of pavement, the damaged portion shall be repaired immediately with additional compound.

If left in place, curing compound acts as a bond breaker between successive layers of concrete, such a situation could occur when concrete for the deck is placed on previously cast concrete girders without properly removing the curing compound from the exposed girder surfaces. The Standard Specifications require complete removal of curing compound prior to placement of additional concrete.

Quality Assurance

While curing compounds are an effective concrete curing medium, its efficacy could only be maintained 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 and requires vigilance on the inspector’s part in order to ensure that we get the maximum benefit out of these curing products.

There are different types of curing compounds, each designed for a specific application, allowed in the specifications. Refer to the Standard Specifications for specifics. Ensure that the correct curing compound is used for each specific application.

For quality assurance purposes, Materials Engineering and Testing Services (METS) policy requires that a curing compound must be tested by the manufacturer and the manufacturer must provide the test results and supporting documentation along with a Certificate of Compliance and Form TL-28 with the shipment of curing compound to the jobsite. In addition, a sample from each batch manufactured for Caltrans is sent to the Chemical Testing Branch for quality assurance testing.

METS policy further requires that field staff ensure that the curing compound is sampled and tested per the Construction Manual (Chapter 6, Section 1). Curing compounds shall not be used until the required evidence or certificate of inspection has been received. Upon final inspection, the curing compound may be released at the jobsite using Form CEM-4102, “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. Curing compounds may be re-sampled and retested to confirm that the material delivered to the jobsite meets the specification and has been mixed properly prior to application.

The specifications require that at the time of use, curing compounds containing pigments shall be in a thoroughly mixed condition with the pigment uniformly dispersed throughout the vehicle. Pigmented compounds should be kept agitated in the container to prevent pigment from settling out. Agitation shall not introduce air or other foreign substance into the curing compound. A paddle shall be used to loosen all settled pigment from the bottom of the container, and a power driven agitator shall be used to disperse the pigment uniformly throughout the vehicle.

The manufacturer shall include in the curing compound the necessary additives for control of sagging, pigment settling, leveling, de-emulsifying, or other requisite qualities of a satisfactory working material. Pigmented curing compounds shall be manufactured so that the pigment does not settle badly, that is, the pigment does not cake or thicken in the container, and does not become granular or curdled. Settled pigment shall be a thoroughly wetted, soft, mushy mass permitting the complete and easy vertical penetration of a paddle. Settled pigment shall be easily re-dispersed, with minimum resistance to the sideways manual motion of the paddle across the bottom of the container, to form a smooth uniform product of the proper consistency.

Settling or separation of solids in containers, except tanks, must be completely re-dispersed with low speed mixing prior to use, in conformance with these specifications and the manufacturer's recommendations. Mixing shall be accomplished either manually by use of a paddle or by use of a mixing blade driven by a drill motor, at low speed. Mixing blades shall be the type used for mixing paint. On-site storage tanks shall be kept clean and free of contaminants. Each tank shall have a permanent system designed to completely re-disperse settled material without introducing air or other foreign substances.

Curing compounds shall remain sprayable at temperatures above 40°F and shall not be diluted or altered after manufacture. Curing compound shall be formulated so as to maintain the specified properties for a minimum of 1 year. The engineer may require additional testing before use to determine compliance with these specifications if the compound has not been used within 1 year or whenever the engineer has reason to believe the compound is no longer satisfactory.

The curing compound shall be packaged in clean 274 gallon totes, 55 gallon barrels, 5 gallon pails, or shall be supplied from a suitable storage tank located at the jobsite. The containers shall comply with "Title 49, Code of Federal Regulations, Hazardous Materials Regulations." The 274 gallon totes, and the 55 gallon barrels shall have removable lids and airtight fasteners. The 5 gallon pails shall be round and have standard full open head and bail. Lids with bungholes shall not be permitted. Steel containers and lids shall be lined with a coating that will prevent destructive action by the compound or chemical agents in the air space above the compound. The coating shall not come off the container or lid as skins. Containers shall be filled in a manner that will prevent skinning. Plastic containers shall not react with the compound.

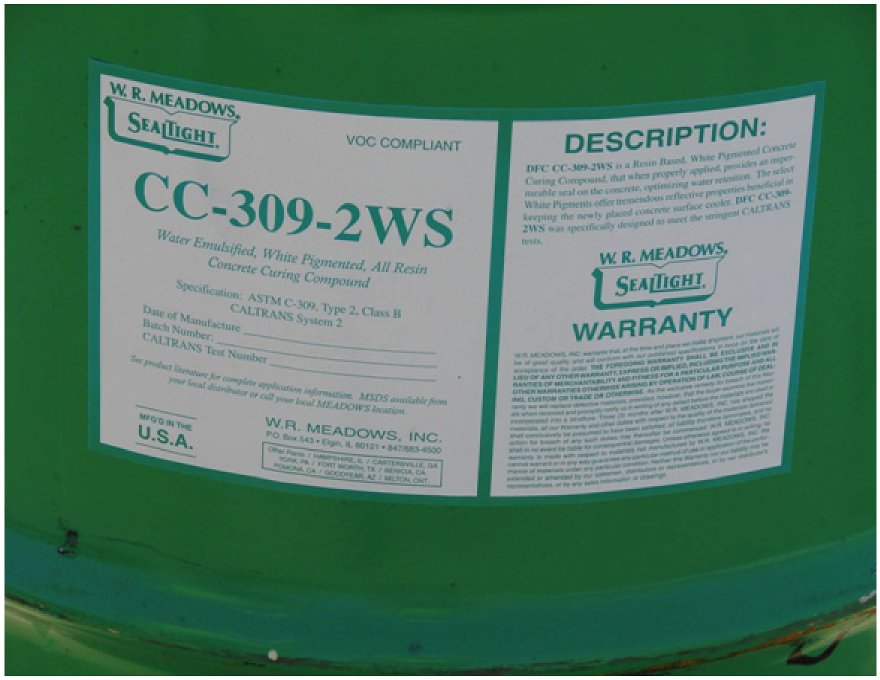

Figure 5-28. Typical Pigmented Curing Compound Label.

Safety

Caution is necessary 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. Applicable local environmental laws concerning volatile organic compound (VOC) emissions should be followed.

The specifications require that each curing compound container be labeled with the manufacturer's name, kind of curing compound, batch number, volume, date of manufacture, and volatile organic compound (VOC) content. Containers of curing compound shall be labeled to indicate that the contents fully comply with the rules and regulations concerning air pollution control in the State of California. The label shall also warn that the curing compound containing pigment shall be well stirred before use.

Precautions concerning the handling and the application of curing compound shall 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 shall accompany each load. The invoice shall contain the same information as that required herein for container labels.

Waterproof Membrane Method

In this curing method, which is used for PCC pavement, the specification requires that the curing membrane remain in place for not less than 72 hours. (For structures, specifications require the Water Method of curing.)

The curing membrane specified as a sheeting material for curing concrete shall conform to the requirements in AASHTO Designation: M-171 for white reflective material. The sheeting material shall be fabricated into sheets of such width as to provide a complete cover for the entire concrete surface. Joints in the sheets shall be securely cemented together in such a manner as to provide waterproof joints with a minimum 4-inch overlap and the sheets shall be weighted down by placing a bank of earth or by other means satisfactory to the engineer. Before the curing membrane is placed, the exposed finished surfaces of concrete shall be sprayed with water, using a nozzle that so atomizes the flow that a mist and not a spray is formed.

Curing Structures

Newly placed concrete for cast-in-place structures, other than highway bridge decks, shall be cured by the water method, the forms-in-place method, or, as permitted by specifications, by the curing compound method.

Pigmented curing compounds cannot be used for portions of structure concrete that is exposed to the view of the public and is specified to receive a Class 1 Concrete Finish. The curing compound method using a pigmented curing compound may be used on concrete surfaces of construction joints, surfaces that are to be buried underground, and surfaces where only ordinary surface finish is to be applied and on which a uniform color is not required and that will not be visible from a public traveled way. If used on construction joints, curing compounds shall be removed, by abrasive methods, from concrete surfaces receiving another layer of concrete. In general, curing compounds are considered to be bond breakers and are detrimental to proper bond between layers of concrete.

The specifications require that the top surface of highway bridge decks shall be cured by both the curing compound method and the water method. For bridge decks, the curing compound shall be curing compound designated in specifications as Pigmented Curing Compound A[8]. If the Contractor elects to use the curing compound method on the bottom slab of box girder spans, the curing compound shall also be Curing Compound A[8].

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[8] 2006 Standard Specifications, Section 90-7.01B, or Curing Compound No.1, 2010 Standard Specifications Section 90-1.03B(3)b.

When deemed necessary by the engineer during periods of hot weather, water shall be applied to concrete surfaces being cured by the curing compound method or by the forms-in-place method, until the engineer determines that a cooling effect is no longer required.

Curing Minor Structures

Concrete surfaces of minor structures, as defined in Section 51-1.02[9], "Minor Structures," shall be cured by the water method, the forms-in-place method, or the curing compound method.

Surface Finishes

Although bridge concrete may possess the requisite strength, durability, and other desired qualities as a structure material, a poor state of its completed appearance may convey an impression of poor workmanship, shoddy construction, low quality, or even unsafe conditions. That is why there is as much emphasis in the specifications on the finish of concrete surfaces as there is on the strength and material quality of the concrete. The specifications place particular emphasis on portions of the structure that are visible from the traveled way, which require a surface finish that is uniform in appearance. This chapter encompasses the contract requirements that pertain to the quality and appearance of surfaces of the hardened concrete of completed structure.

This section covers the concrete finishing the formed surfaces of the hardened concrete, as specified in Section 51-1.18[10], “Surface Finishes,” of the Standard Specifications.

Specified Concrete Finishes

Requirements for final finishing of concrete surfaces are found in Section 51-1.03F of the Standard Specifications. 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

[9] 2006 Standard Specifications, or 2010 Standard Specifications, Section 51-7.

[10] 2006 Standard Specifications, or 2010 Standard Specifications, Section 51-1.03F "Finshing Concrete".

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 these characteristics are desired.

In general, other factors being equal, the amount of surface finishing that will be necessary to meet the contract requirements is a function of the quality of the formwork. The specifications note that the degree of care in building forms and character of materials used in form work 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. If good quality form materials are used and the forms are constructed in a workmanlike manner to the required lines and grades, the need for surface finishing will be much less than if the formwork is constructed otherwise.

Ordinary Surface Finish

Ordinary surface finish consists of filling holes and surface depressions, patching rock pockets, removing fins, and, on surfaces that are visible from a traveled way, removing stains or discolorations. Snap ties, bolts, or other steel form appurtenances must be removed to the specified depth. 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. After the forms are removed, the ordinary surface finishing should be completed at the earliest possible opportunity.

Ordinary surface finish is specified for all structure concrete surfaces, either as a final finish or preparatory to the application of a higher class finish. Even though ordinary surface finish is required to be applied to all concrete surfaces, this does not mean that the same finishing techniques are appropriate for all surfaces. For example, when 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 a traveled way, appearance is also a factor, so 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.

Ordinary surface finish, unless otherwise specified, shall be considered as a final finish on the following surfaces:

- The undersurfaces of slab spans, box girders, filled-spandrel arch spans, and floor slabs between girders of superstructures.
- The inside vertical surface of T-girders of superstructures.
- Surfaces that are to be buried underground or covered with embankment and surfaces above finished ground of culverts which are not visible from traveled ways. On

surfaces which are to be buried underground or surfaces which are enclosed, such as the cells of box girders, the removal of fins will not be required.

Patching Snap-Tie Holes

The specifications require that all form bolts and any metal placed for the convenience of the contractor, such as snap ties, shall be removed, to a depth of at least 1 inch below the surface of the concrete and the resulting holes or depressions shall 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 because if any moisture gets to the tie, corrosion will occur, resulting in expansive rust which would cause surface spalls and rust staining.

Removable portions of ties should be removed unless the contract documents specifically permit otherwise. The specifications allow form bolts projecting into the cells of box girders to be left in place unless deck forms are removed from the cells, in which case the bolts shall be removed flush with the surface of the concrete. Because it is non-corroding, glass-fiber reinforced plastic ties, commonly referred to as fiberglass ties, may be cut off flush with the concrete surface, leaving no hole to patch.

Snap-tie holes, bolt holes and other cavities on the surface of the concrete 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 clean and should be 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 layers of about 1/2 inch thick, with each layer given a scratch finish to improve bond with subsequent layers of mortar. The vigorous packing of the dry-pack mortar is the chief means of ensuring a good bond with the surrounding concrete and minimum patch shrinkage. It is also important that the color of dry-pack patch must match the surrounding concrete, which may be achieved by adding a small amount of white cement to the mortar patching material. Metal tools should not be used in dry packing as they tend to discolor the mortar.

Special admixtures may be used in the patching mix to improve moisture resistance and adhesion of the patch. Non-shrink grouts are also viable options. BCM 105-1.0 states that mortar additives (shrinkage reducers, water reducers, bonding agents, etc.) are acceptable provided the additive must be acrylic-based and it does not have polyvinyl acetate as an active ingredient. However, since the performance of specific patching materials or additives are not generally well founded, it is recommended consulting with your Structural Materials Representative or concrete subject matter experts at the Caltrans Transportation Laboratory (Translab) prior to allowing their use.

Repair of Rock Pockets

The specifications require that all rock pockets and other unsound concrete be removed. 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. For deeper rock pockets the exposed aggregate may have to be removed and replaced with a bonded patch.

When the rock pockets are widespread and/or a significant amount of reinforcing steel is exposed, a complete structural repair may be necessary. When rock pockets are present, selecting an appropriate repair method will involve subjective judgment. Concrete repairs are covered in Chapter 6 of this manual. It should be noted, however, that the specifications require that if the rock pockets, in the opinion of the engineer, are of such an extent or character as to affect the strength of the structure materially or to endanger the life of the steel reinforcement, the engineer may declare the concrete defective and require the removal and replacement of the portions of the structure affected.

Patches usually appear darker than the surrounding concrete. The specifications require that for exposed surfaces, white cement shall be added to the mortar or concrete in an amount sufficient to result in a patch which, when dry, matches the surrounding concrete. To ensure a proper match, it is considered best practice to make sample patches, using different proportions of white cement, in inconspicuous locations.

The specifications require the mortar or concrete used for patching or repair to be cured in conformance with the provisions in Section 90-7.03[11], "Curing Structures."

Class 1 Surface Finish

Class 1 surface finish 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.

Class 1 surface finish is applied to certain specified surfaces which 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. From this it should be apparent that if the forms are carefully constructed

[11] 2006 Standard Specifications, or 2010 Standard Specifications, Section 90-1.03B, "Curing Concrete".

and ordinary surface finish diligently applied, little or no Class 1 surface finishing will be necessary to fulfill the intent of the specifications

Class 1 surface finish shall be the final finish for the following surfaces, unless otherwise specified in the special provisions:

- Except for those surfaces listed in ordinary surface finish, the surfaces of bridge superstructures, including the undersurfaces of deck overhangs.
- Surfaces of bridge piers, piles, columns, and abutments, and retaining walls above finished ground and to at least 1 foot below finished ground
- Surfaces of open spandrel arch rings, spandrel columns, and abutment towers.
- Surfaces of pedestrian undercrossings, except floors and surfaces to be covered with earth.
- Surfaces of culvert headwalls above finished ground and endwalls visible from a traveled way.
- Interior surfaces of culvert barrels having a height of 4 feet or more for a distance equal to the culvert height where visible from a traveled way.
- Interior surfaces of pump house motor and control rooms and engine-generator rooms.
- Surfaces of railings.

The specifications require Class 1 surface finish to be sanded, with power sanders or other approved (by the engineer) abrasive means, until the required surface appearance is obtained. The specifications require the use of power carborundum stones or disks to remove bulges and other imperfections. As a best practice, power sanding should be done with a flexible disk abrasive wheel as opposed to a rigid abrasive disk, which, more often than not, produces a burned surface if used improperly. The skill of the person performing the power sanding is a significant factor in achieving the desired Class 1 surface finish. Furthermore, it is recommended that to obtain best results power sanding should be postponed as long as possible.

Whip blasting

Per BCM 105-1.0, whip blasting, also known as light sand blasting or light abrasive blasting, may be used to produce a Class 1 Surface Finish. 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 affects the surface finish and should, therefore, remain the same throughout.

The skill of the person performing the work is a critical factor that affects the outcome of the desired uniform appearance of the Class 1 surface fin sh. Surface defects due to concrete forming and placement, such as bug holes, leakage lines and cold joints between concrete lifts, tends 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 considering the appropriate means and method of 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.

The following precautions should be taken when using abrasive blasting:

- In order 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.
- To aid the field engineer and workers in maintaining a uniform whip blast operation, they may apply a light lumber crayon mark approximately 1 foot in length to the surface of the work at random locations. The force of whip blasting operation should be of sufficient force to just remove the mark.
- Caution should prevail as an over aggressive application could result in a damaged surface that would be difficult to repair.
- The signs of an unacceptable result would be excessive pinhole, whip marks, and exposed aggregate.
- Abrasive blasting must conform to Regional Air Quality Management District regulations and permitting requirements.

Once these factors have been determined, the engineer must inspect the work periodically to be assured that workers are following those procedures which have been determined will give satisfactory results.

Engineer's Roles and Responsibilities

As provided in the Standard Specifications, the engineer is the sole judge who 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.

This is a heavy burden for the engineer, since the finishing requirements are among the most subjective in the contract. When determining the results of the contractor's finishing effort against contract requirements, the engineer should keep in mind that finished concrete should look like concrete and not some other material; that surface finishing is as much art as science, so that obtaining the intended result is more a matter of the practitioner's skill than of the particular method or procedure employed; and that compliance with the intent of the contract will be more apparent if the work is viewed from afar, which is how the public views it, than from up close. All factors considered, proper administration of the surface finishing specifications not only requires engineering judgment and experience, it also requires common sense.

Unacceptable Class 1 Finishes

The Standard Specifications require that concrete finish on exposed concrete surface (Class 1 Concrete Finish) shall be achieved solely by abrasive methods. Consequently, per BCM 105-1.0, any sprayed-on cement finish or applications similar to surface painting, where cement or grout (which is cement mixed with water) is applied to the concrete surface as the surface finish, will NOT be acceptable as a Class 1 Surface Finish, unless it is otherwise explicitly provided for in the contract.

Class 2 Surface Finish

Class 2 Surface Finish, or gun finish, is not a common concrete surface finish, and when it is required, it will be shown on the plans or specified in the special provisions. This finish consists of the pneumatic application of a mortar coating, similar to shotcrete, after the ordinary surface finish is completed.

When Class 2 surface finish is specified, ordinary surface finish shall first be completed. The concrete surfaces shall then be abrasive blasted to a rough texture and thoroughly washed down with water. While the washed surfaces are damp, but not wet, a finish coating of machine applied mortar, approximately 1/4 inch thick, shall be applied in not less than two passes. The coating shall be pneumatically applied and shall consist of sand, Portland cement and water mechanically mixed previous to its introduction to the nozzle, or premixed sand and Portland cement to which water is added previous to its expulsion from the nozzle. The proportion of cement to sand shall be not less than one to four, unless otherwise directed by the engineer. Sand shall be of a grading suitable for the purpose intended. The machines shall be operated and the coating shall be applied in conformance with standard practice. The coating shall be firmly bonded to the concrete surfaces on which it is applied.

Safety and Environment

Over the years there has been increasing emphasis placed on mitigating the impact of concrete construction practices on the environment. A lot of these requirements are required in the Storm Water Pollution Prevention Plan (SWPPP) embedded in the contract documents or in permits from regulatory agencies. Similarly, there have been improvements in construction safety practices. A few of those that affect concrete finishing practices are discussed below.

Working Over Water and Environmentally Sensitive Areas

When it is necessary that the contractor perform finishing operations over water ways or environmentally sensitive areas (ESA), all necessary precautions should be taken to prevent cement dust, sand, rinse water, or any other related finishing materials from entering these areas.

Working Over Traffic

When it is necessary that the contractor perform finishing operations over a traveled way, lane closures should be made beneath the finishing operation if there is any possibility that the scaffolding will be lower than the bridge soffit, or if there is any possibility that objects will fall onto the traveled way.

Special Concrete Construction Practices

This section covers special concrete construction practices employed for situations that are not commonly encountered on most Caltrans bridge construction projects, such as hot and cold construction and placing concrete underwater, but presents technical challenges requiring extensive discussion to ensure that the concrete used or placed in these special conditions meets the strength, durability, and other quality standards.

When the ambient temperature is higher or lower than an optimum range of about 50°F to about 90°F, special procedures and precautions are necessary to avoid the detrimental effects on concrete quality that can result from either hot or cold weather conditions.

High temperatures will increase the water demand, decrease workability, reduce strength, and increase shrinkage. Low temperatures will retard strength gain, and 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. Engineers on projects involving concrete construction under adverse weather conditions 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 properties of the concrete will be obtained despite the adverse weather.

Specification Requirements

When placing concrete under adverse weather conditions, the most effective means of assuring satisfactory results is keeping the concrete temperature within an acceptable range of 50°F and 90°F while it is in the plastic state. However, in cold weather construction, neither aggregates nor mixing water can be heated beyond 150°F.

Hot Weather Construction

When concrete is placed under 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, the water demand increases as temperatures rise, and this increases the water-cement ratio unless compensating measures are taken. For a given concrete, the amount of water needed to maintain the same consistency will increase as much as 15% as the temperature of the fresh concrete increases from 50°F to 100°F.

At high temperatures the time during which concrete remains plastic is decreased, and this in turn decreases the window within which the concrete must be mixed, delivered to the site, 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, and this may result in the formation of rock pockets and cold joints 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 within the concrete mass becomes more difficult, so curing becomes a more critical activity. Also, controlling the air content in air-entrained concrete is more difficult. For a given amount of air-entraining agent, less air will be entrained as temperatures increase.

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 (80°F for bridge decks) 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% 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 will increase the temperature of the concrete mixture about 30°F.

Several methods may be used to lower aggregate temperature. Shading stock piles 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.

Sand in stockpiles is more difficult to cool, but sand (because of its normally higher moisture content) is less likely to experience a significant increase in temperature unless the stockpiles remain unused for a long period of time.

Other factors being equal, 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 taken from the coldest available source. If above ground storage tanks are used, they should be shielded from the sun or, if this is not possible, painted white.

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. If ice is used to cool the concrete, discharge of the mixer will not be permitted until all ice is melted.

Using ice in the mixing water is highly effective in reducing the concrete temperature because melting ice removes heat at the rate of 144 BTU per pound. For example, if 50% 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 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.

Note: There are many published construction guides that a contractor may use as a guide for placing concrete in hot weather that include a version of the ACI nomograph shown in Figure 5-22 that may be used to estimate water evaporation rates while the concrete is plastic. While estimated variables (temperature, humidity and velocity) may be used during the planning stage, it is important to note the variables used during planning must be checked with actual readings during the concrete placement.

Mixing and Delivery

When transit-mixing equipment is used, the trucks should be dispatched and the work should be planned and organized 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, but this is strictly an emergency procedure. The important point is that truck mixers must be unloaded as soon as possible after they arrive at the site, and the work should be 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 and black painted surfaces may be as much as 30°F warmer; and 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.

Under hot weather conditions, the Standard Specifications place a restriction on the 90-minute time normally allowed between batching and discharge of concrete when truck mixers are used. The specific provision is that a time less than 90 minutes may be required under conditions contributing to quick stiffening of the concrete, or whenever the ambient temperature is 85°F or above. The specifications give the engineer authority to limit the time available for delivery and standby at the site by reducing the overall time allowed, and the engineer is expected to use this authority in any situation where, in his judgment, a reduction is warranted to ensure a satisfactory end product.

Placing and Finishing

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

Prior to placing concrete, the forms and reinforcing steel should be wet down with cold water. Wetting the area around the work is also beneficial since it cools the surrounding air and increases its humidity, thus reducing both the rate of evaporation and temperature rise during the placing operation.

Concrete dries 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 where exacting surface fin shing requirements make it imperative that finishing follow closely behind placing to minimize moisture loss from evaporation. Preventing excessive loss of surface moisture is important for two reasons. First, surface moisture is necessary for satisfactory deck finishing. Second, and more important from a structural standpoint, 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 are favorable for the rapid evaporation of surface moisture. However, the conditions that contribute to plastic shrinkage cracking are exacerbated by hot weather. In view of this fact, special care is necessary to minimize the rate of evaporation of surface moisture when high temperatures prevail. Plastic cracking and bridge deck fogging have been covered previously in this chapter.

During extremely hot periods when temperature conditions are critical, consideration should be given to placing concrete during the early evening or at night when lower temperatures will reduce the rate of evaporation.

Curing

During periods of hot weather, a special effort may be required to ensure that the purpose of curing (i.e., keeping the concrete in a moist condition and within an optimum temperature range) is achieved, as these conditions become increasingly more difficult to obtain as ambient temperatures rise.

All curing equipment and facilities should be at the site of the pour and available so that curing may begin without delay as soon as the concrete is placed and finished. Particular care must be taken during hot weather to ensure that all exposed surfaces are kept continuously wet to prevent moisture loss until the permanent curing medium is applied.

In the case of bridge decks, it may be necessary to apply water to the deck surface (by means of a mist or fog spray) 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 amount of water applied should be carefully controlled, and should not exceed the minimum amount required to prevent surface drying.

During hot weather, it is important to keep in mind that for optimum curing, concrete must be kept cool as well as moist during the curing period. 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.

The specifications provide that during periods of hot weather and when directed by the engineer, water shall be applied 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. (Standard Specifications, Section 90-7.03[12].) Application of water pursuant to this specification is paid for as extra work at force account.

When applying water to cool exposed surfaces, avoid the use of water that is excessively cooler than the concrete. Extremely cold water may cause cracking as a result of thermal stresses due to temperature change at the surface.

Use Of Admixtures

Even though admixtures may not be required, their use should be considered during hot weather as a means of mitigating some of the undesirable side effects of hot weather construction.

[12] 2006 Standard Specifications, or 2010 Standard Specifications, Section 51-1.03H, "Curing Concrete Structures".

A set retarding admixture may be used to delay the initial set and thereby compensate 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, and this may have a detrimental effect on surface finishing. If an air-entraining admixture is not specified, the average air content of three successive tests may not exceed 4%, and no single test value may exceed 5-1/2%.

Cold Weather Construction

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

Mixing And Delivery

To prevent freezing while the concrete is still plastic, the specifications require a minimum concrete temperature at time of placement of 50°F . Therefore, when the ambient temperature falls below 50°F, it will be necessary to heat the water or 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 unless the stockpiles and batch bins are protected and/or the aggregate 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 should be protected by covering them with tar paulins 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 some adjustment of the batching cycle will be necessary to prevent the water from mixing directly with the cement, as direct contact may induce premature setting (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.

Under the current specifications, neither the water nor the aggregate may be heated above 150°F. 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 California.

Placing and Finishing

The temperature of all surfaces that the fresh concrete will contact must be above freezing before concrete is placed. Specifications prohibit placing concrete 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, concrete placement should be suspended 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 period and that a temperature favorable for hydration be maintained. The specifications require concrete, to be maintained at a temperature of not less than 45°F for 72 hours and not less than 40°F for 96 hours more. Additionally, when requested by the engineer, the contractor must submit his 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.

Many methods are available to maintain concrete temperature. When the work area can be enclosed or covered, space heaters are an effective heating method. 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 first cost and operational standpoint, but they are effective and may be economical under severe weather conditions.

Curing

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 any heat from outside sources to maintain the required minimum temperature. In any case, it is essential to conserve the heat generated, thereby reducing to a minimum 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 about 40°F.

Measuring Concrete Temperatures

Thermometers provided by the State should be used to measure concrete temperatures. The temperature of hardened concrete should be measured by inserting the stem of the thermometer full depth into a previously formed water-filled hole in the concrete. (A drinking straw makes a good form for this purpose.) When no longer needed, the hole should be plugged at the surface to keep out debris. When measuring the concrete temperature, sufficient time must be allowed for the thermometer to stabilize before the temperature is recorded. Corners and edges are particularly vulnerable, and a special effort should be made to check temperatures at these locations.

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.

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.

Contract requirements for seal course concrete are found in Section 51 of the Standard Specifications. Requirements for water displacement or slurry displacement procedures will be found in the specifica ions for the project where that particular construction method is specified.

Seal Course Concrete

By contract definition, a seal course is a layer of concrete that is placed within a watertight cofferdam by means of a tremie or concrete pump. The seal course must be of sufficient strength and thickness to resist the hydrostatic pressure developed at the bottom of the cofferdam when the cofferdam is dewatered.

The specifications permit seal course concrete placement using either tremie methods or by means of a concrete pump. 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.

Note that 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, and 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. This requires a fairly fluid mixture; consequently, the specifications require 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. Seal course cementitious content is controlled by specification.

Concrete Placement

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.

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 lower end of 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.

Every precaution must be taken to minimize segregation. As work progresses, the previously placed concrete should be disturbed as little as possible, and the top surface of the concrete should be kept as near level as possible. The discharge tube should not be moved laterally through previously deposited concrete. When it becomes necessary to move the discharge tube to a new position, the valve should be closed and the tube removed from the concrete before it is moved.

The specifications require a nominal 5-day cure period for seal course concrete before dewatering the cofferdam. However, when water temperatures are below 45°F, a longer cure time may be required to offset the slower strength gain at colder temperatures. Periods of time during which the water temperature is below 38°F are not considered as curing time.

Water and Slurry Displacement Method

The water and slurry displacement methods of underwater concrete placement are similar in that structure 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.

Generally, slurry displacement is specified. Water displacement is only acceptable when allowed by the special provisions. In 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.

Slurry displacement is most often used to facilitate installation of CIDH piles where all or a portion of the pile is below groundwater and the sides of the pile are not self-supporting. In such cases the slurry, which is commonly synthetic drilling slurry or a commercial quality mineral drilling mud, supports the sides of the pile until concrete is placed.[13]

Water displacement may be used to place concrete in CIDH piles constructed in fully cased holes and in mined shafts in rock formations where the excavation is below the ground-water surface and the amount of water present cannot be controlled using conventional de-watering procedures.

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[13] Information on these products may be obtained from OSC Headquarters in Sacramento.

The concrete is placed in a continuous operation. 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 remain 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.

Note: Where concrete is placed under slurry, the current standard specifications establish criteria for the minimum slump.

- For piles where the time required for concrete placement is 2 hours or less, the concrete mix design should achieve a slump of at least 7 inches for twice the concrete placement time.
- For piles where the time required for concrete placement is more than 2 hours, the current Standard Specifications, require that the concrete mix design achieve a slump of at least 7 inches at the end of concrete placement plus 2 hours.

When either water displacement or slurry displacement concrete placing methods are to be used, the specifications will include concrete materials and production specifications, placing procedures, testing requirements, and when a slurry is used, slurry material and production requirements as well.

Bridge Construction Practices

This section is intended to highlight the recommended concrete construction practices that are applicable to each of the various bridge elements, within the context of State construction contracts. Particular emphasis is given to concrete box girder bridges, which is by far the most common type bridge constructed by the Department.

In general, the concrete in each integral part of the structure must be placed continuously and the contractor should not be allowed to begin unless the forms are ready, there is sufficient material on hand, and the contractor's forces and equipment to complete the contemplated work without interruption.

Foundations

Bridge foundations are not only the structural support of a bridge, but they are also in essence the template that serves to fix the location, position and alignment of a bridge. As such, it is incumbent upon the inspector to ensure that the bridge foundations are located, positioned and aligned according to plans. The primary means of establishing the lines and grades for bridges are through the "control stakes" provided by Caltrans' surveyors for the bridge foundations. Since bridge foundations control the bridge lines and grades, the inspectors should invest time and effort in ascertaining that the survey stakes for the bridge foundations are correct before they are constructed.

Concrete Piles

There are two types of concrete piles that are in common use in Caltrans bridge construction projects: pre-cast concrete piles and cast-in-place concrete piles.

Cast-in-place piles are further classified by whether the concrete is placed in a dry hole or deposited under slurry, also known as wet pile. Refer to the Foundation Manual for detailed descriptions of cast-in-place piles.

For piles cast in dry holes, the concrete placing, consolidation and finishing requirements are similar to that of any other bridge structure concrete, with some special requirements unique to this type of piles. In general, piles having a diameter of 30 inches or more are vibrated from the bottom of the reinforcing cage to the top of the pile. Unless otherwise specified, piles with diameters of less than 30 inches, vibration is required only in the top 15 feet of the pile, regardless of the depth of the reinforcing cage. There are no specified limitations on the fall distance for concrete placed in piles, provided that the falling concrete falls to the center of the pile without hitting rebar on the way to the bottom.

For dry piles, the concrete, in some instances, may be placed directly from transit-mix trucks, using the truck-mounted chute. The use of a small hopper at the top of the pile shaft will reduce segregation, since it will recombine the concrete as it leaves the chute and provide a vertical fall through the reinforcing cage. This may be particularly important if a more fluid mixture is being used. Care must be taken to minimize amount of concrete falling directly on the reinforcing steel cage or striking the sides of the pile by using drop chute, for example. To minimize the formation of voids and rock pockets in the lower, unvibrated length of the pile, consideration may be given to increasing the water content to secure a more fluid mixture. In no case however, should the water content exceed the specified maximum amount.

For wet piles, extra care and precaution in placing the concrete is necessary because of the high likelihood of concrete defects. Because of the high risk associated with concrete placed under water, standard special provisions were developed for this challenging concreting process. Additional information can be found in the section entitled "Placing Concrete Under Water" earlier in this chapter of this manual and in the Foundation Manual.

Footings

Immediately before placing concrete, the ground surface on which the footing concrete will be deposited should be thoroughly dampened with water. During concrete placement, the ground should be saturated, but there should not be any puddles of standing water.

Footing concrete is usually deposited directly from transit-mix trucks using truck-mounted chutes. In cases where the distance between the truck and the footing is too great to be reached with truck-mounted equipment, special chutes may be employed. Water should not be added merely to facilitate the use of chutes. Where the bottom of the footing is on a slope, the concrete should be placed first at the low end and then proceed up the slope. In all cases concrete should be deposited near its final location, and use of vibrators for extensive shifting of the concrete should not be permitted.

Revibration is required for footings that are more than 2-1/2 feet thick and have a top layer of reinforcing steel. The purpose of this revibration is to minimize the presence of voids below the top layer of reinforcing bars. Such voids, which may occur as a result of bleed water collecting below the bars, will reduce the bond between the concrete and the reinforcing bars. The specification requirement is that revibration is to be performed as late as the concrete will respond to further vibration, but no sooner than 15 minutes after initial screeding has occurred. To hasten final finishing, most contractors would prefer to perform the required revibration sooner rather than later. When determining the optimum delay period, the engineer should keep in mind that for maximum effectiveness, revibration should be delayed as long as possible.

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

Columns and Walls

Concrete for columns and walls are usually placed by means of concrete pump or by crane and bucket. When the form height exceeds 8 feet, the specifications require the use of a drop chute below the hopper to prevent segregation and to direct the concrete so that it does not strike the bar reinforcing steel or the sides of the forms above the level of placement. Adjustable-length metal or plastic tubes are commonly used for this purpose. When pumps are used, the pump discharge hose may be used to satisfy this requirement, in which case a hopper will not be needed.

Concrete should be placed in successive lifts, and placement should be planned so that the horizontal level of the concrete rises at a uniform rate over the entire area being placed. In general, lifts should not exceed about 2 feet in height in narrow walls or 1 foot for wider walls and columns; otherwise the effectiveness of vibration will be severely reduced. To ensure bond between lifts, vibrators should penetrate through the lift being placed into the previously placed lift. In any case, no more concrete should be deposited into the forms than can be vibrated conveniently and effectively.

Finally, the placing rate must be controlled so as to avoid excessive form pressure. The pressure exerted against the side form is directly related to the height of the plastic concrete in the form. If the placement rate is greater than assumed in the form design, the resulting higher pressure may produce excessive deflection, or even failure. Additionally, because vibration makes concrete more fluid, form pressures are greater in areas being vibrated, an otherwise stable pour could experience form failure while undergoing vibration.

Bent Caps

Occasionally, a particular sequence of construction will require that concrete be placed in the columns and bent cap in the same pour. In such cases, it is essential that placing of the cap concrete be delayed until the concrete in the columns has taken its initial set. By following this procedure, settlement and shrinkage of the column concrete will occur before the cap concrete is placed, thus substantially reducing shrinkage stresses at the joint between the column and cap.

Superstructure

The current specifications require concrete for girder spans (box girder and cast-in-place T-beams) to be placed in not less than two operations, with the last operation being the top deck slab. Unless otherwise permitted by the engineer, at least 5 days must elapse between each operation. The 5-day minimum time period is included in the specifications to allow the girder stem concrete to gain sufficient strength to resist stresses caused by additional falsework deflection and settlement under the added load of the concrete deck.

Stem and Soffit-Box Girder

In a conventional box girder construction, the concrete for the bottom slab (soffit) is placed with the concrete for the girder stems in one concrete placement operation. Although there is no specified construction sequence, when the soffit and girder stems are placed in a single operation, most contractors place concrete in the bottom slab first, and follow with the girder stems. For this placing sequence, a decision must be made as to how far ahead (of the stems) the soffit concrete should be placed before placing concrete in the stems. This decision is influenced by several factors, including the length and width of the super-structure, the expected rate of concrete placement, and probably most important, the size and experience of the construction crew. Ideally, the bottom slab concrete should be allowed to set until it is stiff enough to retain concrete placed in the stem, but not so long that it cannot be reworked.

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

Placing the girder stem concrete first has the apparent advantage of reducing the slab fin shing effort, but this saving is seen to be illusory when all factors are considered. When the girder stems are placed first, vibrating of the soffit slab adjacent to the stem tends to draw concrete from the lower part of the stem into the soffit slab area. When this occurs, voids will be created around the longitudinal reinforcing at the bottom of the stem and, for cast-in-placed prestressed construction, below the pre-stress ducts near mid-span. Unless the stem concrete is thoroughly revibrated after the bottom slab is placed and vibrated, rock pockets are a certainty. For longer spans having relatively deep girders, the bottom slab (soffit) may be placed first, as a separate operation, to reduce the size of the combined concrete pou .

Regardless of the placing sequence followed, as the bottom slab is placed, the top surface should be struck off to grade and hand-floated with a wood float. As the concrete sets, the slab should be re-floated as necessary to seal the surface. Girder stem concrete should be placed in lifts, and each lift must be thoroughly vibrated. To ensure bond between successive lifts, the vibrator must penetrate through the fresh concrete and into the previously placed lift. And as previously noted, if the stems are placed first, thorough revibration to the bottom of the stem after the soffit slab is poured is necessary to prevent voids and rock pockets near the bottom of the stem.

Stem/Deck Construction Joint

Since the girder stems and bridge decks are not placed in one single operation, as per specification, the construction joint between these two bridge elements is critical in making the box girder function as a monolithic structural member intended by its design. The horizontal shear capacity across the stem-to-deck joint increases significantly when the construction joint is intentionally roughened to a minimum amplitude of 1/4 inch. In theory, roughening the surface at the construction joint interface allows for the joint surfaces to ride up on each other as they attempt to slip. This action places the reinforcing steel across the joint (stirrups) in tension and provides a strong clamping force. Design codes allow for significantly more horizontal shear capacity when the construction joint is intentionally roughened to a minimum of 1/4 inch amplitude.

Per BCM 105-7.0, the top of girder stems is required to be intentionally roughened to a minimum of 1/4 inch amplitude. With this new method of roughening stem concrete, abrasive blasting will no longer be required to intentionally expose the aggregate. However, abrasive blasting is still required to clean the top surface of the girder stem of materials that are detrimental to a proper concrete bond prior to placing the deck concrete.

Figure 5-29. Stem Concrete with 1/4 Inch Roughening.

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

During the roughening operation, care should be exercised to avoid excessive dislodging of coarse aggregates when using the roughening tool, floating/troweling of the top surface of the stem, and over vibrating the concrete. Floating forces coarse aggregate into the paste and makes the surface smooth and overvibration causes the cement paste to rise and cover coarse aggregates, also making the surface smooth.

In addition to roughening the stem concrete, it is also extremely important that the surface of the construction joint be cleaned by abrasive means prior to placement of deck concrete to remove all laitance, curing compound, and loose concrete.

Bridge Decks

Of all the elements in a reinforced concrete structure, the bridge deck is the element that is subject to the most severe conditions of exposure and wear. Bridge decks are subjected to high live-load stresses and alternate cycles of wetting and drying, and may be exposed to extreme temperature changes as well. Additionally, in many parts of California, bridge decks are exposed to freezing and thawing and the deliberate application of de-icing salt.

Bridge decks contain a congestion of reinforcing steel, making the use of a workable concrete essential. Because of bleeding and surface finishing requirements, the worst quality concrete in the deck is at the surface. Clearly, to ensure the adequacy and integrity of the completed work, bridge deck construction should receive the engineer's personal attention, with special emphasis on production, placing, finishing, and curing of the concrete.

For recommended practices, inspection procedures, policy, and other information of interest to field engineers who are involved with bridge deck construction, refer to the Bridge Deck Construction Manual. It is noted, however, that the deck construction manual is concerned primarily with engineering and inspection of deck construction as a whole; it does not (and is not intended to) stress the procedures that are necessary to obtain quality concrete. Accordingly, and in addition to the instructions and information in the deck construction manual, the following points are emphasized:

- First and foremost, obtaining a workable concrete with the lowest possible water-cement ratio should be the engineer's goal. Since the deck is the last major element constructed, there should be ample time during previous concrete pours to refine production methods and construction procedures to achieve this goal.

- Emphasis should be placed on reducing the water demand. In particular, the use of a water-reducing admixture will be beneficial under almost all circumstances.

- When pumps are used to place concrete mixtures having a high percentage of crushed aggregate, the increased water demand may be reduced by the use of a workability admixture. While there are several products, which are marketed as pumping aids or lubricants, and are available commercially to facilitate pumping of concrete, only products that are on the METS approved admixture list may be used.

- The deck finishing operation should be planned and carried out so as to minimize the need to apply water to the deck surface. An excessive amount of water applied to the surface, either while finishing is in progress or after finishing is completed but before application of the curing compound, will increase the water-cement ratio at the surface, and this in turn will increase scaling and accelerate deterioration of the wearing surface.

- Water should not be applied merely to facilitate deck finishing. If additional moisture is needed to properly seal the surface, it can be obtained by applying a thin layer of grout by the hand brush method. (Any grout used for this purpose should conform to applicable provisions in Standard Specifications 50-1.09[14].)

- Any water applied should be in the form of a fog spray, and the amount applied should not exceed the minimum amount needed to replenish moisture lost by evaporation.

- Air-entraining admixtures provide increased workability; however, they also reduce the rate at which bleeding occurs, and this may adversely affect deck finishing operations.

- For hot weather conditions, particular emphasis should be placed on keeping the temperature of the concrete mixture as low as practicable, and minimizing the indiscriminate use of water to increase workability and/or to facilitate finishing.

- The specifications require grinding of the completed bridge deck if grinding is necessary to obtain the profile and/or texture requirements specified. While grinding is a contract requirement to improve profile and surface characteristics, it is also detrimental to the structural integrity of the bridge deck, for two reasons. First, grinding reduces the cover over the embedded deck reinforcing

[14] 2006 Standard Specifications, or 2010 Standard Specifications, Sections 50-1.02C and 50-1.03B(2)(d)

steel and second, it abrades the finished surface, leaving exposed and fractured aggregate particles. Grinding is particularly detrimental in areas subject to repeated freeze-thaw cycles and the application of de-icing salt. In view of this, the engineer should keep in mind that deck grinding is not a panacea to solve surface problems that should have been solved during the deck finishing operation.

Barrier Rails

The specifications require that, when ordered by the engineer, the height of the concrete railings shall be adjusted to compensate for the camber and dead load deflection of the superstructure. When concrete barriers are to be constructed on existing pavement or existing structures, the height of the barriers shall be adjusted to compensate for irregularities in the existing grade. The amount of adjustment will be determined by the engineer and will be ordered before the concrete is placed.

Emergency Construction Joints

There is always the possibility that unanticipated circumstances will make it necessary to stop the work and form a construction joint at a location where none was intended. Examples of such situations include form failures, usually caused by form tie failure; 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.

The specifications require that when a construction joint is necessary, it shall 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. In girder stems, the joint should be formed with step keys and additional reinforcing steel added in the manner shown on the Standard Plans 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. In slabs, the joint may be installed at any convenient location.

When installing an emergency joint, it may be necessary to remove some concrete that is already in place. This can be accomplished by cutting a hole in the forms and washing out the concrete if SWPPP concerns can be met, by removing the concrete by hand, or if the concrete has started to set, by removing it with jackhammers or similar equipment. Reinforcing steel should continue through the emergency bulkhead, but if this is not possible for some reason, the means by which the cut bar will be spliced later should be considered, and the bar cut with splicing in mind. Emergency construction joints may be made with any available material, keeping in mind that they must be removed later and the joint prepared for the following 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 the joint in a girder stem will be dictated by the location of the concrete front when the emergency arises, its location with respect to the supporting falsework should be reviewed before work continues. If the joint is located near the center of a falsework span, additional beam deflection occurring when work resumes will remove the support under the previously placed stem. To prevent loss of beam support, it may be advisable to install a supplemental post at the joint location.

During a concrete pour, the need for an emergency construction joint may arise at any time. The engineer should be prepared to take whatever action is required, and should at all times know the best location for an emergency joint, the configuration required, and whether keys and/or additional reinforcing steel will be needed. Until all concrete is in place, the possibility of an emergency occurring should be anticipated, and the placing rate and location controlled with this in mind.

Weight Limits

Weight limitations are addressed in the Standard Specifications. The contractor may redesign the structure if an increased load carrying capacity is needed for construction purposes.