Chapter 5: Concrete Structure Repair and Rehabilitation

Table of Contents

5-1 Overview

In ideal conditions, concrete that has been properly manufactured, placed, and cured should last beyond the 50-year design life. However, for a myriad of reasons, structural concrete may require maintenance and repair. Damage can occur at any stage of the structure's service life; see Figure 5-1 for an illustration of bridge deck damage. Repair may be required early in the structure’s service life during construction if it is damaged by the Contractor doing the work or improperly placed. Another example may be extensive cracks in a newly placed bridge deck caused by difficult weather conditions while the material cures. Repair and maintenance may be required after the structure is put into service. Damage can occur from vehicular traffic accidents and natural disasters like floods and earthquakes. Structures in freeze/thaw areas can be subjected to additional cycles of stress during winter months from water intrusion, as well as routine damage from the use of tire chains needed for additional traction. Even the concrete material used could fail over time. For example, alkali-silica reactivity creates an expansive gel linked to concrete failure. This chapter will provide an overview of structural concrete repair and rehabilitation.

Figure 5-1. Example of Bridge Deck Damage

5-2 Concrete Defect Categories

Notable defects fall into several categories:

1. Surface imperfections like soft surfaces or surface voids
2. Insufficient strength
3. Cracking
4. Scaling
5. Spalling

6. Delamination
7. Abrasion or surface wear
8. Surface profile defects
9. CIDH pile anomalies
    a. Refer to BCM 49-3, *Piling – Cast-In-Place Concrete Piling* (from Volume II of the Structure Construction (SC) *Bridge Construction Records and Procedures (BCR&P) Manual*) and the *Foundation Manual* for pile mitigation and acceptance procedures.

5-2.01 Surface Imperfections

Voided surfaces, like those shown in Figure 5-2, are caused by rock pockets, honeycombing, and cold joints, which may be due to any of the following:

1. Improper mix design
2. Poor placement
3. Improper consolidation
4. Leaky forms
5. Excessive form deflection
6. Excessive bar reinforcing steel (rebar) congestion
7. Any combination of the above conditions.

Soft surfaces are usually caused by improper treatment of wooden forms before concrete placement. New plywood may be affected by sunlight exposure. Tops of wall forms may deflect slightly and pull a thin layer of mortar away from the parent concrete. Excessive bleed water will carry fine materials to the surface, resulting in laitance or sand streaking.

Figure 5-2. Rock Pocket Damage- both Minor and Major

5-2.02 Insufficient Strength

Contract plans often require minimum compressive strength for specific structural elements such as the bridge superstructure. When a concrete element requires a minimum compressive strength, concrete samples are obtained for testing. Accordingly, when the compressive strength requirements shown on the contract plans are not met, the *Standard Specifications* Section 90, *Concrete*, may require non-compliant concrete to be removed.

5-2.03 Cracking

Because of concrete's low tensile strength and the volume changes accompanying temperature and humidity fluctuations, cracking is a concrete characteristic that can occur at any time during the life of a concrete structure. In new construction, cracks occasionally occur due to problems encountered as concrete is placed, such as excessive falsework settlement or form deflection. Most cracking associated with new construction, however, is plastic shrinkage cracking.

Plastic shrinkage cracks appear on the surface of fresh concrete after it is placed and finished, and while it is still in the plastic state; hence the name "plastic" shrinkage cracking. Plastic shrinkage cracks are a consequence of excessive evaporation of moisture from the concrete surface.

When curing ceases, the free water within a concrete mass begins to evaporate. As the concrete dries, microscopic changes in the concrete structure caused by water loss result in volume reductions of the concrete mass. If the concrete is restrained in any way, say for instance by reinforcing steel, cracks will develop. Such cracks are called "drying" shrinkage cracks. Unlike plastic shrinkage cracks, which occur on horizontal surfaces, drying shrinkage cracks can occur on any surface of any element in the structure or within the concrete mass itself.

Cracking of sufficient severity to warrant repair is a rare occurrence in new construction. Severe cracking, when it does occur, occurs most often on the bridge deck and is usually the result of plastic shrinkage, although construction problems such as excessive falsework settlement or deflection can cause cracking problems as well. The contract remedy for excessive bridge deck cracking is methacrylate treatment. Epoxy injection is the appropriate repair method for vertical cracks in other elements of a new structure where crack repairing is warranted; refer to Section 5-6.01B, *Epoxy Crack Injection*.

From a structural standpoint, cracks in concrete usually are not a cause for alarm because cracking, in most cases, will not impair the load-carrying capacity of a concrete member. There are two exceptions to this general observation: structural cracks and cracks that are indicative of internal stress development.

Structural cracks (i.e., cracks caused by load overstress) can be troublesome, particularly if there is significant crack movement under load. When warranted by safety or maintenance considerations, structural cracking can be repaired and the integrity of the member fully restored; this is accomplished by filling the cracks (by pressure injection) with an epoxy adhesive. Corrosion of embedded bar reinforcing steel (rebar) is a major crack-inducing factor in bridge decks in freeze-thaw areas where the deck is subjected to the application of deicing salts.

Corrosion of rebar may also occur in structures located in a marine environment or when rebar concrete coverage is inadequate. Corrosion-induced cracking, while not of serious consequence from a structural standpoint, is detrimental because it facilitates the ingress of moisture, oxygen, and chloride ions, and thereby exacerbates the corrosion process.

Map cracking (sometimes called pattern or craze cracking) may occur several years after construction in a concrete structure made with reactive aggregate. In this case, cracking is the manifestation of a more serious problem, which is the formation of expansive gels (alkali-silica reactions) within the concrete mass. This causes disruptive expansive forces which can lead, eventually, to the complete disintegration of the concrete. Typical map cracking of a bridge deck is shown in Figure 5-3.

Figure 5-3. Map Cracking of a Bridge Deck

5-2.04 Scaling

Scaling is the flaking of surface mortar, often accompanied by the loosening of surface aggregates. Scaling occurs as a result of repeated cycles of freezing and thawing. If concrete cools below the freezing point, free water in the concrete freezes and forms ice crystals. The expansive pressure thus developed causes cracking and mechanical fracturing in the hardened paste. Cracking and fracturing continue with each repeated freeze-thaw cycle. Eventually, the hardened paste disintegrates to the point where the aggregate particles are no longer bonded together and are easily eroded. In cases of severe scaling, the mortar portion of the concrete is completely broken down and loose aggregate can be scooped out by hand. See Figure 5-4 for an illustration of severe scaling.

When a concrete structural element is exposed to deicing salt, air entrainment may not give complete protection because the salt increases the amount of water absorbed by the paste. This increase occurs because the low vapor pressure of the salt solution allows many more of the entrained air voids to fill with water, and thus they are not available as reservoirs. As the saturation point is reached, air-entrained concrete becomes susceptible to frost damage because of its relatively high porosity and the large amounts of freezable water it contains. Air entrainment, however, will greatly improve resistance to scaling in all cases.

Resistance to frost damage can also be improved by using a low water-cement ratio concrete. As the water-cement ratio decreases, there is a corresponding decrease in the porosity of the cement paste, which reduces the amount of freezable water in the concrete.

Figure 5-4. Severe Bridge Deck Scaling (Small Pothole)

5-2.05 Spalling

A spall is a chip or fragment of concrete that has broken away from a larger concrete mass, as illustrated in Figure 5-5. A pothole or pop-out is a roughly circular or oval depression in the deck surface. Potholes are caused by the separation and removal of a portion of the surface concrete, revealing a horizontal or slightly inclined fracture. The formation of a pothole is preceded by the development of a roughly horizontal delamination slightly below the surface. Historically, spalling has been defined as the chipping or breaking of a slab at a joint or other edge location. However, as deck deterioration attributable to deicing salt became increasingly widespread over the past two decades, the meaning of the term spalling was gradually broadened, and it now includes potholing as well. Today, the two terms (potholing and spalling) are used synonymously to describe surface fracturing in a bridge deck, and spalling in the traditional sense is now referred to as edge spalling.

Figure 5-5. Spalling

Spalling may be the consequence of corrosion of the embedded deck reinforcing steel, which occurs in structures where the deck is subject to repeated applications of deicing salt. Corrosion-induced spalling may involve substantial thicknesses of concrete. Once initiated, the corrosion process cannot be reversed, and a permanent structural repair (short of complete replacement of the salt-contaminated concrete) is nearly impossible to achieve. Although primarily associated with bridge decks, spalls may also occur as a result of vehicle collisions, as shown in Figure 5-6.

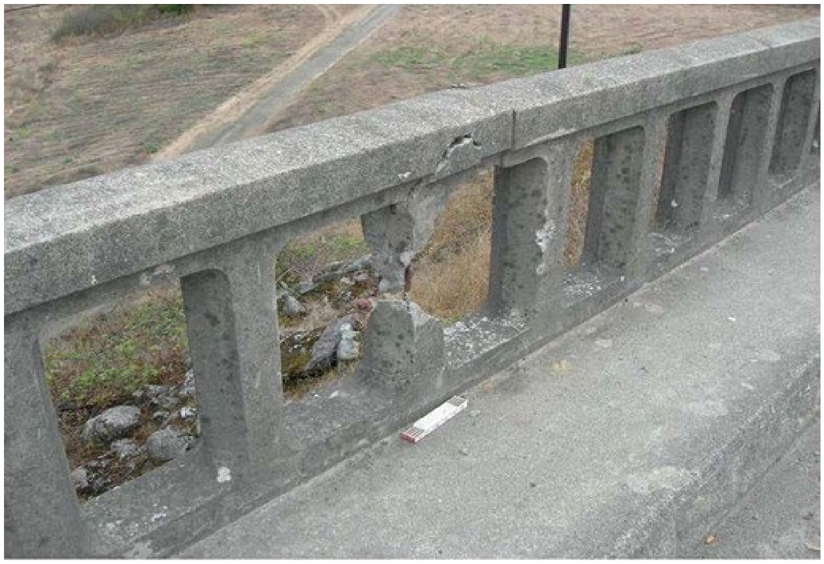


Figure 5-6. Surface Spalling Caused by Vehicle Impact

The cycle of events that leads to concrete spalling can begin when deicing salt is applied to inhibit the formation of ice on concrete wearing surfaces. In the presence of water, the salt goes into solution with sodium and chloride ions. The chloride ions eventually permeate through the concrete with moisture until they reach the reinforcing steel. Penetration may proceed slowly by permeating the concrete, or more rapidly through any cracks that may be present. Cracks, of various causes, often develop over the uppermost reinforcing steel bars, usually those that run transverse to the highway alignment; such cracks permit rapid chloride penetration. Once the chloride ion concentration reaches the threshold value, corrosion begins. As iron oxide deposits (which are the end product of the corrosion process) form on the reinforcing steel in the anodic areas, the deposits occupy a much larger volume than the original metal. The increase in volume is generally considered to be several times the volume of the original metal, and pressures exceeding 4,500 psi have been measured under laboratory conditions. However, much smaller pressures are sufficient to produce the undersurface fractures that lead to most of the corrosion-induced damage in salt-contaminated decks.

The expansive pressure developed as these deposits form acts outward (radially) in all directions from the rebar, but because there is little resistance above the rebar, the upward-acting forces eventually lift the concrete from the rebar. This causes a vertical crack to form over the rebar (or enlarges the crack if one already exists at this location) and causes a horizontal crack, or delamination, extending outward from the rebar. As corrosion continues, the expansive pressure increases, enlarging the vertical cracking and extending the horizontal delamination. Eventually, the concrete above the rebar may break loose, forming a conical spall, while the delaminated area enlarges until it reaches a similar delamination produced by an adjacent corroding rebar.

5-2.06 Delamination

Delamination of the concrete at or near the level of the top mat of rebar is characteristic of a chloride-contaminated concrete element where corrosion has occurred.

Areas of delamination (the undersurface fracture plane) may cover a large area before there is any visible evidence of a problem. Note however, that undersurface fractures may be easily detected by the hollow sound they emit when the concrete is struck with a hammer or the surface is sounded with a chain drag. As the delaminated area enlarges, the vertical width of the fracture also increases. Deterioration of the concrete above the fracture is accelerated by additional pressure developed if ice forms in the fracture and by vehicle live load forces. Eventually, the concrete over the delamination breaks out, forming a depressed area, or spall, in the deck surface. Spalling, because it results in uneven depressions on a bridge deck, has a pronounced adverse effect on traffic, and even moderate spalling will seriously impair the riding quality of a bridge deck.

From a structural standpoint, spalling during its early stages is not a serious defect, for two reasons. First, the concrete above the top mat of the deck reinforcing does not contribute significantly to the load-carrying capacity of the structure. Second, spalling (as visible evidence that corrosion has occurred) is usually well-advanced before there is a significant loss of reinforcing steel. This is true because very little expansive pressure is necessary to crack the concrete. As corrosion progresses, however, severe pitting occurs, resulting in a significant loss of the steel section. Loss of section is accelerated when the reinforcing steel is exposed to atmospheric conditions and pollutants, as would occur when an open spall leaves reinforcing bars uncovered. In such cases, the rapid section loss is the result of a relatively small anode (the exposed steel) leading to corrosion of a much larger cathodic area consisting of the adjacent embedded steel.

Traditionally, unsound concrete was found by dragging a chain over the bridge deck and marking the affected area. Other sounding devices worked by percussion, such as the use of a geologist hammer or machines that produce a hammer effect with wheels that resemble sprockets; the individual projections on the wheel strike concrete like a small hammer blow.

More recently, technologies like ground-penetrating radar, seismic-impact sound analysis, and infrared thermography have been used to map delaminated areas on bridge decks. SC staff may request these testing services from Materials Engineering and Testing Services (METS) by using Form TL-701[1], *Field Investigation Team (FIT) & Instrumentation Service Request Form*, and emailing it to the METS' office of Field & Forensic Services.

[1] Caltrans internal use only

5-2.07 Surface Wear

Deck deterioration caused by abrasive wear is often found in mountainous regions where winter driving conditions dictate the use of studded tires and/or tire chains. Differential wear in the wheel lines, which occurs where chains and studded tires are used, will produce depressions in the deck surface. Where the deck is relatively flat, depressions can result in ponded water and accelerated scaling.

5-2.08 Surface Profile Defect

Defects in surface profile can be caused by excessive bridge superstructure sagging due to creep. They may also result from construction tolerances in manufacturing and the placement of structural elements (such as bridge decks), or from an incorrect bridge crown after widening.

5-3 Materials that Can Be Used for Concrete Repair

5-3.01 Cementitious Materials

Although portland cement is not naturally a rapid-setting product, sulfoaluminate cement can be combined with portland cement to produce rapid-setting, early-strength concrete. Grinding portland cement to a finer screen accelerates the set time and produces higher early strength. The specifications may permit chloride-free accelerators, Type C accelerators, and Type E water-reducing/accelerating admixtures. Portland cement patching materials have an inherent advantage in that the patch and the concrete substrate will have nearly identical thermal and physical properties. These are important considerations because thermal compatibility reduces the stress transmitted to the bond plane and physical compatibility results in a relatively homogeneous structural section. Portland cement mortar or concrete is the least expensive patching material for permanent reconstruction of deteriorated concrete, and it (or a cement-based product) is generally used unless there is a compelling reason to use another material or product. Disadvantages include high drying shrinkage, the need to cure the patch, and a relatively poor bond between the patch and the substrate. Because of poor bonding characteristics, an epoxy bonding agent is normally used with cement-based patching materials. The water-activated magnesium phosphate/sulfoaluminate cements are a standard repair option. They are also rapid-setting, self-leveling cement with good surface bonding qualities. Magnesium phosphate reacts with aluminum, so aluminum finishing tools must not be used per *Standard Specifications* Section 51-1.02C, *Concrete Structures – Bonding Materials*.

5-3.02 Polymeric Materials

Polymers are a large class of materials that includes natural and synthetic molecules. The typical polymer will consist of a single monomer molecule repetitively assembled into a molecular chain or a mixture of monomers, usually linked together by covalent bonds. Most polymers have high initial shrinkage and a high thermal coefficient of expansion. Intimate contact between the resin and the bonding surface is necessary to ensure an adequate bond at the polymer/substrate interface. Polymer patching materials are self-curing, and most will reach about 80 percent of their ultimate strength in a few hours. The aggregate content must be as high as feasible, considering workability constraints, to increase the thermal compatibility with the concrete substrate. A rounded aggregate will improve workability, and a dry non-absorptive aggregate will decrease the total resin demand.

Polymers formed by linking monomers together – without material loss – are called addition or chain-growth polymers. Addition reactions are easier to process as volatile byproducts are not produced; this process is used with epoxies and urethanes. Because polymer molecules are large, they generally pack together in a non-uniform fashion, with a mixture of crystalline-like and amorphous material. Crystalline structure is influenced by chain length, chain branching, and interchain bonding. Increased crystallinity is associated with an increase in rigidity, tensile strength, and opacity (due to light scattering). Amorphous polymers are usually softer and transparent. In some cases, the entire solid may be amorphous, composed entirely of coiled and tangled macromolecular chains.

5-3.02A Thermoplastic/Thermoset

Thermoplastic and thermoset polymers are two major categories of polymeric materials, each with distinct properties and applications, especially in the context of concrete repair and construction.

Synthetic polymers can be classified as thermoplastic or thermosetting, according to the effect of heat on their properties. Thermoplastics grow softer as temperature increases and eventually melt at elevated temperatures; as temperature decreases, thermoplastics harden. Repeated heating and cooling cycles do not affect the properties of thermoplastics. Typical thermoplastics are polyesters such as Mylar, polyvinyl chloride (PVC), and acrylonitrile butadiene styrene (ABS). Thermoplastics can be reinforced like fiberglass with short, chopped fibers such as glass. Nylon, also a thermoplastic, is made from repeating units of two monomers, diamine and dicarboxylic acid. Polyethylene, a thermoplastic, is based on repeating units of ethylene.

Thermosetting polymers (thermosets) are a one-way reaction formed when resin and initiator are mixed. Thermosets maintain standard properties when heated, as long as temperatures do not exceed the Glass Transition Temperature (**Tg**), which varies with the particular resin system and quality of preparation methods. Above the **Tg**, the molecular structure of a thermoset material changes from a rigid crystalline polymer to a more flexible, amorphous polymer where properties such as stiffness, compressive and shear strength, water resistance, and color stability drop. When material temperatures drop below **Tg**, the original material properties return.

5-3.02B High-Molecular-Weight

Molecular weight is calculated by summing the individual atomic weights in a molecule. Water's molecular weight (**H_2O** =18 grams/mole) is determined by combining the atomic weight of oxygen (**O** = 16, 1 x 16 = 16) with that of hydrogen (**H** = 1, 2 x 1 = 2). If another oxygen atom were added (**H_2O_2**), the molecular weight would be 34 grams/mole, but the molecule would be hydrogen peroxide, not water. Polymers are varying-length monomer sequences, but the properties of the molecule remain stable regardless of the sequence length. Simple compounds like hydrogen peroxide have low molecular weights. Polymers, because of their chaining nature, have high molecular weights. Polyethylene molecular weights range from 3,000,000 to 6,000,000 grams/mole. When high-molecular weight is used to describe materials, the intention is to denote the polymeric reaction that links several small molecules into a larger molecule of repetitive elements.

5-3.02C Chain-Reaction Polymerization

One type of chemical reaction used to create high molecular mass molecules from monomers is called chain reaction polymerization. This type of reaction involves using free radical peroxides. Free radicals characteristically have an unpaired electron and readily attack other molecules to attain electron balance. Introductory chemistry covers electron shell configurations; the first electron shell has space for two electrons and the second shell has room for eight electrons. Hydrogen has one outer electron but needs one more to fill the first shell. The inner shell of a carbon atom is full, but the second shell only has four electrons; four more electrons are needed to fill the second shell. Oxygen also has a full inner shell but 6 electrons in the outer shell, so oxygen will look for 2 additional electrons, like in the formation of water (**H_2O**).

Polymeric chaining begins with the introduction of an initiator, which provides the free radicals, and possibly a promoter or accelerator. The free radical takes an electron from a monomer, making the monomer into a free radical. The chaining process starts when an adjacent monomer links at the free radical site and then becomes a free radical itself. The process continues until the lack of resin leads the chain to create a termination end.

5-3.02D Key Variables

The chain-reaction polymerization rate is controlled by temperature and the amount of initiator. The polymerization reaction is extremely sensitive to temperature. If the temperature is even a few degrees outside the specified temperature range, there is a real risk that the polymerization reaction will occur too fast at higher temperatures or not occur at all at lower temperatures.

5-3.02E Polymeric Material Commonly Used in Concrete Repair and Bridge Rehabilitation Work

The following materials are polymers that are commonly used in bridge repair/rehabilitation work:

5-3.02E(1) Methacrylate

Methacrylate, particularly Methyl Methacrylate (MMA), is widely used in bridge repair and rehabilitation due to its excellent properties, such as rapid curing, high strength, and durability.

Methacrylate can be used to bind aggregates together to form polymer concrete, but it is generally used to fill and rebond cracks in concrete elements such as bridge decks and as surface sealants. Because of the rapid strength gain and very low viscosity, methacrylate seeps into cracks by gravity flow and returns cracked concrete to near original strength. The earliest methacrylates were based on methyl methacrylate resin monomers that were sequentially mixed with promoters and accelerators and then an initiator (cumene hydroperoxide) to create polymethyl methacrylate polymer chains. The initiator broke the double carbon bond on the methyl methacrylate monomer, turning the monomer into a free radical, which then chained to another monomer. In the process of chaining, the newly linked monomer turned into a free radical, and the polymer chain continued growing until the supply of monomers was depleted. The idealized reaction is shown below in Figure 5-7.

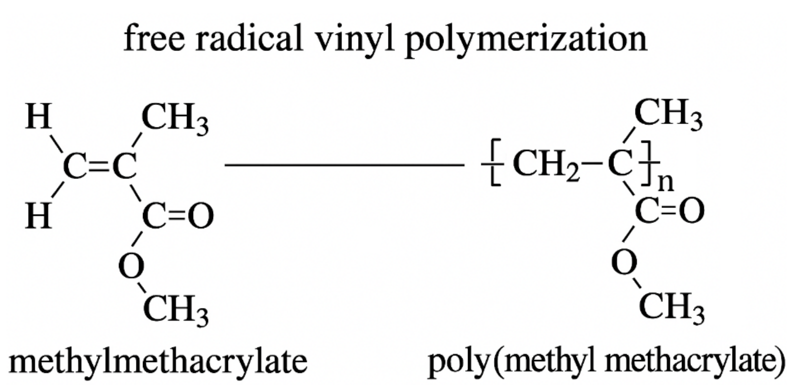


Figure 5-7. Methyl Methacrylate Polymer

Water has a standard viscosity of 1 centipoise; methyl methacrylates have viscosities as low as 0.6 centipoise. Unfortunately, methyl methacrylate is also highly volatile and burns readily. Urban legends have chronicled several bridge decks that were completely enveloped in fire. Sonny Fereira, Bridge Construction Engineer, promoted the legendary status of methacrylate component volatility as an instructor for the SC 1986 Concrete Technology Winter Training Seminar when he mixed small portions of promoter and initiator directly together in a shielded container with impressive results.

Several manufacturers replaced the methyl groups (Figure 5-7, $\mathbf{CH_3}$ atomic weight of 15) with proprietary molecules that had atomic weights approaching 300. The resulting High Molecular Weight Methacrylate, although less viscous than Methyl Methacrylate, was able to meet the Caltrans viscosity specification of 25 centipoise. The high-weight molecules also reduced volatility and virtually eliminated the possibility of a bridge deck fire.

5-3.02E(2) Polyester Concrete

Polyester concrete is a composite material made from polyester resin and aggregates. It is widely used in bridge deck overlays and as a patching material due to its excellent properties and performance.

Polyester-styrene concrete (commonly referred to as polyester concrete) is a versatile construction material used extensively for bridge deck overlays and as an excellent patching material. Physical properties are similar to those of methacrylate except that it does not gain strength as rapidly. Polyester concrete is a solid concrete matrix produced by mixing resin with coarse and fine aggregate to bind the aggregate into a solid concrete mass. Polyester resin hardens into the binding agent through a chemical reaction called polymerization, which is set off by mixing chemical catalysts, called initiators and hardeners, into the resin. Polyester concrete produces concrete that is durable, impermeable, and most importantly, achieves high strength in a matter of a few hours. Because of these highly desirable qualities, and also due to their relatively high cost in high-quantity applications, the most common application of polyester concrete in Caltrans is thin (3/4-inch-thick) overlays on concrete bridge decks. They have also been used in similar applications, such as expansion dam headers.

The raw materials for polyester concrete are dry aggregates, a liquid mixture of polyester resin and styrene monomers, and an initiator and promoter (cobalt naphthenate and methyl ethyl ketone peroxide (MEKP). During the polymerization process, the cobalt initiator causes MEKP to release oxygen molecules, which causes the styrene monomers to crosslink with the polyester polymers within a paving mix to form a polymer matrix around the aggregate. The polyester resin molecules shown in Figure 5-8 are the first component of the polymerization reaction. Within the polyester resin, carbon atoms are bound together with double covalent bonds, as shown in Figure 5-9. The in-reactive sites on the polyester molecule shown in Figure 5-8 are identified as “B” in Figure 5-9. The MEKP free radical breaks the double bonds at the reactive sites and forms polymer free radicals. The final component of the polymerization process, the styrene monomer, acts as a coupling agent and forms a bond with the unpaired carbon bond of the polyester resin. As successive bonds form between polymer resins and the styrene monomers, a three-dimensional polymer matrix is formed, as shown in Figure 5-10.

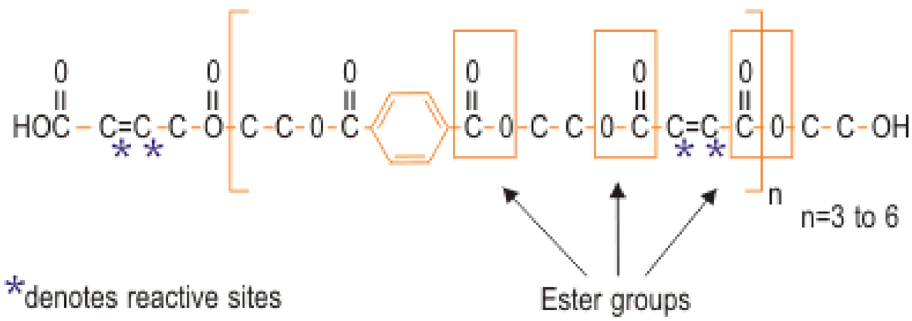


Figure 5-8. Idealized Polyester Resin

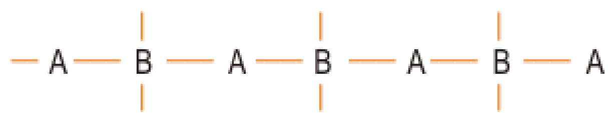


Figure 5-9. Schematic of Polyester Resin (B = carbon bond)

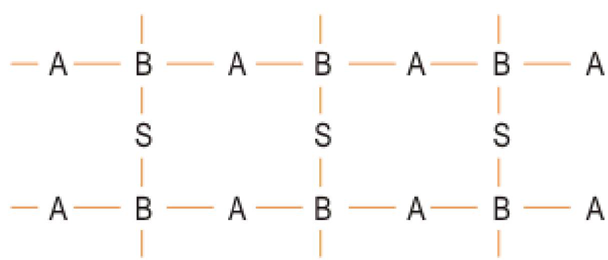


Figure 5-10. Schematic of Cured Polyester Styrene Thermoset

5-3.02E(3) Urethane

In the past, urethane resins were used in deck rehabilitation work. The deck overlays were performed by alternatively spreading urethane and aggregate until the required section was established. With the development of polyester concrete in the 1990s, Caltrans’ strategy has been to replace urethanes with polyester-styrene concrete, which is less expensive and otherwise equally suited for the purpose.

As a patching material, urethane resins are easy to work with and bond well to both portland cement concrete and asphalt concrete. Standard surface preparation is required. Urethane resins can be obtained with a wide range of set times to accommodate usage and temperature requirements, but the resin components must be mixed according to instructions. The amount of initiator cannot be modified as a means of varying the set time. The only variable that can affect the set time is surface temperature; a warmer temperature will accelerate the set time. Rapid-setting urethanes may be set before conventional aggregate mixing is complete. In those instances, a two-step placing procedure was followed. First, coarse aggregate was placed to grade in the void to be filled. Second, after the aggregate was placed, the urethane resin was poured over the aggregate, filling the voids between the aggregate particles and forming a solid mass. Only coarse aggregates were used because urethane resins expand appreciably when mixed with fine materials, such as graded concrete sand.

5-3.02E(4) Epoxy

Epoxies are used extensively in Caltrans as adhesives (for traffic markers, rebar dowels, and concrete), crack sealers (vertical wall repairs), and binders of aggregates to form polymer concrete. Epoxy is one of the oldest and most versatile of the polymer patching materials. Epoxies are viscous resins that also harden into a solid mass through the use of chemical catalysts in a polymerization reaction. Many epoxy resins have high viscosity and a putty-like mortar consistency. High viscosity may be an advantage or a disadvantage depending on the location of the patch. However, with epoxy compounds, many reaction mechanisms may occur; consequently, different epoxy compounds may have widely differing properties and characteristics. Epoxy resins provide:

1. High strength
2. Low shrinkage characteristics
3. Good adhesion properties
4. Resistance to water, chlorides, and sulfates.

Epoxies used for construction are two-component systems that are mixed at the site in either a 1:1 or 2:1 ratio. Epoxy is not tolerant to deviation from the specified component ratio, and even minor variations will result in significant strength reduction. Lab tests show a 100 percent decrease in strength resulting from only a 10 percent variation in the required mixing ratio.

In the past, epoxy was occasionally used for bridge deck overlays. These epoxy overlays were constructed by repeatedly alternating layers of epoxy with layers of aggregate – broadcast on the previous layer of epoxy – gradually building up the overlay to the specified thickness. Experiments were performed with premixed systems, but a workable system was not developed.

In the 1990s, epoxy injection was specified to seal cracks on newly completed bridge decks; since then methacrylate, which seals smaller cracks than epoxy due to its low viscosity, has become the preferred and specified material. Epoxy injection is still used to repair cracked concrete walls. Injection epoxies are formulated specifically for use in pressure injection work. Compared to other epoxy resins, they have good flow characteristics and relatively low viscosity at normal working temperatures. Many can be used in either dry or wet conditions. When properly performed, epoxy injection can completely restore the structural integrity of a cracked concrete member.

5-3.02E(5) Epoxy Mortar

Since even thin sections of epoxy materials have high strength, epoxy mortar is especially well-suited for use at tapers or locations requiring a feather edge. Epoxy mortar is made from a mixture of 1 part epoxy to about 4 parts of concrete sand, by volume. Ideally, for a workable mix, the mortar should contain slightly more epoxy than is necessary to coat the aggregate particles and fill the voids; however, the amount of epoxy needed for workability varies inversely with the temperature, i.e., as the temperature decreases, more epoxy will be required for the same degree of workability.

Experimentation may be necessary to determine the optimum epoxy content. As a rule, it is better to have too much, rather than too little, epoxy in the mix, since lean mixes are difficult to place and the resulting patches may be porous. For filling larger voids, epoxy mortar may be extended by the addition of pea gravel to make epoxy concrete.

5-4 Concrete Repair Due to Contractor’s Operation versus Rehabilitation of Existing Structures

While discussing the repair of concrete defects, an important distinction needs to be made between the repair of concrete defects due to the Contractor’s operation, such as defects in newly placed concrete, versus rehabilitation and maintenance of existing concrete structures. In the following sections, the contract requirements and SC field personnel roles related to both types of work will be discussed.

5-4.01 Concrete Repair due to Contractor’s Operation

Previously in this chapter, different types of concrete defects were described. Accordingly, below are a few of the *Standard Specifications* sections that describe concrete properties that a newly placed concrete must have:

51-1.03C(2), *Concrete Structures – General – Construction – Preparation – Forms*; this section states that structure concrete needs to be without excessive undulations. It also defines excessive undulations.

51-1.03D, *Concrete Structures – General – Construction – Placing Concrete*; this section states that concrete must be dense and homogeneous without voids or rock pockets.

51-1.01D(3), *Concrete Structures – General – Quality Assurance – Department Acceptance*; this section describes the limits of bridge deck crack intensity before the deck has to be repaired with methacrylate treatment. This section also describes the bridge deck surface friction and smoothness requirements.

51-1.03F, *Concrete Structures – General – Construction – Finishing Concrete*; this section describes the type of surface finishing that different elements of a bridge must have and the allowable methods to achieve the desired finish.

90-1.01D(5)(a), *Concrete – General – Quality Assurance – Compressive Strength – General*; the contract plans (perhaps on an "Index to Plans" sheet) typically will indicate the strength requirement for various elements of a concrete structure.

Standard Specifications Section 90-1.01D(5)(a) states that if the 28-day compressive strength described is 3,600 psi or greater, the concrete is designated by compressive strength. It also states: "If a strength test result at the maximum age specified or allowed is below 85 percent of the strength described, you must remove the concrete represented by the test unless you obtain and submit evidence that the strength of the concrete placed in the work is at least 85 percent of the strength described and this evidence is accepted by the Engineer." In other words, concrete is often specified a minimum strength that it must reach.

When newly placed concrete does not meet the requirements of the contract, that work must be repaired or replaced per *Standard Specifications* Section 5-1.30, *Noncompliant and Unauthorized Work* (please see "Inform Contractor of Noncompliant and Unauthorized Work" later in this section for further detail). However, concrete repair due to the Contractor's operation is not limited to only newly placed concrete work. Existing concrete structures can also get accidentally damaged due to the Contractor's work or equipment; for example, the Contractor's equipment might collide with a barrier and cause a spall. *Standard Specifications (SS)* Section 5-1.36, *Control of Work – Property and Facility Preservation*, requires the Contractor to preserve and protect the existing facility. However, accidents do happen and this section of the specifications requires the Contractor to immediately report damage. The specifications also hold the Contractor responsible for repairing damage if the damage was caused by the Contractor. As can be expected, the type and extent of the concrete repairs required due to the Contractor's operation are not known before the start of the construction project and they are not described in the contract plans. However, when concrete repairs become necessary, the requirements described in *Standard Specifications* Section 60, *Existing Structures*, are used to verify that the repair work is performed properly.

In 1736, to fire-threatened Philadelphians, Benjamin Franklin famously said: “An ounce of prevention is worth a pound of cure.” This is also true with concrete damage due to the Contractor’s operation. For a new structure, with good planning, preparation, and workmanship, defective concrete (i.e., does not comply with contract requirements) can be avoided. Accidental damage to an existing concrete structure can also be avoided by practicing good work habits such as being observant, not rushing, studying plans carefully, and not being complacent. Concrete repair work is often an expensive and time-consuming effort, making it something that both Contractors and Caltrans aim to avoid. SC staff can significantly contribute to minimizing concrete repair work. Specifically, SC staff should carefully read and understand the relevant Bridge Construction Memos (BCM), found within the *BCR&P Manual*. For example, when working on new structures, SC staff should frequently refer to BCM 51-1.03C-D, *Concrete Structures – General – Construction – Preparation and Placing Concrete.* Another reference that field staff should read often is the *Outline of Field Construction Practices*[1].

By performing field work and inspection as described in our BCMs, SC staff can help avoid costly repairs, and a good Contractor would appreciate their efforts. For example, by careful inspection of forms, SC staff can help identify deficiencies such as the forms not being mortar-tight and have the problems corrected before they become concrete defects (and require concrete repair). Similarly, with proper inspection, SC staff can try to prevent concrete that does not comply with requirements (such as being too wet) from being deposited into the form. Also, when working near existing structures, SC staff need to understand and review Attachment 2, *SC Staff Responsibilities for Performing Standard Construction Activities,* of BCM A-1. This attachment includes *SS* Section 5-1.36, *Control of Work – Property and Facility Preservation*, which provides guidance to SC staff to help prevent damage to existing structures.

To perhaps complete Benjamin Franklin’s thought, “despite the ounce of prevention, from time to time the pound of cure is needed.” At least this is true for concrete repair; despite efforts to prevent concrete defects, problems sometimes happen, which require concrete repair. There are several different types of concrete repair methods that will be discussed in this manual. However, before discussing each repair method, the tasks that must be done before the concrete repair starts need to be explained. Below is a summary of tasks to be performed before the start of repair work:

1. **Identify the concrete defect**:

   Defects that are to be repaired as part of the maintenance and rehabilitation of a structure are described in contract plans and documents. However, when the defect is a result of the Contractor’s work, such as the spalling of concrete due to an accident with construction equipment, or surface imperfections in a newly

[1] Caltrans internal use only

placed concrete element, it is the responsibility of SC field staff to perform the following:

a. For existing structures, the condition of the structure needs to be documented well before the start of the rehabilitation work. This includes taking adequate photos and notes about the condition of the structure and any existing defects. SC staff’s pre-construction inspection photos and notes will serve as a tool to identify any damage found after the construction started if it is due to the Contractor's work, which they would be responsible for repairing. It is also important that when the Contractor is working in a tight area with large equipment, the inspectors are observant for any potential accident that might damage the nearby existing structures. Always be careful and inspect at a safe distance. An accident with an object can easily be an accident with a person instead!

b. For newly placed concrete, detailed inspection is necessary to discover defects. Typically, defective concrete is found by a visual inspection of the concrete surface. It should be noted that SC manpower is a precious resource that must be used wisely. In other words, on a typical day, the area of inspection, the number of construction crews working, and the number of work items to be inspected by SC staff can be substantial. SC staff need to evaluate and prioritize inspection based on several factors, including access for inspection, along with probability and consequence of a defect. Accordingly, when inspecting concrete for defects, SC staff should try to do their inspection when the Contractor is stripping the forms. After stripping, additional work might occur that could hide or obscure defects. For example, defects in the stem and soffit will be hidden after the placement of the lost deck form, and gaining access for inspection will be very difficult if not almost impossible. Similarly, when it comes to consequences and probability of failure, close attention must be paid to concrete subject to high demand stress (relative to the tensile or compression strength of the concrete). For example, concrete near the prestressing block out will typically be under high compression stress and the failure in these areas will be critical; the probability of defective concrete near high-stress areas is also typically high because generally a lot of reinforcement is placed at these areas making consolidating the concrete (i.e., vibrating the concrete) difficult. Similarly, the areas of high tensile stress under service loads will typically occur in the bridge deck over or near the bridge bents, as well as the bottom of girder and soffit near midspan. In these areas, the probability of defects (i.e., tension cracks) is high, and a closer inspection of these areas will be necessary.

2. **Determine if repairs are necessary**:

Not all defects require repair, and often engineering judgment needs to be used to determine if a newly placed concrete item is “fit for purpose”. For example, concrete surface cracks in bridge decks may not exceed the crack intensity thresholds given in the standard specifications and may be subsequently ignored (bridge deck cracks will be covered in detail in Section 5-7.03B, *Methacrylate Resin Bridge Deck Treatment*). Minor damage may deteriorate so slowly that the service life of the structure will never be affected. On the other hand, as an example, if surface grinding does not meet the required friction coefficient, bridge deck concrete must be replaced or overlaid. Similarly, if a profile correction is needed, the deck concrete must be overlaid or replaced.

3. **Inform Contractor of noncompliant and unauthorized work/take a pay withhold**:

   When the Engineer (i.e., SC staff) determines that a repair is necessary for any item of work (i.e., what is being described here is not limited to concrete work), the Contractor needs to be informed of defective work or damage to an existing structure. The notice provided to the Contractor must include enough detail to let them know what the defect or the damage is. For example, the location can be provided by specifying the bridge name and if the defect is on a column, abutment, etc. Typically, SC staff will do the following:

   a. For new work that is defective, SC staff will cite *Standard Specifications* Section 5-1.30, *Control of Work – Noncompliant and Unauthorized Work*. Please note that this section does not just pertain to concrete work; It applies to any work and may include damage to existing structures.
   b. For damage to an existing structure, SC staff will cite *Standard Specifications* Section 5-1.36, *Control of Work – Property and Facility Preservation*. Again, this section is not limited to damage to existing concrete structures; it covers damage to any existing property or facility.

   Per the above specifications, repair work does not justify additional payment. It is important to note that in our notice to the Contractor, the Engineer does not tell the Contractor how to make the repair. Instead, the sole purpose of the Engineer's notice is to let them know about the defect or the damage. Per the cited specification for non-compliant and unauthorized work, the Engineer (i.e., SC staff) may require the Contractor to submit a work plan for the corrective, removal, or replacement work; this work plan is commonly known and referred to as the "Repair Plan." In other words, the Contractor needs to describe how they plan to achieve the correction. The Contractor's "repair plan" can be an in-person meeting, or it can be a formal work plan submittal with sufficient plans and details to describe the work. The nature of the "repair plan" is decided by the Engineer. The complexity of the repair should be considered carefully when deciding what the "repair plan" should be or what details it needs to provide. It should be noted that construction should be viewed as a partnership, working with the Contractor in the delivery of a quality product for the benefit of the public. In this partnership, SC staff are here to work together to solve problems;

this includes repair work. The repair work is not just writing notices or letter(s). As in partnership, a lot of the problems are solved at the lowest levels by making ourselves available for simple face-to-face discussions. While SC staff do not dictate how the Contractor should perform the repair, SC staff often hear the Contractor's repair proposals in informal settings and work as a team evaluating the pros and cons of the repair proposal.

SC staff also need to take a pay withhold based on a rough estimate of manhours and material that will be required for the repair. Ask your experienced coworkers and supervisor to assist you in making this estimate. Remember, the beauty of working for Caltrans is that you are never alone. You have a team that is there to help you. If the Contractor protests the amount of a payment withhold, don't see it as a negative incident. First, recognize that the Contractor's protest serves as an acknowledgment that the Contractor has been made aware of noncompliant work that they need to fix. Second, see this as a team-building opportunity with the Contractor to solve a problem and come up with a solution agreeable to both parties. Document your negotiation with the Contractor in your diary. Also, document any payment withhold in your monthly pay estimate and your final punch list.

4. **Review and authorize the Contractor's "Repair Plan" when the proposed repair method is deemed acceptable**:

   After the Contractor describes how they plan to do a repair, the Engineer needs to decide whether the repair is acceptable and if it can be authorized. As a reminder, the "Repair Plan" may be a very elaborate document (with a significant number of plan sheets and details describing the work) or it can be as simple as a conversation in a meeting. The complexity of the repair should be a factor (but not the only one) in the Engineer's decision for what should be in the "repair plan." As part of keeping the Bridge Construction Engineer (BCE) updated on the progress of projects and important developments, the BCE should be made aware of the Contractor's repair plans. SC staff should remember that staffing of a construction office is a dynamic situation. People get sick, get promoted, and/or transfer to a different project, for example; therefore, important matters need to be communicated and documented so that more than one person is aware of the important issues. Depending on the repair and its complexity, the Engineer might need to involve other functional units – such as Bridge Design – to help decide on the suitability of the Contractor's proposed repair plan. It should also be noted that while this discussion is generally applicable to most repairs (i.e., concrete and nonconcrete work), what has been described so far is specifically for repair of work described in *Standard Specifications* Section 51, *Concrete Structures,* and for repair of accidental damage to concrete structures. When the repair is for work performed under different specification sections, the *BCR&P Manual* should be reviewed for specific sections and the specific protocol. For example, when a repair is needed for new CIDH piling (i.e., *Standard Specifications* Section 49, *Piling*), there is a strict protocol that the Engineer needs to follow, which is described in Attachment 2, *CIDH Concrete Piling – Contract Administration and Department Acceptance*, of BCM 49-3.

5. **Discuss with the Contractor on how to prevent future problems**:

   As mentioned earlier, repairs are costly and time-consuming. Contractors do not want to do the same work twice and SC doesn't want the time delay. So, as a partnership and a team, SC staff need to discuss how a repeat of a problem can be prevented for the benefit of all.

5-4.02 Concrete Repair for Maintenance and Rehabilitation of a Structure

As mentioned at the beginning of this chapter, concrete repair is often needed as part of the maintenance and rehabilitation of a structure.

For this type of repair, the contract documents will provide sufficient information to describe the work. Included in the contract documents are contract plans that show the type of repair, limits of work, and any additional details that might be needed to perform the work. Figure 5-11 shows an example of a General Plan sheet, showing the bridge and type of repair, the limits of the repair, and the applicable pay quantities.

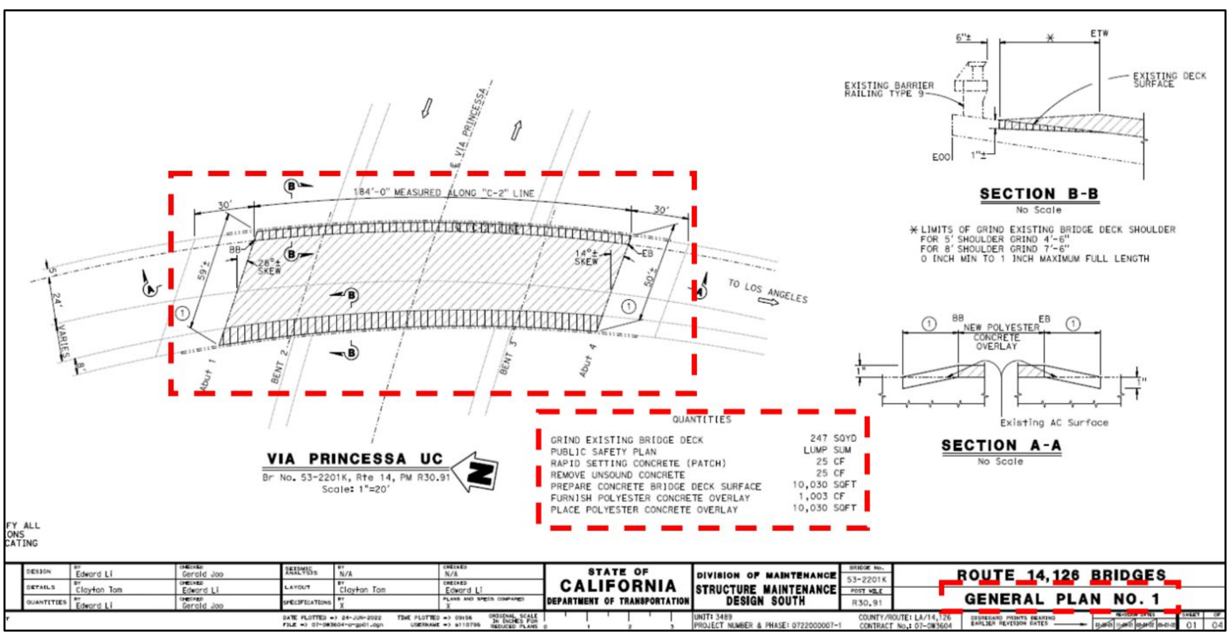


Figure 5-11. General Plan Showing Repair Method, Limit of Work, and Pay Quantity

The documents needed to describe the concrete repair work for the rehabilitation of a structure are not always in the contract at the beginning of the project (at the time of award). Sometimes, the need and extent of concrete repair become evident after the project has started, and the appropriate documents (such as plans and specifications) are then added to the contract via change order. For example, in a project involving joint seal replacement, it might become evident that concrete repair for spalled joints is needed after the project has started. Regardless of when the concrete repair plan is provided in the contract documents, if the repair work is not due to the Contractor’s operation, the contract documents must provide sufficient information and details for the Contractor to understand the required repair work.

5-5 Concrete Repair Activities

The concrete repair activities that are performed by the Contractor are listed below and described in this section:

- Removal of unsound concrete
- Placement and curing of the repair material.

Repairs discussed in this section include:

- Repair work required which was not anticipated in the original contract (i.e., such as repair of defective concrete work and accidental damage to a facility).
- Repair work (structure rehabilitation), which is planned and included in the contract.

To follow is a list of some of the specific repairs that will be discussed in this section (this is not a comprehensive list):

1. Repair of defects that often occur in new construction, such as rock pockets, bulges, and finish.
2. Irregularities (these defects are relatively minor).
3. Repair of bridge deck cracks caused by plastic shrinkage.
4. Structural repairs that require replacing portions of structural elements.
5. Bridge deck overlays.

5-5.01 Removal of Unsound Concrete

Before placement of repair material can begin, it is often necessary to remove the defective material. When unsound concrete removal is part of a maintenance and rehabilitation project, the contract document will show this item of work, the limit of work, and the pay quantity as shown in the example of Figure 5-12 below. As seen in the example, while the plans will always show the limit of work, the actual location(s) and exact quantity of the unsound concrete are often not shown. However, sometimes, the approximate location and size of the unsound concrete may be provided in the contract plans; see Figure 5-33 for an example. If an anticipated quantity for removal and patching is provided, it may be of interest to note how this approximation was determined. The quantity in Figure 5-12 is likely an estimate based on 1 percent of the deck area and an average depth of 3 inches. Later in this section, the method to determine the location and extent of unsound concrete will be discussed.

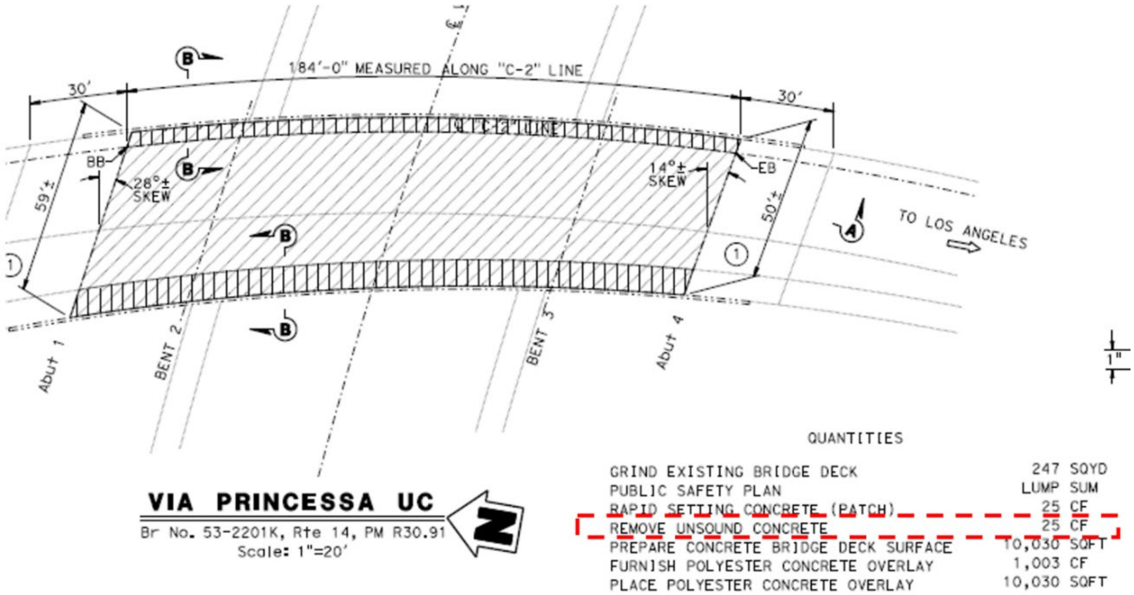


Figure 5-12. Contract Plan Showing a Bridge and the Expected Removal Quantity

In addition, the contract plans might provide additional details of unsound concrete removal. Figure 5-13 shows an example of contract plan details for unsound concrete removal work.

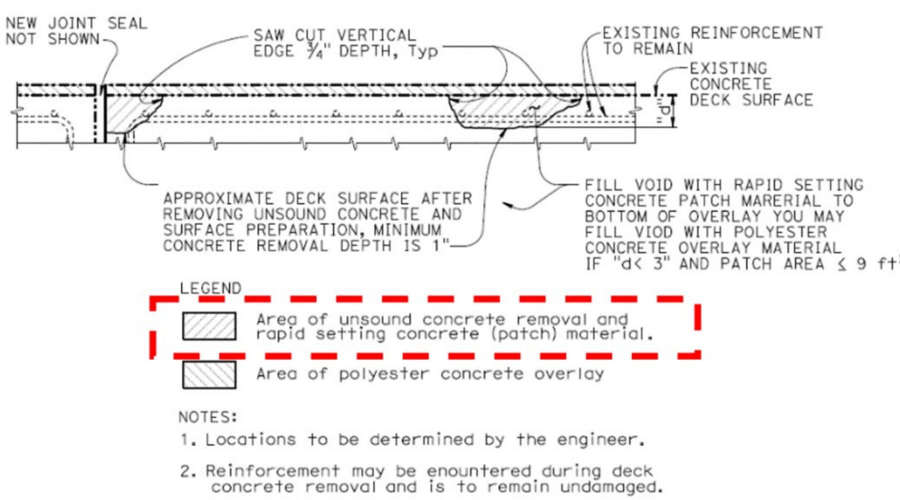


Figure 5-13. Contract Plan Showing Details of Unsound Concrete Removal

It should also be noted that it can take considerable time for contract plans to be developed (this time can even be a few years). As a result, the condition of the bridge might have significantly changed since the early stages of plan development. The changes could include further deterioration of the structure; on the other hand, the structures might also have been partially repaired by maintenance. As such, on maintenance projects, SC staff need to closely examine structures for unsound concrete to verify that all unsound concrete has been identified for removal before repair is performed. If unsound concrete is identified that is not shown in the contract plans initially, it needs to be added to the contract via change order (CO). Performing repair work when unsound concrete has not been removed will most likely not produce a durable repair. Also, while contract plans will often show unsound concrete removal as a work item, estimating the quantity for the unsound concrete removal is difficult. As a result, the quantities shown in contract plans in the past were sometimes not accurate and required change orders for quantity modification. Due to this difficulty, Bridge Design has sometimes completely omitted to show this item in the contract plans and has instead relied on construction (SC) to request a CO for adding this item along with the required quantity. Therefore, SC staff need to be vigilant in performing visual inspection, along with sounding and locating unsound concrete (even when the item is not shown in the contract plans) before performing the actual repair item shown on the plans, such as bridge deck methacrylate treatment.

If the unsound concrete is in the bridge deck, *Standard Specifications* Section 60-3.02C(5), *Existing Structures – Structure Rehabilitation – Bridge Deck Prepare and Preparation – Construction – Removing Unsound Concrete,* describes specific requirements that also must be complied with.

When the removal of unsound concrete is required in newly completed concrete work (i.e., work done by the Contractor), such as rock pockets in a newly placed concrete (as shown earlier in Figure 5-12), then SC personnel need to investigate the extent of the defective concrete and work with the Contractor to verify all unsound concrete is removed. Earlier, when talking about the repair of new concrete work, the things SC staff do to identify defects in concrete were described. Please note that identifying concrete defects is a different task than determining the location and extent of unsound concrete removal. Specifically, the repair of defective concrete may or may not include unsound concrete removal work. For example, repairing cracks in a newly placed concrete deck typically does not involve unsound concrete removal.

Determining the location and extent of unsound concrete usually includes the use of tools in addition to visual examination. Once a defect has been visually identified, the surrounding area should be probed and sounded with a geologist's or prospector's hammer or similar tool to determine the extent of the defective or unsound concrete. When using a hammer to explore damage, remember the hammer may also damage sound concrete. Figure 5-14 shows an example of a geologist/prospector hammer.

Figure 5-14. An Example of a Geologist/Prospector Hammer

Another method used for locating unsound concrete (on horizontal surfaces) is called “chaining”. Although visual inspection will reveal most defects, in some cases it will be necessary to check for unsound concrete (due to delamination), which is not readily apparent by visual examination of the surface. The most efficient method of locating such defects is to “sound” the concrete by dragging the surface with a noise-producing object such as a chain. The use of a chain is particularly suitable when it is necessary to check a large horizontal surface, such as a bridge deck, whereas a hammer is useful when checking small areas and vertical surfaces. Delaminated concrete emits a hollow sound when a chain is dragged over its surface or when it is struck with a metal tool. Unsound concrete also includes concrete that encases corroded bar reinforcing steel. Please refer to section 5-2.06, *Delamination*, for further discussion of other techniques used to discover delaminated concrete.

The use of chaining (by SC staff) for determining the limits of unsound concrete is required per BCM 60-3.02, *Existing Structures – Structure Rehabilitation – Bridge Deck Repair and Preparation*. Figure 5-15 shows an example of a chaining tool, and Figure 5-16 illustrates the areas on the bridge deck identified as having unsound concrete. When looking at the photo of the bridge deck, it is worth noting that some areas identified as having unsound concrete **do not** visually look defective. For best results in locating unsound concrete on the bridge deck, the Engineer should be chaining in a systematic pattern (as opposed to randomly picking deck areas to chain). It is very useful when performing this work for the first time to ask the assistance of an experienced coworker to guide you. For large bridge decks, it is advisable to have two or more SC personnel, both to increase efficiency and to corroborate on areas in question. Also, when trying to chain the bridge deck, there is often significant vehicle traffic noise that can make it difficult to hear the chaining sound; using a heavy gauge chain can significantly improve SC staff's ability to detect unsound concrete using chaining.

Figure 5-15. Example of Chaining Tools

Figure 5-16. Locations of Unsound Concrete Identified by Chaining Marked on Bridge Deck

With unsound concrete removal, the extent of defective concrete is one consideration in determining the removal depth; the repair procedure to be employed and the size of aggregate used in the repair material are other factors in the removal depth (please refer to Section 5-5.02, *Placement and Cure of the Repair Materials,* for further details about repair procedures). For example, for “dry-pack” mortar repairs (i.e., non-bridge deck repair), the minimum depth should be at least 1/2 inch; this minimum depth is also satisfactory for shotcrete applied without adding aggregate.

For other repair procedures, including the use of any material containing an aggregate the size of pea gravel or larger, a minimum depth of 1 inch is recommended; this will allow for aggregate to properly flow over the repair surface and/or rebar without segregating. It needs to be pointed out that when contract plans provide details for unsound concrete removal, all the requirements shown in the contract detail must be complied with, and the information provided in this paragraph is only provided so that the reader gains an engineering understanding of factors involved in the unsound concrete removal and patching process.

Removal of unsound concrete involves careful examination of the bridge deck. In other words, SC staff need to verify that all the unsound concrete is removed. After the Contractor removes the initially marked area, the inspector visually inspects and resounds the concrete with the geologist hammer to verify delamination (i.e., unsound concrete) has been removed. At that point, the final saw cuts are laid out and the final concrete removal is completed. To do otherwise could lead to a situation where the Contractor applies a square cut, but the delaminated area extends beyond the saw cut and the Contractor is required to enlarge the removal area and duplicate cutting efforts. Figure 5-17 below is a photo of an example of saw-cutting of the unsound concrete removal area. It is important to note that the saw-cutting operation warrants careful inspection - the occurrence of flying sparks is indicative of rebar contact, which should be minimized and avoided. If the rebar is scored, it can likely be retained. However, if it is significantly or completely cut, a repair will likely be required and should be included in the Contractor’s repair plan.

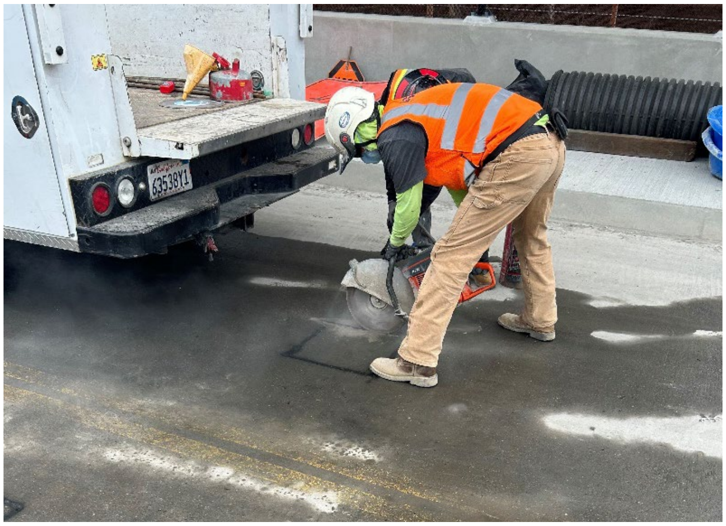


Figure 5-17. Saw-cutting of the Unsound Concrete Removal Area

Depending on the extent and nature of the defect, abrasive blasting, hand chipping, or the use of smaller air-operated chipping hammers can be used to remove defective concrete and expose sound concrete. If a jackhammer or similar piece of equipment is used, some chipping with smaller tools may be necessary to clean up the surface because the impact of heavy chipping tools may damage reinforcement and often produce small fractures in the underlying sound concrete as the defective material is removed.

Edge treatment requires special consideration. For voids to be filled with a patch material, either as a permanent repair or as an initial step before the construction of a deck overlay, the perimeter edge should be saw-cut approximately 1-inch-deep to avoid a weak feather edge.

Current practice prohibits the use of tools or equipment that will remove excessive amounts of sound concrete along with the unsound concrete, or that will damage concrete to remain in place. *Standard Specifications* Section 60-3.02C(5), *Existing Structures – Removing Unsound Concrete,* states that “Equipment and tools that in the Engineer's opinion remove excess quantities of sound concrete are not allowed.” See Figure 5-18 below for an example of a handheld tool used for unsound concrete removal.

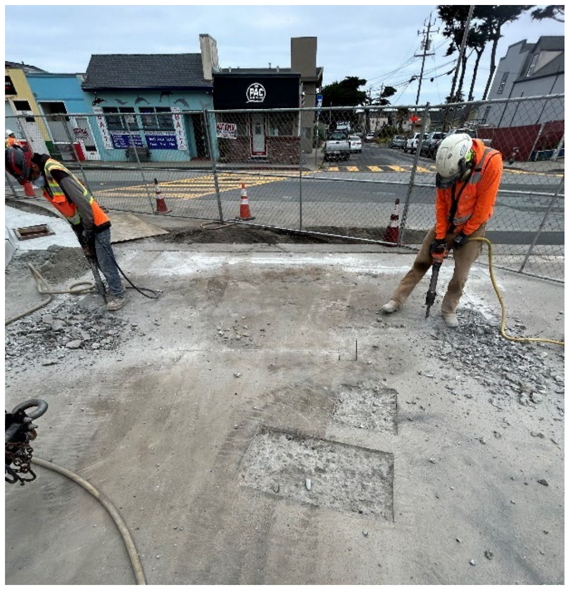


Figure 5-18. Small Pneumatic Chipping Hammers for Unsound Concrete Removal

A clean, sound substrate is required for any concrete repair so that the minimum amount of concrete to be removed will include all structurally unsound concrete, which will be all the concrete above delamination. Some judgment is required when determining whether to remove additional concrete beyond the areas of delamination, that is encasing corroded reinforcing steel bars, which is otherwise sound. In general, concrete should be removed to expose reinforcing in any case where a crack is visible in the concrete directly over a bar, where the bar is heavily rusted, or where there are heavy rust deposits in the concrete next to the bar. However, the temptation to engage in “rust chasing” along lightly corroded bars should be avoided, as this is not cost-effective. To ensure an adequate repair, all defective material must be removed, and the exposed concrete surface must be sound (free of any underlying fractures) and clean. In this context, clean means free of any extraneous material or substances that would impair the bond between the patching material and the concrete substrate.

After removing all unsound concrete, the exposed concrete surface must be cleaned of all contaminating substances. This is normally done by abrasive blasting, followed by blowing with compressed air to remove sand and dust particles. Abrasive blasting has the added benefit of removing any fractured aggregate particles remaining on a chipped surface. Wire brushes may be used if the area to be cleaned is small and readily accessible, but wire brushing will not remove fractured particles. Other methods, such as sweeping, washing, or air-blowing alone, are less effective and must not be used as the primary cleaning method. Following this operation, the surface should be inspected, and any loose or fractured aggregate particles removed with small air tools or hand chipping to ensure a completely sound substrate before placing the replacement material.

A concrete surface that has been chipped, abrasive blasted, and then air-blown to remove all loose material and surface dust will be sound and sufficiently clean, provided the repair work is done within a reasonable time. If contaminating substances (dust, dirty water, form oil, etc.) are allowed to accumulate on the exposed surface, additional cleaning will be necessary before the repair is made. It is sometimes assumed that a freshly sawn surface is clean since it has been washed by the saw-blade cooling water. Such is not the case, however, since the water leaves a residue of fine material on the surface. To ensure a bond between a sawed surface and new concrete, the sawed surface should be cleaned by abrasive blasting. Regardless of the cleaning method employed, all freshly cleaned surfaces must be protected until the repair work is performed to prevent contamination by any substance that would reduce or prevent bond; otherwise, additional cleaning will be required. The importance of surface preparation cannot be overemphasized. Figure 5-19 below illustrates a properly cleaned and prepared surface after the removal of unsound concrete.

Figure 5-19. Unsound Concrete Removed and Areas Prepared

Remedial work is virtually certain to fail when the patch or other repair is placed upon an unsound or unclean surface.

5-5.02 Placement and Cure of Repair Materials

The second step in the repair process is the placement and curing of the repair material. The material used in concrete repair is used to either fill voids in the concrete or to remedy surface defects. Per our earlier discussion on concrete defects, voids in the concrete can include cracks in the concrete or voids that result from defective concrete removal. Similarly, surface defects can be wear and tear defects or defects in the shape or profile of a bridge element, such as sagging of a bridge deck due to long-term creep. When defects are repaired as part of maintenance and rehabilitation of a structure, contract plans and documents will specify the repair methods and details.
When the repair is required as a result of the Contractor’s work, such as inadequate consolidation during concrete placement, the contract documents will also provide repair requirements for “*common”* new construction defects. For example, if surface imperfections are found on a column, the *Standard Specifications* Section 51-1.03F(3), *Class 1 Surface Finish*, describes repair requirements to achieve a smooth and even surface. Similarly, if cracks in the bridge deck are found after curing of newly placed bridge deck concrete, *Standard Specifications* Section 51-1.01D(3)(b)(iv), *Testing Concrete Surfaces – Crack Intensity,* describes the repair method and the repair requirement. However, there are times when concrete defects caused by the Contractor’s operation must be further examined before the best repair strategy can be decided. In general, the size and location of the defect will determine the repair strategy. For instance, extensive removal of unsound concrete may warrant the installation of formwork before replacing concrete. In other cases, however, the defect might be small enough to be repaired satisfactorily by placing a mortar patch (dry-packing) in the void. Satisfactory results should not be left to chance. Repair work must receive the same attention to detail by the Contractor and the inspecting engineer as the original construction.

Achieving satisfactory repair results starts with knowledge of the procedures and materials used for the repair work. Accordingly, the contract requirements for the following types of repairs will be looked at:

1. General concrete repair (except bridge deck), including:
    a. Minor & moderate repair
    b. Severe damage/defect repair- concrete replacement (reforming).
2. Bridge deck repair, including:
    a. Rapid-setting concrete patches
    b. Refinishing bridge decks
    c. Methacrylate resin bridge deck treatment
    d. Polyester concrete overlays, expansion dams, and patches
    e. Portland cement concrete overlays
    f. Combining two or more repair methods/modified repair methods.

Before further discussion about the above repair methods, an explanation is needed for the preceding organization of topics. As can be seen, the bridge deck repair method has been separated from any other structural item repair. While the repair work for the bridge deck is similar to other structural items, the bridge deck is subjected to harsher conditions throughout the life of the structure and has additional performance requirements, such as a smooth roadway traveling surface and drainage; as such, bridge deck repair will be discussed separately. See Section 5-7.01, *Rapid Setting Concrete Patches,* for related information on patching bridge decks.

5-6 General Concrete Repair (Except Bridge Deck)

5-6.01 Minor & Moderate Repair

As a guideline, a minor & moderate defect repair is merely filling small void(s) in the mass or on the surface of concrete using replacement material. See Chapter 7, *Emergency Repairs*, for categories of defects. This repair is “cosmetic” only and the defect does not affect the strength and structural integrity of the concrete element. However, a defect can become larger over time if not repaired and affect the structural integrity of the structure. For example, a small spall or crack in a bridge girder if not repaired might allow intrusion of water and moisture that could lead to further rusting of steel elements and/or further increase the size of the spall or crack. Minor defects can include surface imperfections, cracking, scaling, spalling, or delamination. When a repair is performed on an existing structure for maintenance and rehabilitation, the contract plans will show the details and requirements of the repair work. Figure 5-20 illustrates an example of a minor repair required to fix a spall in a bridge soffit.

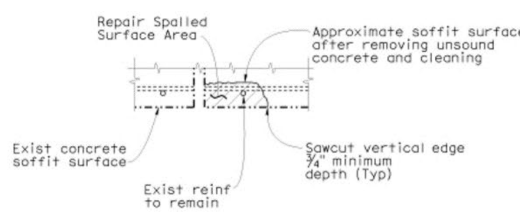
DECK SOFFIT REPAIR TABLE

BRIDGE NAME	BRIDGE No.	APPROX. AREA (%) DAMAGED	APPROX. DEPTH (INCHES)	REMOVE UNSOUND CONCRETE (CF)	FILLED SPALLED SOFFIT (CF)
210-134/E210 Separation	53-2256	1	2	62	62
Route 210-710/E210 Separation	53-2341	1	2	56	56

NOTES:

SOFFIT SPALL REPAIR

1. Patch the deck soffit overhang spalls and chunks of spalls near overhang joint seals. If the patching thickness is thicker than 5", install #5 hook dowels @ 8" o.c., with 8" deep embedment and bond with epoxy adhesive, or other equivalent anchorage technique.
2. The location of soffit spalls to be determined by the engineer.



SOFFIT SPALL REPAIR DETAIL

Note: Reinforcement may be encountered during soffit concrete removal and is to remain undamaged.

Figure 5-20. Example of Minor Repair for Bridge Soffit

Earlier it was stated that minor defect repair might also be needed as a result of the Contractor's work, such as rock pockets in a newly placed concrete stem. It was mentioned that SC staff need to investigate the extent of the defective concrete and work with the Contractor to verify all unsound concrete is removed before the repair can be started. Similarly, SC staff have an important role in verifying that the minor repair is performed properly by the Contractor. As previously mentioned, SC staff should read BCMs frequently to make sure they are aware of their inspection duties and what they need to do to administer a project.

Next, it is necessary to discuss minor concrete repair requirements stated in the contract specifications that the Contractor must comply with. *Standard Specifications* Section 60-3.05B, *Existing Structures – Structure Rehabilitation – Repairing Structures – Repairing Spalled Surface Areas*, describes requirements for several types of repairs that are used for minor concrete defects (except on bridge decks); the following repair methods are discussed in this section, and each of the repair methods will be looked at separately:

- Dry-packing
- Patching using conventional concrete, commercial patching material, or epoxy mortar
- Shotcrete.

When performing any of the above repairs, surface preparation is a critical component of the repair. *Standard Specifications* Section 60-3.05B(3), *Construction*, states that the concrete surfaces and existing reinforcing steel are to be cleaned by abrasive blasting before placing filler material. As with all repairs, the durability of the repair is significantly dependent on the choice of repair material. Consult with Materials Engineering and Testing Services Representative (METS Rep) for proposed replacement/repair products. The SC field personnel must also review BCM 60-3.05B, *Existing Structures – Structure Rehabilitation – Repairing Spalled Surface Areas* (Except Bridge Decks), to properly inspect and administer a project involving spall repair.

Standard Specifications Section 60-3.05C, *Epoxy Crack Injection*, describes the requirement for another type of minor concrete defect repair. As indicated by the name of the specification, this repair method involves filling cracks by epoxy injection.

5-6.01A Repairing Spalled Surface Areas

5-6.01A(1) Dry-Packing

Standard Specifications Section 51-1.03E(2), *Concrete Structures – General – Construction – Miscellaneous Construction – Placing Mortar*, describes the requirements of repair work that is commonly called "dry-packing". Dry-packing consists of filling a void with a relatively dry (not fluid) sand/cement mortar and pressing the mortar into place. Figure 5-21 shows a sample of dry-pack mortar.

Figure 5-21. Sample of Dry-Pack

It was mentioned earlier that dry-packing can be used to repair spalls. However, dry-packing is also particularly suited to the repair of surface imperfections such as filling form tie rod holes or rock pockets, since these defects occur in vertical surfaces or on the bottom of a horizontal member where other repair methods would be difficult to accomplish. When performed properly, dry-packing results in a reconstruction that is nearly equivalent, in strength and durability, to the original concrete. Either cement or an epoxy adhesive may be used as the bond coat, depending on the size of the void. The proportions for mortar used for dry-packing are 1 part cement to 2 parts sand, measured by volume, with just enough water to bind the materials together and facilitate placing and compacting. The proportions and requirements of the mortar are described in *Standard Specifications* Section 51-1.02F, *Concrete Structures – General – Materials – Mortar*. While proportions used for mortar can be prepared in the field, the material is also readily available in prepackaged containers, as illustrated in Figure 5-22.

Figure 5-22. Prepackaged and Proportioned Dry-Pack

Shallow voids up to about 1 inch in depth may be filled in a single operation by tamping the material in place with a hardwood stick by hand, or by tapping with a hammer. Wooden sticks eliminate the dark, slightly polished surface appearance, which often results from the use of metal tools. Deeper voids should be filled in 1/2- to 1-inch-thick layers. The surface of the underlying layers should be scratched before the next layer is placed. Successive layers may follow immediately unless plasticity develops. Should this occur, stop work until the mortar sets. The final layer should be slightly over-filled to ensure adequate surface compaction and then trimmed to the lines of the parent concrete.

If the location is visible to the public, the color of the cured patch must match the parent concrete; for non-building work, the assistance of the local District Landscape Architect can be requested to corroborate the desired aesthetic. White cement may be added to trial batches until the correct color is obtained; note that this process may be more of an art than a science. For related information, refer to the *Reinforced Concrete Construction Manual* Section 5-13, *Concrete – Concrete Surface Finish*. In the past, for exposed surfaces, at least 3 days of continuous water cure were recommended for dry-pack patches. If the patch was not visible to the public, a membrane cure was used. However, current *Standard Specifications* Section 51-1.03E(2), *Placing Mortar*, makes water curing for three days a requirement for all patches (i.e., it is no longer just a recommendation for the visible items).

When inspecting this work, SC field inspectors need to make sure they read and understand BCM 51-1.03E, *Concrete Structures – General – Miscellaneous Construction*. When dry-packing is used for spall repair, the inspectors need to also review BCM 60-3.05B, *Existing Structures – Structure Rehabilitation – Repairing Spalled Surface Areas* (Except Bridge Decks), to properly inspect and administer spall repair work. It is intended not to repeat the instructions provided in the above documents. However, it is important to emphasize that a clean and sound substrate, suitable repair material, and proper curing are all critical for constructing a durable repair. Accordingly, verify repair material meets all contract requirements; seek METS Rep assistance as needed.

5-6.01A(2) Patching Using Conventional Concrete

Patching with a sand/cement mortar with aggregate filler may be an appropriate repair procedure, particularly when the void to be filled is relatively deep and covers an extensive area; this typically occurs in a concrete spall defect. In most cases, pea gravel will be used as the aggregate filler. Such mixes should be proportioned to provide a 1:1 ratio of sand to pea gravel and should contain enough cement to make a workable mixture. Avoid using too much cement, however, as this will increase shrinkage. The use of a conventional sand/cement mortar without the addition of aggregate is not recommended for repairing concrete because of the undesirable shrinkage characteristics associated with such mixtures. Concrete patches in surfaces that require a Class 1 surface finish should be water-cured. For other surfaces, curing may be accomplished by either water or the curing compound method.

When inspecting this work, SC field inspectors need to make sure they frequently read and reference BCM 51-1.03C-D, *Concrete Structures – Preparation and Placing Concrete.* Inspectors also need to review BCM 60-3.05B, *Repairing Spalled Surface Areas* (Except Bridge Decks), to properly inspect and administer spall repair work. It is important to emphasize the need for a clean and sound substrate, suitable repair material, proper curing, and protecting the concrete while it sets (i.e., gains sufficient compressive strength); these factors are critical for constructing a durable repair. Accordingly, verify the repair material meets all contract requirements; seek METS Rep assistance as needed.

5-6.01A(3) Patching Using Commercial Materials

There are several proprietary products marketed commercially as concrete patching materials. Figure 5-23 illustrates an example of a commercial concrete patching material.

Figure 5-23. Commercial Concrete Patching Material

However, many of these products have one or more undesirable characteristics (such as low bond strength, excessive rigidity, high chloride or sulfate content, or high shrinkage) and thus are not suitable for patching rock pockets. Some generic materials, such as magnesium-phosphate concretes and high alumina cement products, are marketed under various brand names. These products have a long history of satisfactory use and may provide satisfactory repair under certain conditions. However, some of these products are self-leveling and therefore, will not be appropriate for vertical or overhead surfaces. While these products are useful when repairing deteriorated concrete, they are not recommended for rock pocket repair in new construction. When use of a commercial material is contemplated, *Standard Specifications* Section 60-3.05B describes test sample submittal requirements and material property requirements that patching material must comply with. In addition, the *Standard Specifications* Section 60-3.05B(3), *Construction*, states that if using commercial material (alternative filler material as called out in the specifications), the Contractor must apply a bonding epoxy before placing the filler material. Furthermore, the specifications state that the Contractor must place the filler material under the manufacturer's instructions.

When inspecting this work, SC staff need to review BCM 60-3.05B, *Repairing Spalled Surface Areas* (Except Bridge Decks). The importance of having a clean and sound substrate, suitable repair material, proper curing, and protecting the concrete while it sets (i.e., gains sufficient compressive strength) cannot be overemphasized; these factors are critical for constructing a durable repair. Accordingly, verify the repair material meets all contract requirements; seek METS Rep assistance as needed.

5-6.01A(4) Patching Using Epoxy Mortar

Because it is relatively expensive, difficult to work with, and darker in appearance than concrete, epoxy mortar is not used as widely as other concrete patching materials. However, the use of an epoxy mortar or concrete may be appropriate at locations where a highly viscous, rapid-setting material is required. Figure 5-24 shows an example of a commercially available epoxy patching product.

Figure 5-24. Example of a Commercially Available Epoxy Patch

Epoxy may be particularly suitable for patching small voids in vertical and overhead surfaces where appearance is not a factor. The contract requirements for this type of patching material are the same as described in Section 5-6.01A(3), *Patching Using Commercial Materials* (of this chapter).

Standard Specifications Section 95-1.02C, *Epoxy – General – Materials – Epoxy Binder,* discusses the requirements for making epoxy mortar. As a general guideline, approximately equal portions of sand and pea gravel will produce a workable mixture, provided the amount of epoxy is adjusted to maintain a 1:4 (approximate) ratio of epoxy to total aggregate content. All aggregates used in epoxy mixes must be clean and thoroughly dry; epoxy will not tolerate the presence of even small amounts of moisture in the mix. When mixing the ingredients, the epoxy resin components should be blended and thoroughly mixed to obtain a uniform color before the aggregates are added. To ensure an adequate bond between the epoxy patch and the parent concrete substrate, the concrete surface must be clean and dry when the patch is placed. Abrasive blasting is the specified cleaning method. For best results, the surface should be abrasive blasted and then air-blown to remove all abrasive blast residue and loose aggregate particles from the substrate on the same day that the patches are placed. Epoxy polymers are intolerant of moisture, so the substrate must be thoroughly dry and the exposed surface of the epoxy patch must be protected from moisture contamination until polymerization is complete.

Before placing the patching material, the surface to be patched should be primed with a bond coat using the same epoxy that is being used in the mortar or concrete mixture. Typically, epoxy patches are placed by working the material around reinforcing steel and into corners by hand, and then consolidating the material by tamping. For patch thicknesses of more than about 2 inches, the patch should be placed and compacted in 2-inch lifts. Epoxy mortar/concrete patches should be finished with steel, rather than wood, finishing tools. Steel is more effective in sealing the sticky surface, which is characteristic of epoxy mixes. The rate at which epoxy hardens to a solid substance (the cure time) is a function of temperature – the higher the temperature, the shorter the cure time. For most epoxies, the cure time will decrease rapidly as temperatures rise above approximately 80 degrees F. Conversely, many epoxies will not cure at all at temperatures below about 50 degrees F. Ideally, the best results will be obtained when the parent concrete, the epoxy patch material, and atmospheric temperatures are all within a range of 60 to 80 degrees F.

To follow are various classes of epoxies, depending on temperature:

1. The State-specified epoxy used as a binder in epoxy mortar, ASTM C 881, Type V Grade 2 Class C, is acceptable for temperatures greater than 60 degrees F.
2. For temperatures between 40 and 60 degrees F, ASTM C 881, Type V Grade 2 Class B is specified. The Class B epoxy is formulated for cold weather conditions and is a rapid-setting epoxy with a very short (10 minutes or less) working window. Mortar made with Class B epoxy may be difficult to mix and place successfully except in small quantities.
3. Class A epoxy for temperatures below 40 degrees F is not permitted under current specifications. For cold weather placement, it is theoretically possible to accelerate the epoxy cure time by applying heat to the parent concrete and/or to the mixed ingredients. This procedure was tried, but results were unsatisfactory because of the difficulty in determining in advance the amount of heat necessary to bring the cure time within the ideal range. In most cases too much heat was applied, so that cure times were significantly reduced rather than merely accelerated as was intended. Given this experience, this practice is not recommended.

When the epoxy mortar is used for spall repair, SC field inspectors need to read BCM 60-3.05B, *Repairing Spalled Surface Areas (Except Bridge Decks).* Inspectors also need to review BCM 95-1, *Epoxy – General*, and its Attachment 1, *Information and Instructions for Epoxy Use*. The importance of having a clean and sound substrate, suitable repair material, proper curing, and protecting the concrete while it sets (i.e., gains sufficient compressive strength) cannot be overemphasized; these factors are critical for constructing a durable repair. Accordingly, verify the repair material meets all contract requirements; seek METS Rep assistance as needed.

5-6.01A(5) Shotcrete

The term “shotcrete” is given to Portland cement concrete or mortar that is applied pneumatically onto a surface. Shotcrete may be a viable means of reconstructing a vertical or overhead surface when the defective concrete covers an extensive area and the depth of repair is relatively shallow. Figure 5-25 illustrates an example of shotcreting to repair exterior surfaces of a bridge.

Figure 5-25. Shotcrete Used to Repair Exterior Girder and Soffit

The requirements for shotcrete are covered in Section 53, *Shotcrete*, of the *Standard Specifications*. All specifications and provisions governing materials, placing, and finishing apply to shotcrete used to fill voids created by the removal of defective concrete.

When shotcrete is used for spall repair, SC staff need to read BCM 60-3.05B, *Repairing Spalled Surface Areas* (Except Bridge Decks), as well as BCM 53-1, *Shotcrete – General*. If the spalled surface includes areas of sculpted shotcrete structures (such as manmade boulders, faux timber, etc.), then inspectors also need to review BCM 53-3, *Shotcrete – Sculpted Shotcrete*. The importance of having a clean and sound substrate, suitable repair material, proper curing, and protecting the concrete while it sets (i.e., gains sufficient compressive strength) cannot be overemphasized; these factors are critical for constructing a durable repair. Accordingly, verify the repair material meets all contract requirements; seek METS Rep assistance as needed.

5-6.01B Epoxy Crack Injection

Epoxy crack injection uses epoxy material to seal cracks in concrete structures (bridges, walls, etc.) and is designed to be a crack sealer and repair for concrete elements. The repair methodology outlined below is a step-by-step process similar to the work the Contractor will perform in conjunction with the project contract plans to complete the structural repairs. The contract requirements for performing this work are described in

Standard Specifications Section 60-3.05C, *Existing Structures – Structure Rehabilitation – Repairing Structures – Epoxy Crack Injection*. While the requirements in this section are discussed, SC staff are referred to the standard specifications for the complete and latest requirements. Note that epoxy crack injection is specialty work, typically performed by a select group of specialty subcontractors.

5-6.01B(1) Locating and Cleaning Cracks in Preparation for Epoxy Injection

The Contractor needs to remove any obstructions that impair the field engineer’s ability to locate the limits of the cracks. For example, if the cracks extend below grade, then the Contractor would need to excavate around the abutment, footing, or other structural element to be repaired by epoxy injection. The Contractor should use compressed air to blow and clean cracks to expose the visible limits of the cracks. Abrasive blasting may also be necessary in some cases to open up or expose more of the crack (or cracks) in the damaged area. The Contractor needs to follow the specifications for cleaning the cracks before moving on to the epoxy injection work. Removing all dirt, dust, and other unsound concrete material from the cracks is an important step in preparation for the epoxy injection procedure. Thorough surface and crack preparation will allow for the proper bonding and flow of the epoxy material into the cracks in the concrete.

When inspecting this work, SC staff need to review the contract plans and locate the cracks in the structural element that require repair. Verify that the Contractor:

1. Removes any obstructions that impair the field engineer’s ability to locate the limits of the cracks.
2. Follows the specifications for cleaning of the cracks to remove all dirt, dust, and other unsound concrete material from the cracks.
3. Flushes the cracks with water under pressure and dries with oil-free compressed air to complete the preparation of the cracks.

5-6.01B(2) Preparation for Epoxy Injection – Installation of Injection Ports

The next step the Contractor must perform is to set the spacing and attach the injection ports into the cracks to receive the epoxy injection (see Figure 5-26). The spacing and number of injection ports installed will depend upon the thickness of the element being repaired and the size of the crack. The specification calls for a maximum injection port spacing along the crack of not more than the thickness of the concrete being injected. At the ends of the crack, the specifications call for a maximum injection port spacing of half of the concrete thickness. The specifications also allow for closer port spacing if needed to ensure the epoxy fills the cracks. The Contractor can install and secure the injection ports over the crack in a variety of different ways. For instance, the Contractor can use hot glue from a hot glue gun or a rapid-setting epoxy to stick the injection ports directly into the crack. The Contractor should be cautious when applying rapid-setting epoxy or hot glue to the injection ports so as not to get any in the injection port or cover the opening at the end of the injection port. Once the ports are properly spaced and set, the remaining length of the crack will need to be sealed.

Figure 5-26. Installing Injection Ports

When the Contractor begins attaching injection ports into the cracks to receive the epoxy injection, SC staff need to verify the spacing of the injection ports to be per contract requirements. SC staff must also verify that injection ports are not accidentally clogged during installation.

5-6.01B(3) Preparation for Epoxy Injection – Sealing Cracks Between Injection Ports

The next preparatory step for the epoxy injection process involves sealing the remaining length of the crack. The specification calls for the use of tape or other temporary sealant “capable of retaining epoxy in cracks during pressure injection” to seal the crack. The Contractor can use a quick-setting epoxy (or even auto body filler), or tape to cover the cracks (See Figure 5-27). Any deficiencies in sealing the cracks may only become evident when pumping epoxy under pressure into an adjacent port. The pressurized epoxy injection may cause a leak to appear along the length of the crack (See Figure 5-28). If this happens, stop the pressurized injection work and have the Contractor repair the leak. In some cases, rubbing beeswax or paraffin over a leak may be sufficient to seal the leak. If this method does not work, the Contractor can place more rapid-setting epoxy or other sealant over the leak before continuing.

Figure 5-27. Sealing a Crack Between Injection Ports

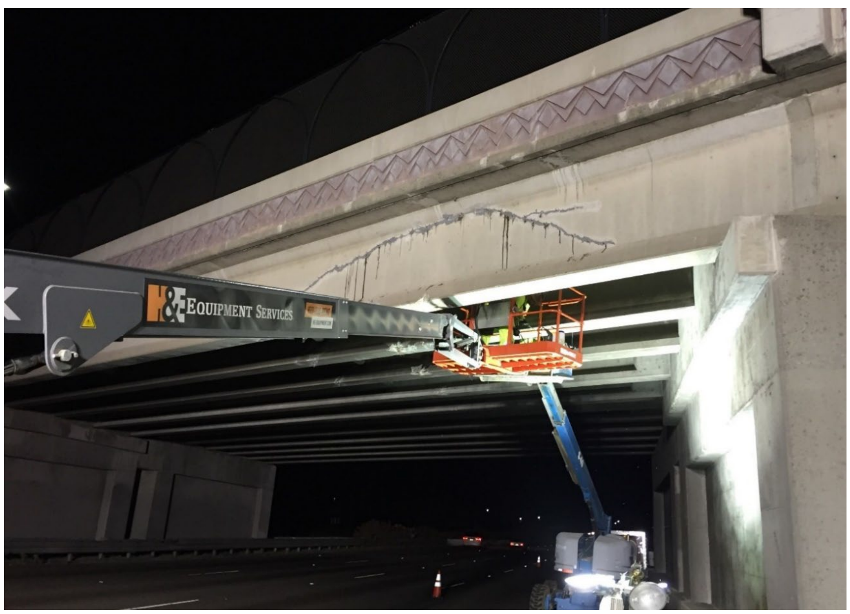


Figure 5-28. Epoxy Leaks on a Structural Element from Pressurized Epoxy Injection Work

SC field inspectors need to verify that the length of cracks between all ports is properly sealed to prevent leaks during epoxy injection.

5-6.01B(4) Pressurized Epoxy Injection

With the completion of the preparatory work, the Contractor can commence the pressurized epoxy injection work. The concrete temperature needs to be within the allowable temperature range per the standard specifications (50-90 degrees F) and the manufacturer's recommendations. The strategy for epoxy injection is to start injecting epoxy at the low end of the crack and keep the epoxy moving from port to port.

Typical injection equipment consists of a positive displacement pump and a gear-driven mixing mechanism that can be calibrated to mix the 2 epoxy components at the exact ratio required, which is not necessarily 1:1 or 2:1 as is the case for other epoxies. It should be noted that epoxy curing may be sensitive to the mixing ratio. Samples taken at the beginning of the operation can be used to verify proper mix and curing. For convenient operation and easy movement, the pump, mixer, and epoxy component storage tanks are usually mounted on the same platform.

The Contractor will insert the injection gun (see Figure 5-29 and Figure 5-30) onto the first port and will keep pressure injecting the epoxy until the epoxy runs out of the next port in line (i.e., return). When the epoxy returns from the adjacent port, the crack between the ports is now filled with epoxy. The Contractor's field crews will then disconnect the injection gun from the first injection port, cap it off, and reconnect to the next port. The epoxy injection work will continue in this fashion, moving from port to port to keep the epoxy flowing, until the entire crack is filled with epoxy. Sometimes the epoxy will follow a subsurface crack that was previously unseen and will come out (return) somewhere else. For example, the epoxy return could occur at another port on another crack, or even start oozing out of an unseen crack. When this happens, the Contractor will need to either cap off the port with the epoxy return or, if it is a new crack, stop and seal the crack. The goal is to completely fill all the cracks with epoxy.

The operation will continue by injecting and capping off the ports. The epoxy will eventually fill all the cracks and return from all the ports. If there is a problem with a crack that keeps leaking, stop pumping on that crack and go on to another crack. This will give the epoxy time to gel in the crack, and the Contractor can come back to it later. The epoxy will need to set overnight to cure or for the duration recommended by the manufacturer. After the epoxy has hardened, the Contractor will seal the ports by removing the port fittings, filling the voids with epoxy, and covering the voids with tape or sealant. Leave the tape or sealant in place until the epoxy has hardened. The Contractor may use a chipping hammer to chip off the ports and most of the excess epoxy. The Contractor can use a grinder or an air-powered sanding disk tool to grind down the remaining epoxy until it is smooth. Selection of an epoxy that meets the standard specifications and the project objectives will ensure the epoxy will flow through even the smallest cracks, allowing for a quality repair of the damaged member.

Injecting pressures average about 25 to 30 psi for normal injection work, but the pressure is somewhat dependent on crack width, with smaller cracks requiring higher injection pressures. Pressures of 60 psi or more may be required for very small cracks. Epoxy injection can be a very slow process. The key to the success of the process is to go at a slow rate when injecting the epoxy into the ports. The pump and mixing machine will continue to inject epoxy if the button is held down. The pressure will build up in the crack and may lead to blowing holes in the epoxy cover over the cracks. To avoid this, the Contractor should inject a little at a time and allow the pressure to dissipate in the crack. Most machines have a pressure gauge on the injection line that the field engineer and the Contractor's personnel can watch. When the pressure goes up, the Contractor should exercise caution and even stop until the pressure goes back down. Once the pressure spike subsides to low or zero pressure, the Contractor can continue to inject epoxy. The Contractor may elect to have a tripod that will hold the epoxy gun during the injection process. On some large cracks, epoxy injection can take place for several minutes nonstop before there is any return. Very small cracks may take a long time to fill, so the Contractor should proceed slowly.

Figure 5-29. Epoxy Injection Pump and Injection Gun

Figure 5-30. Epoxy Injection Pump, Injection Gun, and Two-Part Epoxy

When inspecting this work, SC staff need to verify that the Contractor:

1. Places epoxy within the allowable concrete temperature range per the standard specifications (50-90 degrees F) and the manufacturer's recommendations.
2. Starts the pressure injecting at the lowest port.
3. Continues injecting into a port until epoxy starts flowing out of the adjacent port.
4. Continues to pump and cap off the ports until the epoxy eventually fills all the cracks and returns from all the ports.

If questions from the Contractor or the Engineer arise on the type of epoxy to use, coordinate with Bridge Design or Structure Maintenance & Investigations[1] (SM&I) Design on which low-viscosity epoxy to select; a discussion with the METS Rep may also be appropriate. Verify that the selection of an epoxy meets the standard specifications and the project objectives.

When epoxy injection is used for crack repair, the inspectors need to read BCM 60-3.05C, *Repairing Structures – Epoxy Crack Injection*. SC staff also need to review BCM 95-1, *Epoxy – General*, and its Attachment 1, *Information and Instructions for Epoxy Use*. The importance of having a clean and sound substrate, suitable repair material, proper curing, and protecting the concrete while it sets (i.e., gains sufficient compressive strength) cannot be overemphasized; these factors are critical for constructing a durable repair. Accordingly, verify the repair material meets all contract requirements; seek METS Rep assistance as needed.

5-6.02 Severe Damage/Defect Repair-Concrete Replacement (Reforming)

When the area of defective concrete results in large voids in primary load-carrying members such as slabs and girder stems, it can result in reduced or impaired load-carrying ability of the member. Large concrete repair is sometimes performed on existing structures as part of an emergency project. The cause of the emergency can vary, but it may involve a vehicular collision with a structure or fire damage. Emergency repair will be discussed again in Chapter 7, *Emergency Repairs*, of this manual.

When large concrete repair work is needed on an existing structure, the contract plans will typically provide the details and requirements of the work. Figure 5-31 shows an example of a contract plan showing details of a large defect repair.

[1] Caltrans internal use only

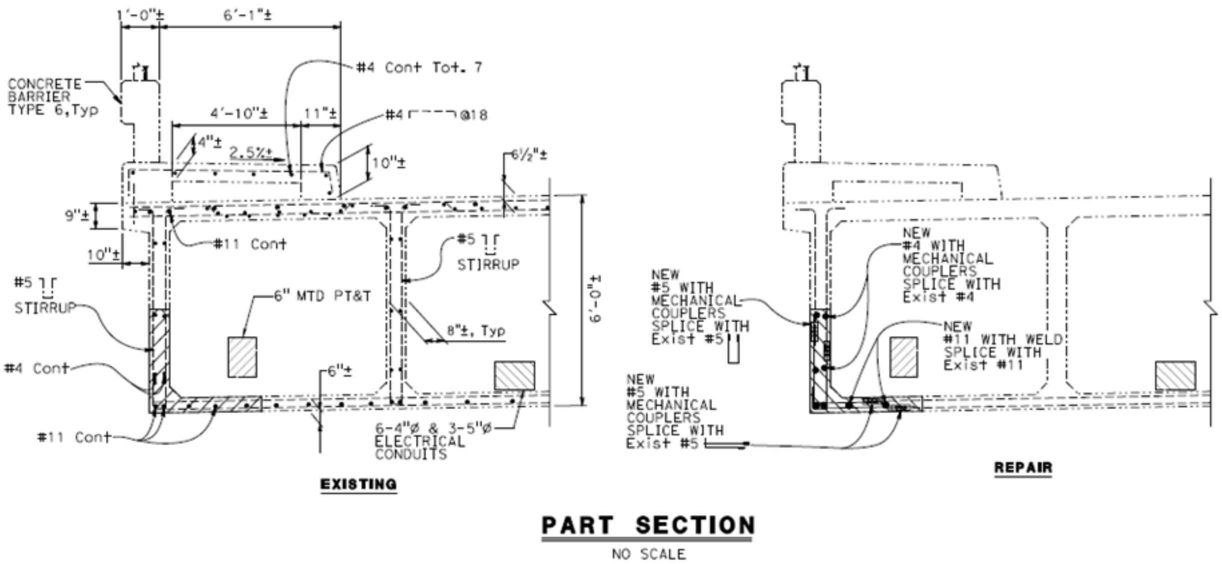


Figure 5-31. Severe Damage Repair of a Bridge Girder and Soffit

When significant concrete repair work is required due to the Contractor's operation – such as extensive unsound concrete in a newly cast bridge member (for example, a girder or abutment diaphragm) – the Contractor must submit a repair plan for review and authorization by the Engineer before removing the unsound concrete and proceeding with the concrete repair work.

When inspecting this work, SC staff need to read BCM 51-1.03C-D, *Concrete Structures – General – Construction – Preparation and Placing Concrete*. It is important to emphasize the need for a clean and sound substrate, suitable repair material, proper curing, and protecting the concrete while it sets (i.e., gains sufficient compressive strength); these factors are critical for constructing a durable repair. Accordingly, verify the repair material meets all contract requirements; seek METS Rep assistance as needed.

Large concrete repair work is, in essence, recasting the member using replacement concrete with the same characteristics as the original concrete. However, while the work itself might appear simple and trivial to do, there are typically many questions and considerations that need to be addressed before the work starts. Below is a summary of typical concerns and considerations that should be addressed before the start of the work; this list is **not** comprehensive, and there could be other job-specific issues that have to be addressed after the review of contract documents and project criteria:

1. **Access to work:**

   Access to the work, including how to place forming material needed for recasting, how to place concrete, and how to consolidate the concrete are all concerns that must be addressed. Whether repairing existing construction or repairing a newly built member, access to the work site for forming, pouring, and placing of concrete might have significantly changed since the item was originally cast. For example, repairing a large defect in the middle of a bridge girder may not be possible by just forming in the middle of the girder; instead, perhaps the top of the girder may also have to be removed or drilled to allow for concrete to be poured and consolidated. See the large concrete repair illustrated in Figure 5-32 below, as an example. If the Contractor were to simply form the voided area on the girder, they would need to describe how they would pour and consolidate the concrete.

Figure 5-32. Large Voids in Bridge Girder

2. **Load-carrying capacity and redistribution of static load:**

   If a large portion of a load-carrying structure element is damaged, the load-carrying capacity of the structure needs to be considered. Bridge Design or SM&I needs to be contacted so that they can make the analysis and provide direction on how to proceed.

3. **Quality of repair considering time and cost constraints:**

   When a structure has a large defect, careful consideration should be given as to whether it's beneficial to repair or to replace the defective structural element. Factors used in making these determinations can include the age and condition of the structure, along with the time as well as the cost required to repair vs replacement. For example, in repairing a defective precast slab bridge deck, it might be easier to replace the deck slab panel than it is to repair it.

5-6.02A Preparation

When large concrete repair is needed, removal of concrete might extend beyond the limits of unsound concrete. For example, after the complete removal of unsound concrete, there might be just a very small amount of concrete left at the edge of a member; in that case, the small amount of sound concrete should also be removed. When the repair work is part of the contract, requirements and details of removal limits will be in the project plans. When the repair work is due to the Contractor’s work, the details of the limit of removal are frequently indicated in the authorized repair plan.

In general, the following details are commonly called out in the plans:

1. Removal limits are straight and square with the structural element being repaired.
2. If approximately 18 inches (or less) of sound concrete remains between the area to be repaired and the top or end of a wall or girder, the sound concrete should be removed as well.
3. Bar-reinforcing steel that is partially embedded in concrete needs to have at least 1-inch clear all around within the repair zone, and not less than the large aggregate in the repair mix.
4. Verify that no voids remain between the existing and the freshly placed concrete. Methods to prevent the inclusion of voids are listed below:
    a. Chipping the top surface of the void on a 3:1 upward slope toward the concrete placing side.
    b. Form a pour window above the void to be filled with replacement concrete.

    Place concrete through the pour window to provide a head on the fluid concrete.

5-6.02B Concrete Placement

To facilitate placement and consolidation of the concrete, consideration may be given to the use of a water-reducing admixture to increase the fluidity and workability of the concrete. All specification requirements for furnishing, placing, curing, and protecting new structural concrete will also apply to replacement concrete. If it is necessary to make a structural repair in concrete that is to be prestressed, keep the following in mind: the replacement concrete must attain the specified compressive strength before prestressing forces are applied, and this could delay the stressing operation. Therefore, take concrete cylinders of the replacement concrete for strength verification.

5-7 Bridge Deck Repair

Defects occurring in bridge decks fall into two general categories:

- Those which impair the drainage and riding quality of the finished deck surface, but have no structural significance.
- Those which, if not repaired, could affect the structural integrity of the bridge itself.

Defects in the first category include deck areas that for various reasons have a poor riding surface (too high, too low, or too rough) where the condition is serious enough to require remedial work other than grinding. Repairing such defects may require the removal of a substantial portion of the finished deck surface.

The second category includes severe cracking and surface defects like rock pockets. Cracks that exceed the intensity threshold as defined in the specifications need to be repaired. Caltrans structural elements, such as concrete bridge decks, experience severe use under potentially harsh environmental conditions. Bridge decks are subject to continuous surface wear and high live-load stresses, due to impact and cyclical loading. For the most part, bridge decks are exposed to alternating cycles of wet and dry, and in many locations, alternating cycles of freeze-thaw and temperature differentials. Bridge decks may contain a significant amount of reinforcing steel, making the use of highly workable concrete essential. Because of finishing requirements and bleeding, the concrete at the deck surface may be of lower quality than the concrete below the surface. Given these influencing factors, it is not surprising that concrete bridge decks, in general, experience a relatively more rapid deterioration rate and require a greater maintenance effort than other elements of concrete structures.

Next, repair procedures will be discussed for both categories of bridge deck repairs. Some of the repair methods, such as spall repair for bridge decks, are similar to those described in earlier sections of this chapter. Specific contract requirements that must be followed when repairing bridge decks will also be discussed. In addition, certain repair methods unique to bridge decks, such as methacrylate treatments or overlays, will be discussed later.

5-7.01 Rapid Setting Concrete Patches

For existing bridges, spalls in the bridge deck are defects that can be repaired using rapid setting concrete patches when rehabilitating a structure. This item of work is covered in the *Standard Specifications*, Section 60-3.02C(6), *Existing Structures - Structure Rehabilitation - Bridge Deck Repair and Preparation - Construction - Rapid Setting Concrete Patch*. See Figure 5-33 for an example plan sheet showing the locations of spalls and specifying the placement of a RAPID SETTING CONCRETE (PATCH) item to repair a bridge deck.

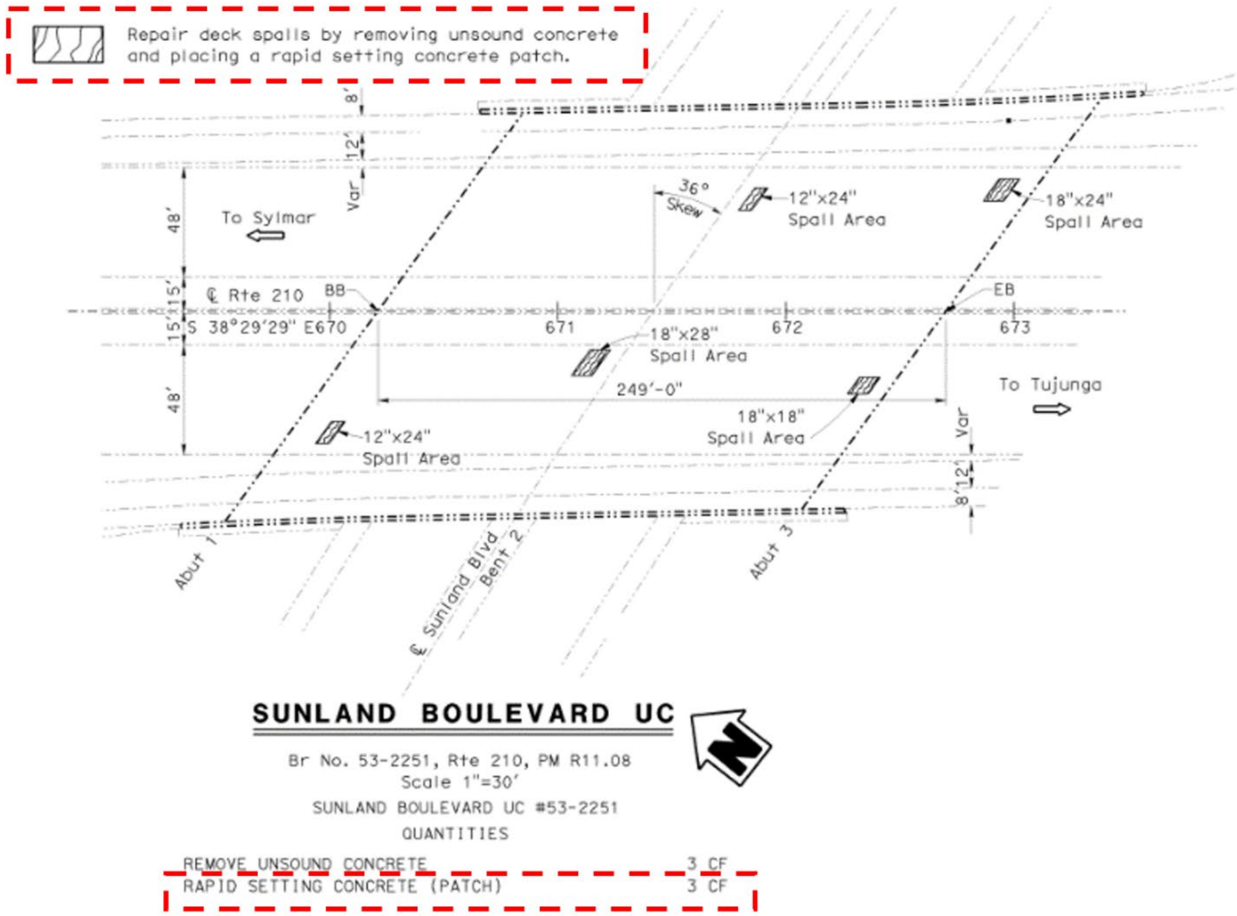


Figure 5-33. Bridge Plan Sheet Showing Specific Spall Repair Locations

The specific location for placement of rapid setting concrete patches is not always identified on the plans. Instead, the plans may specify limits on the bridge deck where unsound concrete is to be identified and removed. See Figure 5-34 showing an example of a plan sheet that describes the placement of a RAPID SETTING CONCRETE (PATCH) item within limits specified on a bridge. Note that the planned quantity for both the removal of unsound concrete and the placement of concrete patch is identical. These are typically estimated by the designer as a function of the concrete area and the anticipated spall depth (for example, 1 percent of the deck area and 3 inches deep). It should be noted that *Standard Specifications* Section 60-3.02C(5), *Removing Unsound Concrete*, states that “the Engineer determines the soundness of concrete”. Earlier, in Section 5-5.01, *Removal of Unsound Concrete*, the methods of how unsound concrete is identified were discussed in detail, along with corresponding field activities that SC field staff need to perform. Here, the importance of field testing for unsound concrete and verifying that all unsound concrete is located and removed before performing any deck repair work will be emphasized. If unsound concrete removal is not included as an item in the contract plans, it needs to be added by change order.

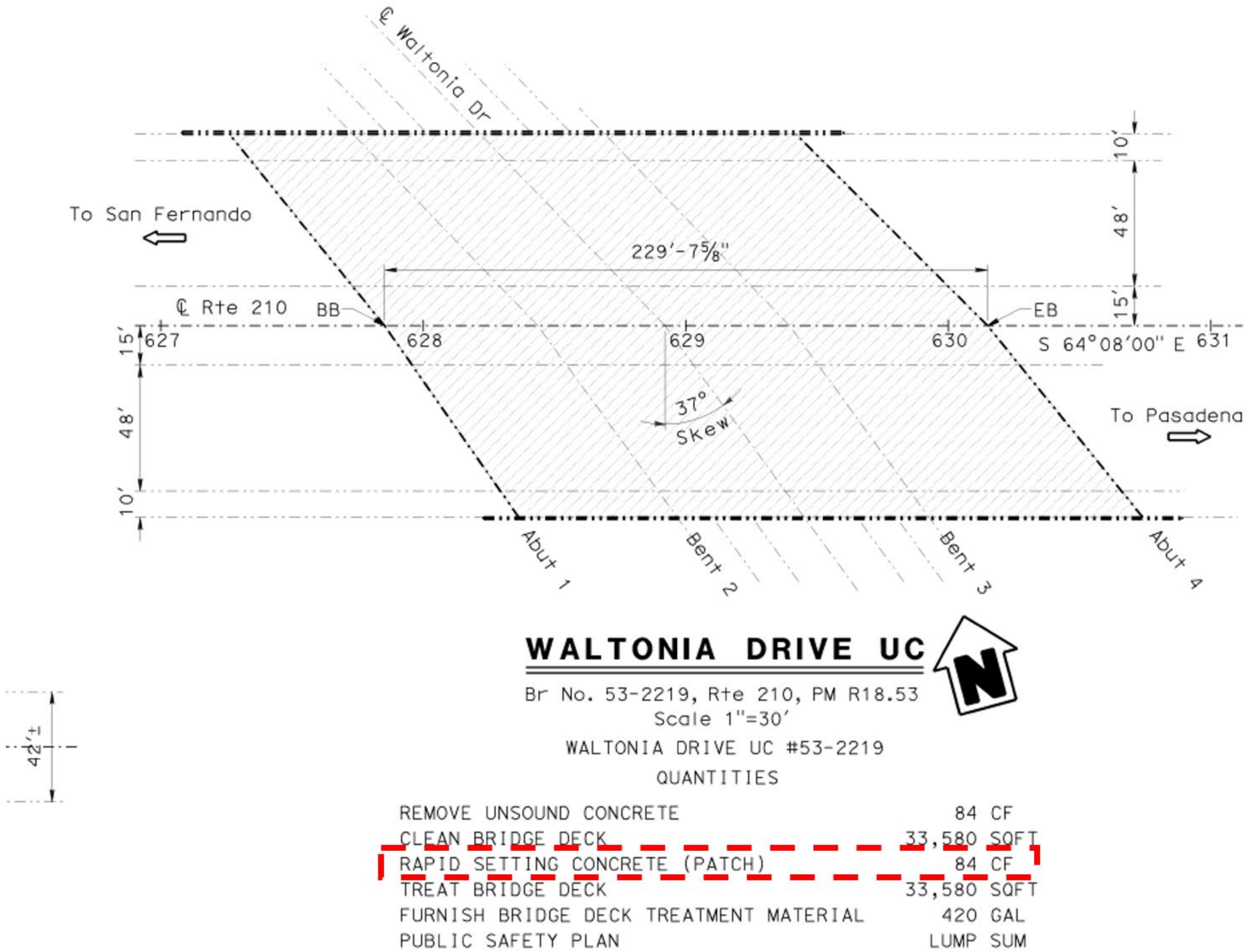


Figure 5-34. Bridge Plan Sheet with Anticipated Spall Repair Quantity

A new bridge deck may also require the placement of rapid setting concrete patches as part of repair work. For example, Figure 5-35 illustrates a defect in a new bridge deck caused by the clumping of polymer microfibers that needs to be repaired.

Figure 5-35. Required Patching in New Bridge Deck

When rapid setting concrete patches are used to repair a bridge deck, the aforementioned *Standard Specifications* Section 60-3.02C(6), *Rapid Setting Concrete Patch*, describes the requirements that must be complied with. These requirements include surface preparation, cleanness, and surface temperature before the patching material can be placed. Additionally, below are a few of the *Standard Specifications* sections that describe further materials requirements when using rapid setting concrete patches:

60-3.02B(2), *Existing Structures – Structure Rehabilitation – Bridge Deck Repair and Preparation – Materials – Rapid Setting Concrete*, describes the material requirements including aggregate gradation.

51-1.02C, *Concrete Structures – General – Materials – Bonding Materials*, describes the performance requirement of the material, such as strength, shrinkage, and abrasion resistance.

51-1.01C(3), *Concrete Structures – General – Submittals – Bonding Materials*, describes the requirements for a test sample that needs to be submitted by the Contractor to obtain the Department's authorization before the material can be used.

Rapid setting concrete is required to gain compressive strength quickly, not to be confused with rapid strength concrete covered under *Standard Specifications* Section 90-3, *Concrete – Rapid Strength Concrete*. Rapid setting concrete and rapid strength concrete (RSC) are two types of concrete that sound very similar and sometimes create confusion about their application and their differences; let's look at each one individually:

1. **Rapid setting concrete**- a material that is typically mixed in small batches to fill a small cavity (i.e., it is a patching material). For this type of concrete, the usual concrete requirements described in *Contract Specifications* Section 90-1, *Concrete – General*, do **not** apply. For this material, there is no requirement for a mix design submittal, cement content, mixing, or transporting of concrete. There

are also no separate requirements for fine and coarse aggregates. Instead, in "simple" language, the standard specifications state that aggregates must be smaller than 1/2 inch and bigger than 0.05 inch. This requirement is logical because the idea is for the aggregate to be small enough to patch relatively shallow spalls. It also states that the material must have low shrinkage, good bond strength, good abrasion resistance, and good compressive strength. Naturally, these are characteristics of having a satisfactory and durable patching material.

2. **Rapid strength concrete**- a material that is commonly used for producing large roadway or structural elements such as approach slabs. For this type of concrete, the usual concrete requirements described in the aforementioned Section 90-1 do apply; this includes requirements for mix design submittals, cement content, mixing, and transporting of concrete. There are also separate requirements for fine and coarse aggregate. This material is typically batched in large quantities by volumetric trucks; see Chapter 3, *Approach Slabs*, for related information

When rapid-setting concrete patches are used to repair a bridge deck, SC staff need to read BCM 60-3.02, *Existing Structures – Structure Rehabilitation - Bridge Deck Repair and Preparation*. SC staff also needs to review BCM 95-1, *Epoxy – General*, and its Attachment 1, *Information and Instructions for Epoxy Use*. It is important to emphasize the need for a clean and sound substrate, suitable repair material, proper curing, and protecting the concrete while it sets (i.e., gains sufficient compressive strength); these factors are critical for constructing a durable repair. Accordingly, verify the repair material meets all contract requirements; seek METS Rep assistance as needed.

5-7.02 Refinishing Bridge Decks

On bridge rehabilitation projects, bridge barriers or sidewalks may need to be replaced, upgraded, or relocated. The tools used during the removal of bridge items (such as barrier or the sidewalk) will often leave a bridge deck surface uneven/rough and may require the deck to be refinished. Figure 5-36 shows an example plan sheet that describes the removal of the sidewalk and existing barrier, along with barrier replacement and refinishing of the bridge deck.

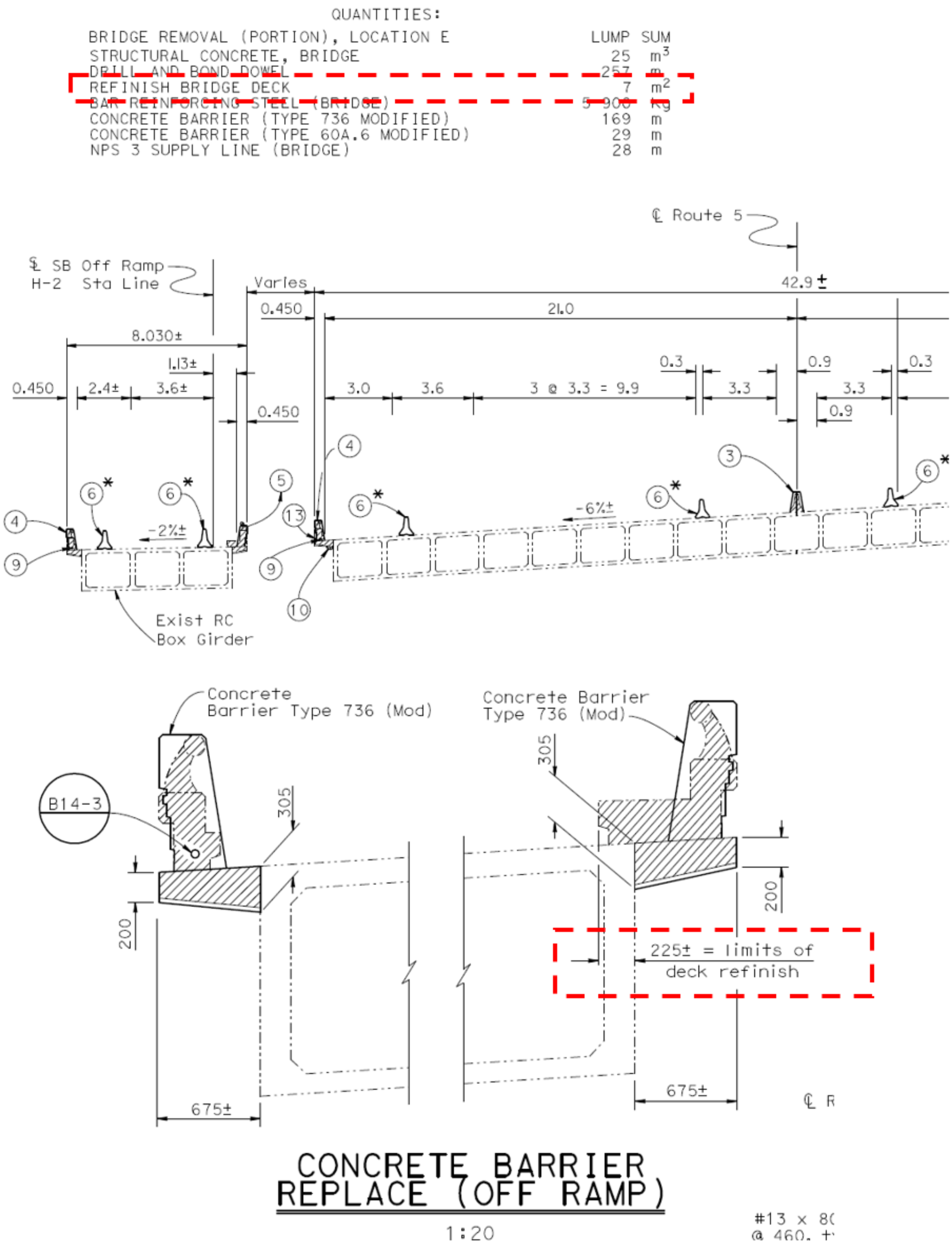


Figure 5-36. Contract Plan Showing Limits of Deck Refinish

Refinishing of the bridge deck may also be used to repair a new deck if the finished deck surface is too high or too low, and cannot be corrected by the typical grind and groove method. As an example, in 2023, a pedestrian overcrossing (POC) was constructed in District 4, city of Berkeley (Br. No. 33-0764, Gilman St. POC, EA: 04-0A7714). The POC bridge deck included closure pours that connected several spans of the bridge, as illustrated in Figure 5-37. After the closure pour was constructed, the bridge deck was surveyed, and it was determined that the bridge deck's vertical profile was out of compliance with the contract plans as well as the maximum allowable Americans with Disabilities Act (ADA) slope near the closure pour area. To correct the problem, the Contractor proposed a repair plan that included bridge deck grinding and refinishing at closure pour areas.

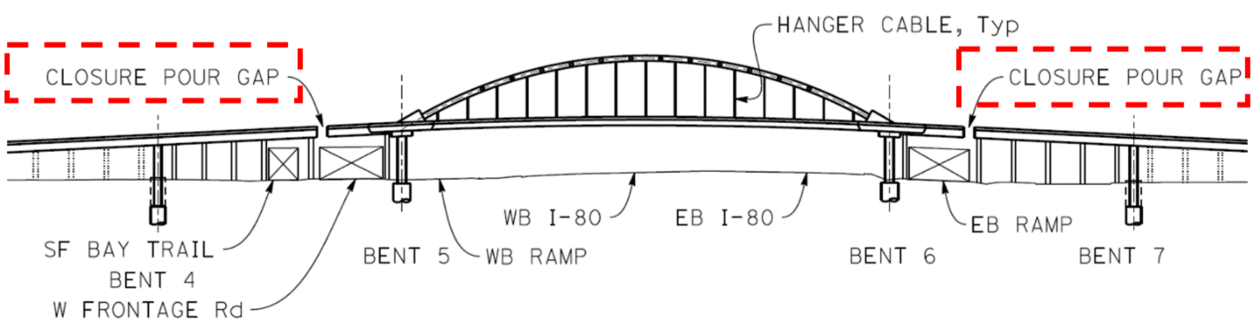


Figure 5-37. Pedestrian Overcrossing Bridge with Closure Pours

When bridge deck refinishing is shown on contract plans or when needed to repair a new bridge deck, *Standard Specifications* Section 60-4.02, *Existing Structures – Modifying Structures – Refinishing Bridge Deck*, contains requirements that must be complied with. We will briefly describe the bridge deck refinishing work here and will provide relevant sample project work; however, SC staff must refer to the aforementioned specification for the latest and complete details of the contract requirements. In refinishing the bridge deck, a 3/4-inch-deep saw cut must be made around the perimeter of the deck to be refinished; then the concrete in areas to be refinished is to be removed to a depth of approximately 3/4 inch. Concrete removal is usually accomplished with handheld pneumatic impact tools; however, if the defective area covers a large portion of the deck surface, the use of power-scarifying equipment may be appropriate. The removal must not damage the concrete that is to remain, and the removal methods must be authorized. After the removal, the area to be resurfaced must be thoroughly clean, dust-free, and free of deleterious material. This is accomplished by abrasive blasting and cleaning by vacuuming and blowing using oil-free air. See Figure 5-38 for a sample project photo of concrete removal during bridge deck refinishing; this happens to be the same bridge as in the preceding figure.

Figure 5-38. Concrete Removal During Bridge Deck Refinishing

Per *Standard Specifications* Section 60-4.02B, *Materials*, these areas are to be restored with the placement of portland cement concrete or placement of rapid setting concrete. Please refer to the above-mentioned specification for complete material requirements. Also, *Standard Specifications* Section 60-4.02C(2), *Construction – Placing Portland Cement Concrete,* or Section 60-4.02C(3), *Placing Rapid Setting Concrete,* provide additional material requirements depending on the final selection of the type of concrete used for refinishing.

When the Contractor is performing the removal of existing items (barriers, sidewalks, etc.), SC field staff needs to verify:

1. The perimeter of the work is saw cut ¾-inch deep.
2. The depth of concrete removal is also ¾ inch from the intended finish surface.
3. All dowels (such as any barrier or sidewalk vertical rebar into the bridge deck) are cut off to 1 inch below the existing deck surface or at the bottom of concrete removal, whichever is lower.
4. Existing concrete to remain in place is not damaged.
5. Traffic is shielded from dust and residue during the removal.
6. The existing reinforcement is protected.

When refinishing bridge decks, much of the inspection work for concrete placement is the same as for new construction. SC staff need to read BCM 51-1.03C-D, *Concrete Structures – General – Construction – Preparation and Placing Concrete*. In addition, they must also review BCM 51-1.03E, *Concrete Structures – General – Miscellaneous Construction*. It is important to emphasize the need for a clean and sound substrate, suitable repair material, and protecting the concrete while it cures (i.e., gains sufficient compressive strength); these factors are critical for constructing a durable repair. Accordingly, verify the repair material meets all contract requirements; seek METS Rep assistance as needed.

5-7.03 Bridge Deck Treatment and Overlays

As the deck deteriorates, the need to maintain a smooth riding surface and the required load-carrying capacity will become increasingly important highway planning considerations. In some parts of California, the application of deicing salt has exacerbated the deck deterioration; corrosion of embedded reinforcing steel causes undersurface delamination at the level of the top mat of steel, and eventually the deck itself. Although the use of epoxy-coated bar reinforcing steel has provided an additional level of corrosion protection, California has many hundreds of structures in freeze-thaw areas that were built before epoxy coating. All these structures have chloride-contaminated decks and some degree of corrosion damage. To mitigate the adverse effects of corrosion damage, California began a deck rehabilitation program in the early 1970s.

As a rehabilitation strategy, the objective of a deck treatment and overlay is to extend the service life of an existing bridge deck at a significantly lower cost than total deck replacement. The ideal overlay will completely restore the bridge deck riding surface with a strong, durable material, and provide sufficient additional protection to the existing deck reinforcing steel; it also needs to be constructed of materials that are relatively easy to produce and place. Efforts include methacrylate deck treatment, asphalt concrete (AC), conventional portland cement concrete, and polyester concrete overlays. Although AC overlays have been successful in restoring the deck-riding surface, they have a relatively short service life and can hide problems with the deck. As such, AC overlays are not widely used on Caltrans bridge decks. Concrete, in general, will provide a durable riding surface, but many concrete systems are not completely impervious and thus cannot prevent future corrosion of the deck reinforcement. Today, the preferred deck treatment is with methacrylate resin to fill surface cracks, and polyester concrete overlays that provide bonded wearing surfaces and can also serve to correct the bridge profile/slope.

5-7.03A Prepare Concrete Deck Surface

Before continuing with the discussion of bridge deck rehabilitation and repair methods (such as methacrylate resin placement or overlay), a brief discussion about bridge deck surface preparation is warranted. Before performing any deck repair, SC staff are reminded to read Section 5-5.01, *Removal of Unsound Concrete*, provided earlier in this chapter. The requirements for this work are found in *Standard Specifications* Section 60-3.02C(7), *Existing Structures – Structure Rehabilitation – Bridge Deck Repair and Preparation – Construction – Prepare Concrete Deck Surface,* and include the need for the bridge deck surface to be prepared before performing repairs such as deck treatment or overlay. The purpose of preparing a bridge deck is to have a concrete surface that is dry, clean, and free of laitance, surface contaminants, and foreign materials. The specifications state that the bridge deck must be abrasive blasted with steel shot, cleaned by vacuuming, and blown by high-pressure oil-free air. Please refer to the specification for the complete and latest requirements. The specifications also state that if the surface becomes contaminated before placing the deck treatment or overlay, the deck needs to be cleaned again.

In general, abrasive blasting can be done using sandblasting or steel shot blasting. At this time, it's worth pointing out the difference between these two types of abrasive blasting. Sandblasting is a cost-effective means of removing surface contaminants and weathered aggregate particles and will ensure a clean, sound substrate for deck treatment and overlay. However, sandblasting has several drawbacks. First, there is a large volume of residue that must be removed and disposed of. Second, it is often necessary to provide a protective barrier between the area being sandblasted and an adjacent lane open to public traffic. Finally, the dust generated by sandblasting a bridge deck is considered hazardous.

To mitigate some of the problems associated with sandblasting, the *Standard Specifications* requires the use of abrasive blasting with steel shot for the deck preparation work. Shot blasting equipment are self-contained units that use small-diameter (1/16 -inch) steel shot to abrade the concrete surface. The shot is continuously recycled, and the units include a dust collector to capture the concrete residue. Shot blasting is the most effective means of assuring a clean, sound concrete deck surface. Shot blasting equipment was originally developed to clean concrete floors before applying a protective coating; these were small units powered by electric motors and intended primarily for indoor use. Later, gas-driven units became available, and as technology improved, larger high-production shot blasters suitable for construction use were developed. These large units are now widely available, and the older, smaller units are not cost-effective for bridge work. When shot blasting, it is essential to use the appropriate equipment, otherwise the intended results will not be obtained. As an example, a small piece of equipment will not efficiently and effectively clean a large bridge deck.

When inspecting this work, SC field inspectors must read BCM 60-3.02, *Existing Structures – Structure Rehabilitation – Bridge Deck Repair and Preparation*.

For informational purposes, a discussion of alternative methods of concrete demolition will be included here. To take advantage of developing technology in the concrete demolition field, the use of hydro-blasting demolition equipment utilizing high-pressure water blasting jets has been specified for deck preparation work on selected projects since the early 1980s. While early efforts were only marginally successful, in recent years, hydro-blasting equipment has become increasingly more sophisticated, and units are now available that are capable of removing concrete to a preselected depth with little difficulty and without damaging the concrete remaining in place. When used for surface preparation, water blasting has the added benefit of removing unsound concrete at the same time, at little increase in total cost. Hydro-blasting equipment that is suitable for concrete demolition work may not be suitable for deck preparation. This is the case because hydro-demolition equipment is designed to remove large pieces of concrete by fracturing and spalling the concrete mass. Current specifications require demolition equipment with rotating or oscillating heads and a nozzle pressure of 30,000 psi. When the proper equipment is used, a water-blasted surface will expose sound coarse aggregate particles with excellent bonding characteristics. See Figure 5-39 for photos of hydro-blasting used on a bridge deck.

Figure 5-39. Hydro-blasting Demolition

Because of the normal distribution of coarse aggregate within a concrete mass, and because water blasting is not abrasive and therefore does not cut or fracture individual aggregate particles, a water-blasted surface will not be a smooth plane, but will appear relatively rough and irregular. For compliance with a depth-of-removal specification, results will be satisfactory if the measured depth to the mortar line is the specified depth, plus or minus 1/2 the diameter of the largest coarse aggregate particles. Water blasting has some disadvantages, notably the need for a water supply and the need to control surface runoff. Containing and removing surface runoff is an environmental concern and must receive adequate attention. Additionally, it is necessary to thoroughly wash down the water-blasted concrete before the residue dries and adheres to the exposed surface; otherwise, the surface must be abrasive blasted before the overlay is placed. Water blasting is also more expensive than roto-milling. However, from a quality control standpoint, the superiority of a water-blasted surface outweighs the disadvantages.

5-7.03B Methacrylate Resin Bridge Deck Treatment

Cracks can develop in a bridge deck throughout the life of a bridge. See Figure 5-40 for a photo of bridge deck cracks. Methacrylate resin bridge deck treatment can be used to seal cracks in a bridge deck that has deteriorated over time, or to repair a newly placed bridge deck. This treatment process is included in *Standard Specifications* Section 60-3.03B, *Existing Structures – Structure Rehabilitation – Bridge Deck Treatm*ent – *Methacrylate Resin Bridge Deck Treatment*.

Figure 5-40. Bridge Deck Cracks

Methacrylate is not a wearing surface but simply fills and seals cracks, preventing water from entering the concrete. Methacrylate flows by gravity into cracks as narrow as 0.02 inches wide. After setting, cracked concrete will be restored to 75-90 percent of its original strength. A METS program checked cored samples of methacrylate work; one of the cores is shown in Figure 5-41. The core on the left is shown under ultraviolet light, with the lighter blue color being the area penetrated by methacrylate. The core on the right of Figure 5-41 is the same core under regular lighting. Under regular lighting, it is difficult to see more than 3 inches of crack depth, but under ultraviolet light, the crack can be seen to have extended the full depth of the core.

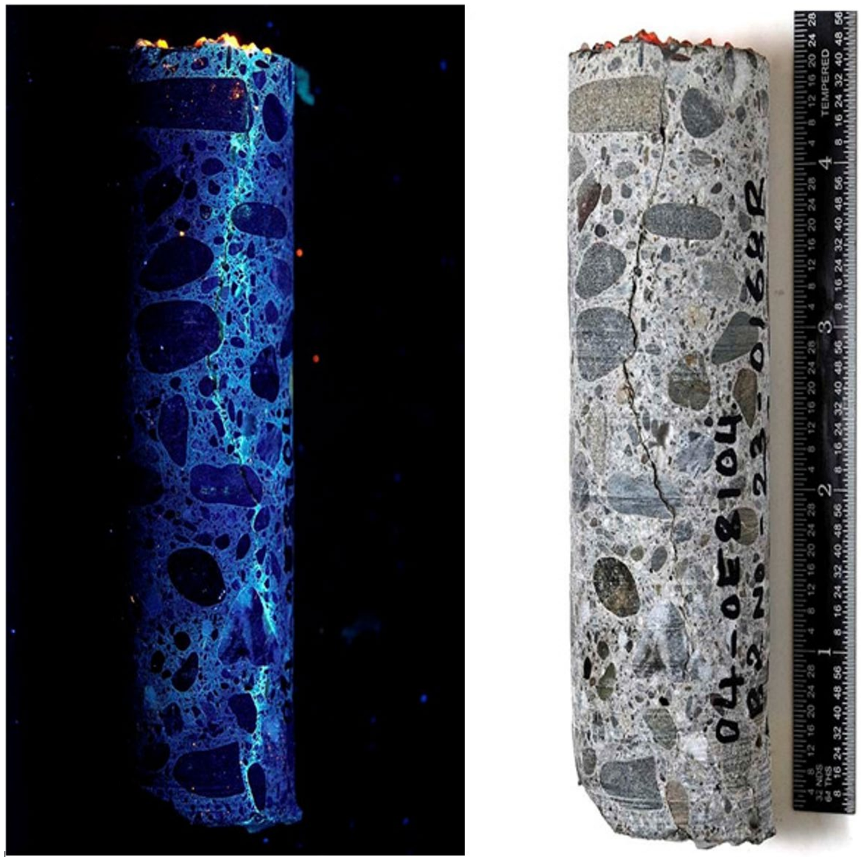


Figure 5-41. Methacrylate Treated Bridge Deck Cores

In a rehabilitation project, when methacrylate resin is used to treat a bridge deck, the contract plans will show this item of work, limits of work, material quantity to be furnished, as well as the quantity of deck area in square feet (SQFT) that needs to be treated. See Figure 5-42 for an example of a contract plan showing methacrylate resin bridge deck treatment.

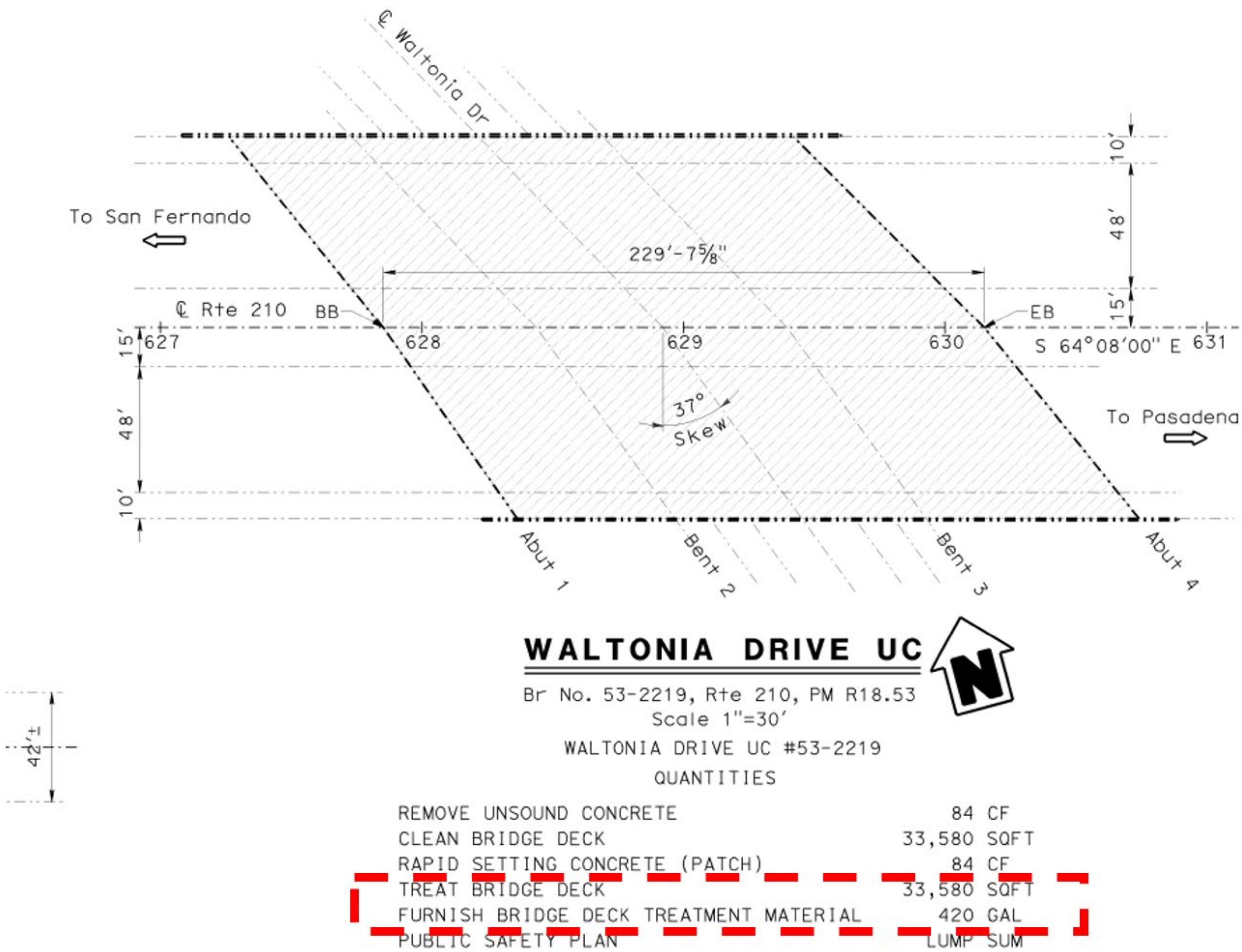


Figure 5-42. Bridge Plan with Bridge Deck Treatment Work

Similarly, a newly placed bridge deck might also develop cracks, and per *Standard Specifications* Section 51-1.01D(3)(b)(iv), *Concrete Structures – General – Quality Assurance – Department Acceptance – Testing Concrete Surfaces – Crack Intensity*, a completed deck is examined for cracks by the Engineer. Accordingly, the specifications state that if in any 500 sq ft portion of a new bridge deck surface, there are more than 50 linear feet of cracks having a width at any point of over 0.02 inch, the deck must be treated with methacrylate resin. Figure 5-43 illustrates two common tools that may be used to measure the width of cracks in concrete.

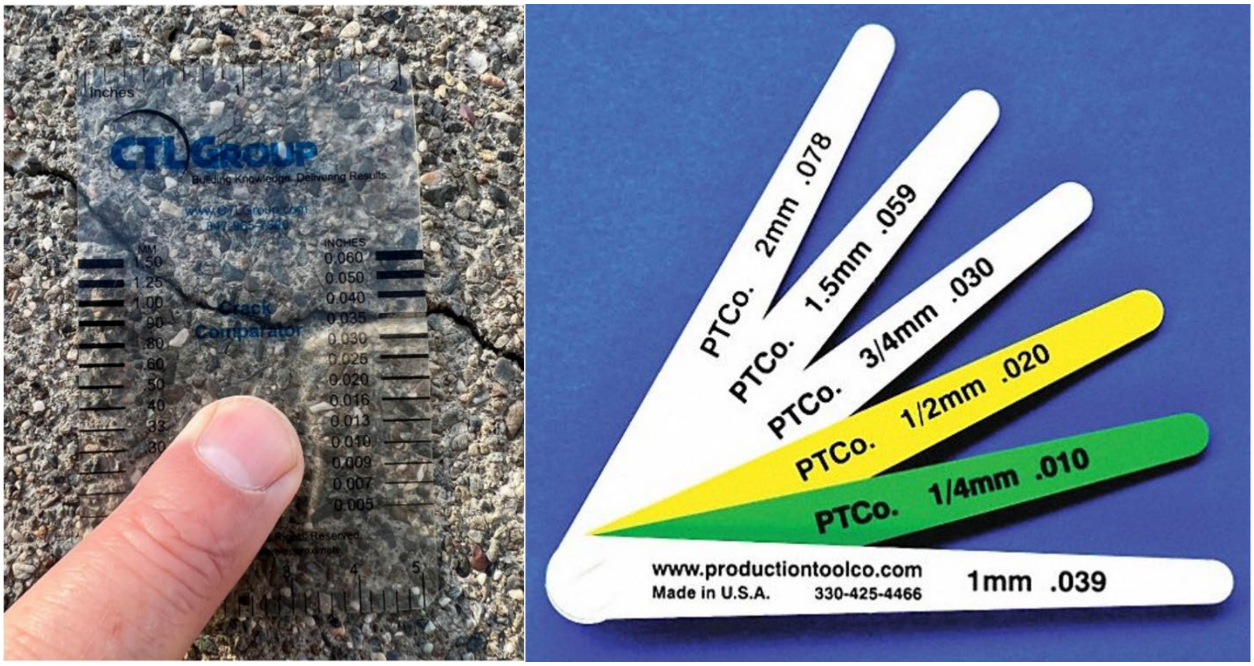


Figure 5-43. Tools used to Measure Cracks in Concrete

However, please note that a simple 0.5 mm lead pencil (i.e., 0.5 mm ≈ 0.02 inch) can also be used to verify if a crack exceeds the contract threshold limit; see Figure 5-44.

Figure 5-44. 0.5 mm Mechanical Pencil

When methacrylate resin bridge deck treatment is needed to rehabilitate or repair a deck, *Standard Specifications* Section 60-3.03B, *Existing Structures - Structure Rehabilitation – Bridge Deck Treatm*ent – *Methacrylate Resin Bridge Deck Treatment*, describes the requirements that must be complied with. This specification has several subsections, including *Submittals*, *Quality Assurance*, *Materials*, and *Construction*. All these subsections will be discussed, as methacrylate resin bridge deck treatment work is explained. However, SC staff are referred to the contract documents, including the *Standard Specifications,* for the latest and complete contract requirements.

Per *Standard Specifications* Section 60-3.03B(1)(c), *General – Submittals*, before the bridge deck can be treated by methacrylate resin, the Contractor must provide test samples of the methacrylate resin components. Methacrylate lots are tested by METS; test results are available through the Caltrans Data Interchange for Material Engineering (DIME[1]) database/website. The material tested must comply with the requirements described in *Standard Specifications* Section 60-3.03B(2) *Materials*, which include requirements for specific gravity, volatile content, viscosity, and several other characteristics. Please note that the lot number might be tagged under a different Expenditure Authorization (EA); in this case, you need to get the pertinent EA from the Contractor to be able to verify/obtain the report from DIME.

The Contractor must also provide the manufacturer's material safety data sheet (SDS) for each resin component and a work plan for applying the methacrylate resin treatment, per *Standard Specifications* Section 60-3.03B(1)(c), *Submittals*. As part of the work plan, the Contractor needs to provide a procedure for storing and handling resin components and absorbent material. Specifically, promoter (typically purple color) and initiator (typically clear color) are two components of methacrylate resin that warrant extra care in handling: if they come in direct contact, the reaction will result in a flash fire. It is very important that the Contractor stores, handles, and mixes the components in proper sequence per the manufacturer's latest information on their website and the SDS. In an example of how **not** to transport hazardous materials, Figure 5-45 includes a 250-gallon container of resin, 4-gallon boxes of initiator, and 5-gallon buckets of promoter. In the event of an accident, the materials in the truck bed could mix in a highly reactive manner. As part of the handling plan, the Contractor should explain how the materials will be safely transported.

Figure 5-45. Methacrylate Components

[1] Caltrans internal use only

As part of the work plan submittal, the Contractor must describe how they intend to perform the work including the description of equipment to be used (for applying the resin, applying sand, removing excess sand, etc.), schedule of work, range of gel time and cure time, as well as procedures for avoiding spills, cleanup of spills, and disposal of excess resins. Refer to *Standard Specifications* Section 60-3.03B(1)(c) *Submittals*, for a complete list of items that must be provided in the work plan. The specifications also require a test area before actual deck treatment, so that the Contractor can demonstrate under field operating conditions that the work can be completed on time and in compliance with contract specifications when the work is performed per the submitted work plan. If field conditions – such as materials in use or time of operation – are changed by the Contractor, another test area would likely be warranted. As part of the test area application, the contract *Special Provisions* will commonly require a Certified Industrial Hygienist to perform air quality testing. The air quality report must be accepted by the Structure Representative before the Contractor can proceed with the contractual deck treatment. Respirators are recommended when applying methacrylate, and physical contact with polymeric materials should be avoided. Refer to the material safety data sheets for decontamination procedures. The work area used for mixing methacrylate should include protective measures to contain material spills. If possible, the mixing should be done off of the traveled way.

To treat a bridge deck (and similarly the test area) with methacrylate resin, *Standard Specifications* Section 60-3.03(B)(3), *Construction* describes requirements that the Contractor must comply with. In general, the application of methacrylate on a bridge deck is a simple process. As a reminder, before a bridge deck can be treated with methacrylate, the deck must be clean and prepared per *Standard Specifications* Section 60-3.02C(7) *Prepare Concrete Deck Surface*. The deck must also be dry and the relative humidity must not be more than 85 percent during the work shift. The temperature of the concrete surface must also be from 50 to 100 degrees F. It is suggested to use an “Hourly Weather Forecast’” tool, such as one found within NOAA (National Oceanic and Atmospheric Administration) website, to view the forecast a few days in advance of upcoming work shifts and share any concerns with the Contractor prior to actual start of shift. In coastal areas, the relative humidity may often exceed the acceptable threshold during the night in late spring and early summer.

As discussed earlier, methacrylate consists of several components that must be mixed in a specific sequence and ratio specified by the manufacturer. The Contractor must not mix too much resin at a time, as it may begin thickening if an excessive amount is mixed and cannot be applied in a timely manner. Accordingly, the specifications limit the maximum amount of resin that can be mixed at a time to 5 gallons. After thoroughly mixing all the components, the resin is typically applied to the deck surface by hand or mechanically sprayed, and spread with a broom or squeegee. Applied materials should be pushed forward with a squeegee and the area swept with a broom to avoid material in grooved surfaces. It is a contract requirement that excess resin is removed from the textured indentations.

The application rate of resin is approximately 90 sq ft/gal, but will vary depending on the condition of the concrete surface and concrete density; the actual application rate can be between 60 sq ft/gal to 125 sq ft/gal. The width of the cracks or the intensity of cracks can significantly affect the rate of application. As a rule of thumb, to verify that the cracks are sealed, the surface above the cracks should be slightly wet with resin 20 minutes after application. This is an indicator that the cracks are filled. If dry after 20 minutes, increase the amount of resin being applied. If ponding is evident, reduce the amount of resin. The resin must remain fluid during application. Per specifications, if rapid gelling occurs, the material should be rejected.

The Contractor is required to protect or avoid placing resin on other parts of the structure not intended for treatment (e.g., barrier rails, joints, drainage facilities, etc.). The resin must not leak or drip into waterways, roadways, or parking areas below the bridge. Sealing of joints and scupper drains is one method to prevent this. Fresh methacrylate is slippery, like ice. Before the methacrylate sets, sand must be spread over the surface to increase friction for vehicles. Specifications state a minimum application rate of 2 lb/sq yd of sand or until saturation (as determined by the Engineer). Sand must adhere to the deck. Any areas found absent of sand adhesion must be abrasively blasted. An absorbent material also needs to be applied to prevent tracking of oily residue onto adjacent pavement. Some methacrylate resins include wax to limit odors and control cure time; this wax can lead to “tracking,” where vehicles leave methacrylate residue on untreated roadway surfaces. In situations where the wax might cause tracking or reduce friction, diatomaceous earth can be spread to absorb wax. After setting, excess loose sand and absorbent material need to be swept away.

Typical problems associated with bridge deck methacrylate resin treatment operations include:

1. **Oiliness**: The tack, or the oiliness, of methacrylate resin can create serious problems, especially in cold night closures. Opening traffic lanes prior to the complete cure of the resin can cause the tracking of residue, oiling of cars, and/or reduced skid resistance. This issue is due to oxygen inhibition of the top surface. Methacrylate resin cures from the lack of oxygen; thus, the exposed surface tends to cure last. Even if the bulk of the resin sets up and can resist penetration with a screwdriver, the surface can still be covered with an oily sheen. Modern methacrylate resins contain additives to prevent this phenomenon.
2. **Inability to spread material**: Heat and sunlight can cause methacrylate to set faster. Occasionally, the resin will set before the material is spread. This causes the worst case for crack sealing as it prevents the resin from properly flowing into the cracks.
3. **Sand does not adhere**: Resin that sets prior to applying sand will result in the creation of glassy spots. The glassy areas may have reduced skid resistance and remedial work to repair these areas would be required. Methods that have been proven effective are to abrasively blast the glassy areas. For larger areas where the sand was not promptly applied and did not adhere, resin and sand can be reapplied (time permitting).

It is a contract requirement that no traffic or equipment is allowed on the treated surface until:

1. The deck is tack-free and not oily.
2. Sand cover adheres and resists brushing by hand.
3. Excess sand and absorbent material have been removed.
4. No material will be tracked by vehicular traffic beyond the limits of the treatment.

When inspecting this work, SC staff need to read BCM 60-3.03B, *Existing Structures – Structure Rehabilitation – Methacrylate Resin Bridge Deck Treatment*. It is important to emphasize the need for a clean and sound substrate, suitable repair material, and protecting the treated area while it cures. Accordingly, verify that the repair material meets all contract requirements; seek METS Rep assistance as needed.

5-7.03C Polyester Concrete Overlay, Expansion Dams and Patches

Polyester concrete was first used as an overlay in California in 1983. A typical polyester overlay is shown in Figure 5-46. Polyester concrete and portland cement concrete (PCC) are similar in that both materials consist of aggregate and a binder. Where PCC initiates hydration with water, the polymeric reaction of polyester resin is initiated with a promoter and initiator.

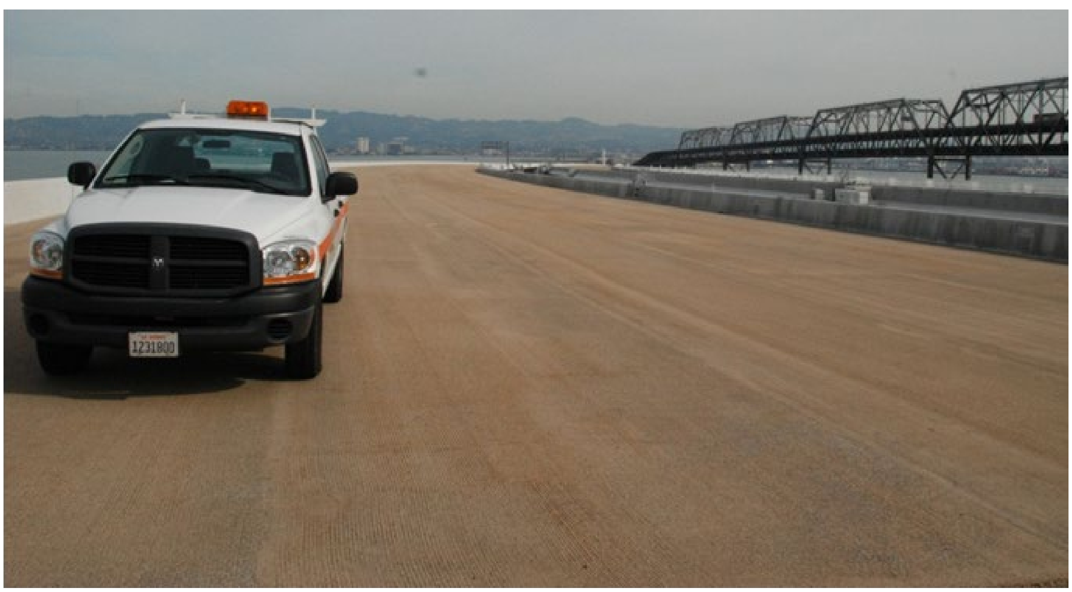


Figure 5-46. Newly Applied Polyester Concrete Overlay

The requirements for a polyester concrete deck overlay are found in *Standard Specifications* Section 60-3.04B, *Existing Structures – Structure Rehabilitation – Deck Overlays – Polyester Concrete Overlays;* Section 60-3.04C, *Polyester Concrete Expansion Dams* includes requirements for expansion dams.

Polyester concrete is a very durable composite material made of hardened polyester resin and aggregate. When compared to PCC with 750 pounds of cementitious material per cubic yard, polyester concrete has approximately twice the flexural strength and nearly equal compressive strength; in addition, abrasion loss is approximately 10 percent, and chloride permeability less than 1 percent of PCC. Please see Table 5-1 for a quick comparison of polyester concrete versus various concrete types.

Table 5-1. Side-by-Side Comparison of Polyester Concrete versus PCC

	Polyester concrete	**Portland cement concrete (8 sacks)**	**Latex-modified concrete**	**Silica-fumed concrete**
Compressive strength, psi	+6000	7,000	9,000	7,000
Flexural strength, psi	+1500	800	900	1,100
Abrasion (weight loss, grams)	1-2	15	14	9
Return to service	2-3 hours	5 days	4-5 days	2-4 days
Chloride permeability, coulombs	0-10	1,000	500	500

Earlier in the chapter (in Section 5-7.03, *Bridge Deck Treatment and Overlays*), it was stated that the main objective of overlays is to extend the service life of an existing bridge deck at a lower cost than total deck replacement. Accordingly, in bridge deck rehabilitation projects, the contract plans may specify polyester as the overlay material to be placed across the entire bridge deck to act as a new wearing surface and extend the life of the deck. See Figure 5-47. for an example of a contract plan sheet specifying the placement of polyester concrete on the entire bridge deck.

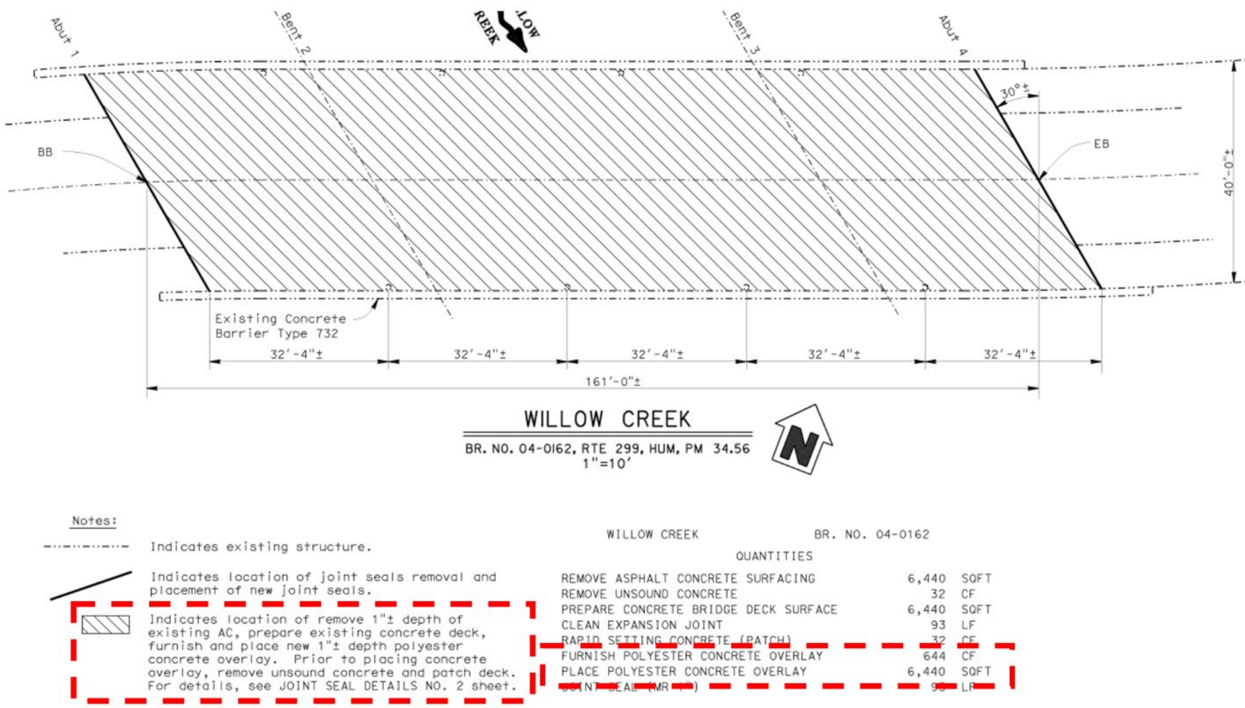


Figure 5-47. Bridge Plan Sheet with Polyester Overlay across Entire Deck

In addition to overlaying the entire bridge deck, on maintenance and rehabilitation projects, polyester concrete may also be used to correct part of the bridge deck surface to create a smooth roadway profile or contour and/or to achieve proper roadway drainage. The surface profile/contour correction might be needed in the longitudinal or transverse direction of the roadway. As an example, in the longitudinal direction, the deflection in the middle of the span of an old bridge can eventually exceed the initial camber built into the bridge due to long-term creep, and result in a sag in the middle of the span. Similarly, in the transverse direction, the bridge cross slope might have to be corrected for proper drainage when changes in roadway crown location are necessary due to median barrier relocation; see Figure 5-48. as an example. Accordingly, to obtain the desired deck surface profile/contour, the contract plans might require the placement of a polyester concrete overlay to create a thin new driving surface with proper profile smoothness and cross slope; see Figure 5-49 for an example of a deck cross slope correction achieved by polyester concrete.

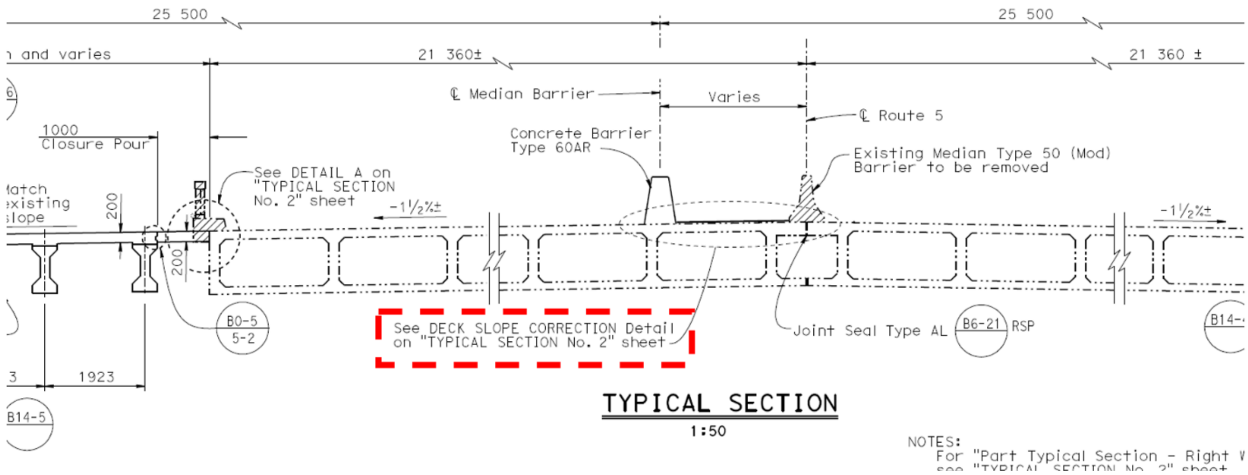


Figure 5-48. Example of Barrier Rail Placement near Deck Crown

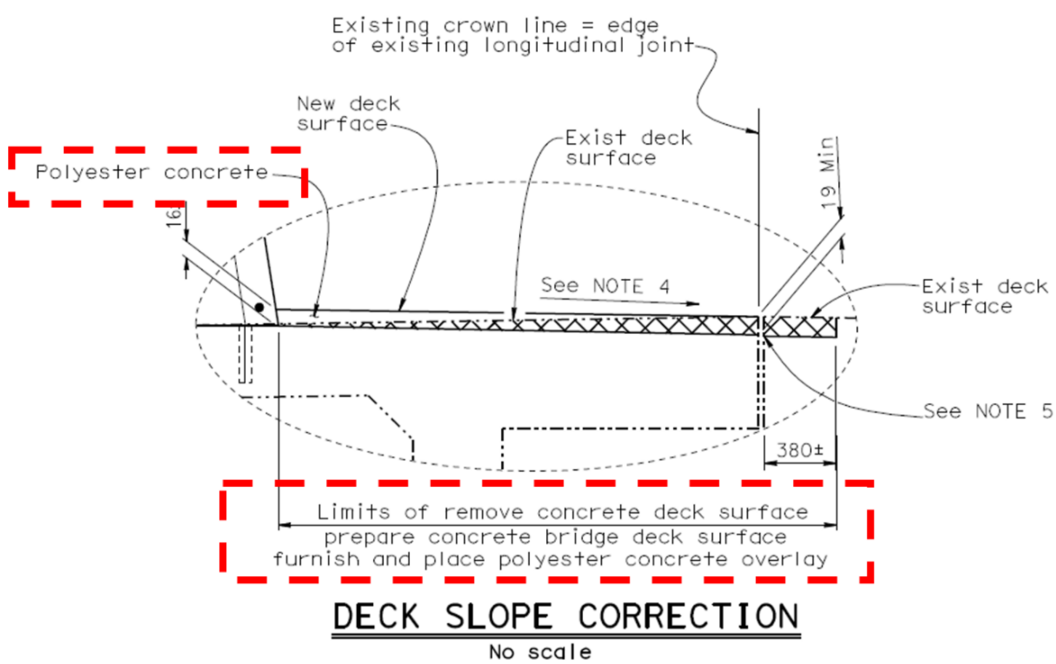


Figure 5-49. Polyester Concrete Overlay Used to Correct the Bridge Deck Cross Slope

Similar to existing structures, surfaces of new structures may also sometimes require correction to obtain a smooth traveling roadway surface and to achieve proper roadway drainage. It is worth noting that on some structures, the bridge deck/superstructure might consist of precast items, and the project special provisions may prohibit grinding of precast items. In such cases, the contract plans and special provisions might indicate the placement of polyester concrete overlay to obtain a smooth traveling roadway surface, as illustrated in Figure 5-50.

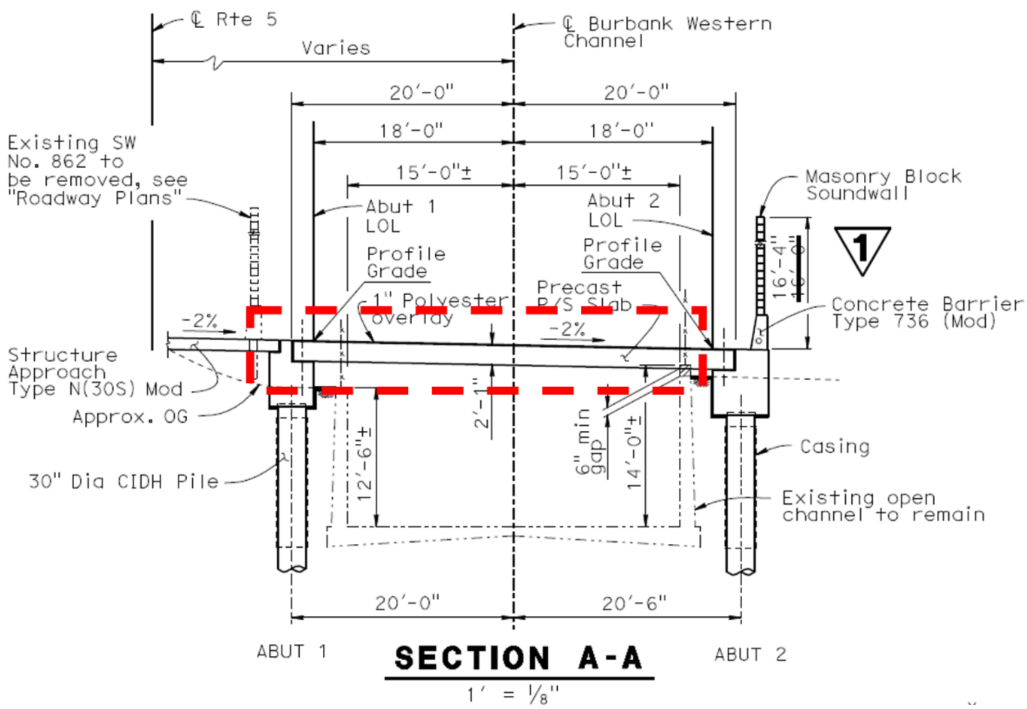


Figure 5-50. Polyester Concrete Used to Provide a Smooth Roadway Surface on a Precast Slab

The actual project photo for the above precast prestressed slab bridge is shown below, in Figure 5-51.

Figure 5-51. Photo of Bridge from Figure 5-50

Also, per *Standard Specifications* Section 51-1.01D(3)(b)(ii), *Concrete Structures – General – Quality Assurance – Department Acceptance – Testing Concrete Surfaces – Surface Smoothness*, roadway smoothness is typically achieved by grinding the high points. However, per the aforementioned specifications, grinding is limited by the minimum allowed rebar clearance of 1.5 inches. In other words, if the deck was constructed with 2 inches of concrete cover, and the high points are greater than 0.5 inches, grinding might reduce the rebar clearance to less than 1.5 inches. In such cases, when grinding alone is not sufficient to obtain smoothness, a polyester concrete overlay can be a suitable solution that might be described in the Contractor's repair plan. In general, when there are shallow depressions/voids in the deck, or when a thin layer of durable wearing material is needed, placement of a polyester concrete overlay material is often a suitable repair solution.

The above paragraphs described specific examples when the placement of polyester concrete overlay is an appropriate repair method for rehabilitating an existing bridge deck or repairing a new bridge deck. Polyester concrete can also be used as a patching material and as expansion dams when replacing joint seals. See Figure 5-52 below for typical plan details when using polyester concrete as an expansion dam.

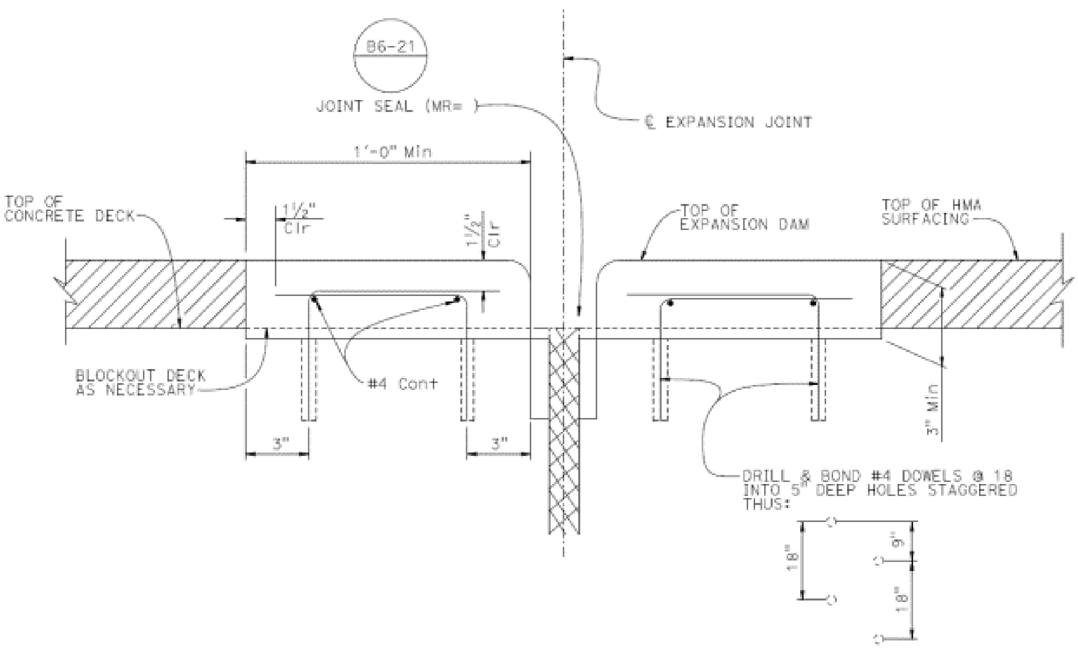


Figure 5-52. Polyester Concrete Expansion Dam

When polyester concrete overlay is used to rehabilitate or repair a bridge deck, the aforementioned *Standard Specifications* Section 60-3.04B*, Polyester Concrete Overlays*, describes the requirements that the Contractor must comply with. As polyester concrete overlay work is described, applicable specifications will also be highlighted. However, the reader is referred to the contract documents for complete requirements.

Per *Standard Specifications* Section 60-3.04B(1)(c), *General - Submittals*, before the bridge deck can be overlaid with polyester concrete, the Contractor must provide test samples of methacrylate resin, polyester resins, and aggregates with a certificate of compliance and manufacturer's test results at least 15 days before use. Materials are tested by METS and test results are available through the Caltrans DIME website. The material tested must comply with the requirements described in *Standard Specifications* Section 60-3.04B(2), *Materials*.

It is worth looking at the material requirements to gain a better understanding of polyester concrete behavior. Per contract requirements, polyester resin must have a minimum elongation of 35 percent and a minimum tensile strength of 2500 psi when tested per ASTM D638. In other words, the resin not only has a high tensile strength (when compared to concrete), but it is also ductile (i.e., not brittle like glass) when compared to other ductile materials such as steel, which has an elongation of about 15 percent at breaking. Another requirement for the polyester resin is that its specific gravity needs to be between 1.05 and 1.10. In other words, polyester resin weighs only slightly more than water for the same volume. When looking at the requirements for aggregates, the same quality requirement as for normal PCC can be seen, except that the fine aggregate must consist of natural sand. The aggregates must be very dry (absorption less than 1 percent) and have a moisture content less than half the absorption. It can also be seen from the gradation requirement that the specifications only allow “3/8 maximum aggregate” or “No. 4 maximum” size aggregate; the small size maximum aggregate allows for the placement of a thin overlay of polyester concrete.

Per *Standard Specifications* Section 60-3.04B(1)(c), *Submittals*, the Contractor must provide SDS for each component of methacrylate and polyester concrete. The Contractor must also provide a work plan for the placement of the deck overlay that includes the method of storage and handling of the components. There is a risk of flash fire during the handling and storage of components for both methacrylate and polyester. Refer to the previous Section 5-7.03B, *Methacrylate Resin Bridge Deck Treatment,* for additional information about this risk and what the Contractor must do to mitigate it.

As part of the work plan submittal, the Contractor must describe how they intend to perform the work. This includes:

1. The description of the equipment to be used
2. Schedule of work
3. Cure time
4. Procedures for avoiding and cleaning up spills
5. Disposal of excess resins and polyester.

Refer to the submittal specifications cited above for a complete list of items that must be provided in the work plan. *Standard Specifications* Section 60-3.04B(1)(d), *Quality Assurance,* also requires a trial polyester concrete overlay. This allows the Contractor to demonstrate under field conditions that the work can be completed on time and in compliance with the contract. Figure 5-53 is a photo of a trial polyester concrete overlay over a concrete slab.

Figure 5-53. Trial Polyester Concrete Overlay of a Slab

The Contractor must describe in their submittal how they intend to block out and isolate joint seals and drainage inlets to prevent the methacrylate and polyester concrete from entering; see Figure 5-54 for an illustration of this.

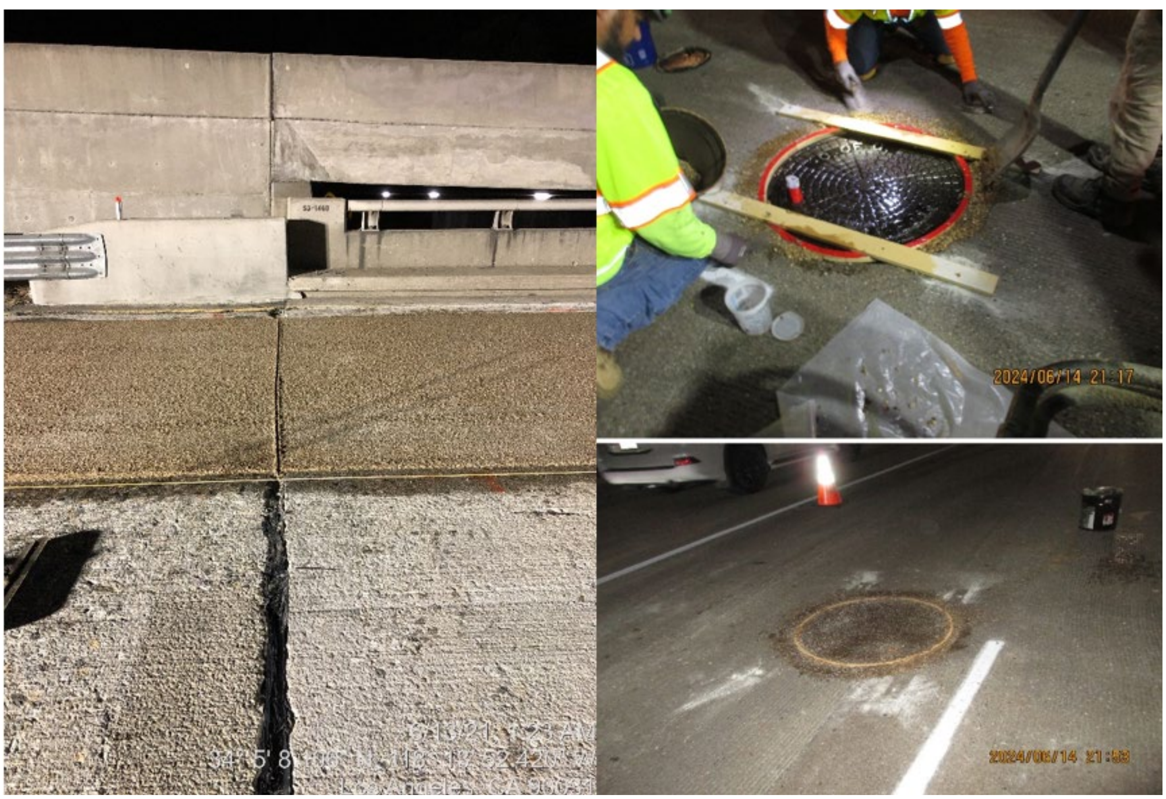


Figure 5-54. Photo of Joint and Manhole Blocked out and Isolated

Respirators may be required when applying methacrylate primer; all personnel should be fitted with and possess respirators while on the job site and comply with the Code of Safe Practices and the *Caltrans Employee Safety Manual*[1] on use of the same. SC staff are to avoid contact with polymeric materials. Refer to the safety data sheets for decontamination procedures. The work area used for mixing materials should include protective measures to contain spills. For methacrylate, if possible, the mixing should be done off of the traveled way.

In general, the construction sequence for the placement of the polyester concrete is as follows:

1. Set up lane/ traffic control
2. Identify & remove unsound concrete
3. Deck preparation (shot blast deck)
4. Block out joints and drainage inlets
5. Clean deck
6. Set grade control
7. Apply methacrylate primer
8. Mix and place polymer concrete
9. Saw cut overlay over joints
10. Sweep deck
11. Pick up grade control
12. Remove traffic control and open to public.

Much of the preparatory activities for polyester overlay, such as removal of unsound concrete, deck preparation, deck cleaning, and applying methacrylate, were discussed in previous sections.

Per *Standard Specifications* Section 60-3.04B(3)(b), *Construction – Placing Methacrylate Resin*, the bridge deck must be clean and dry when the methacrylate primer coat is placed. The concrete surface must also be from 50 to 100 degrees F, and the relative humidity must not exceed 85 percent. If magnesium phosphate patching materials are used, there must be a 3-day wait before proceeding with the overlay. Polyester overlays will not bond to dirty or wet bridge decks; they will also not bond to freshly placed mag-phosphate patches. Figure 5-55 is an example of a polyester concrete overlay failure attributed to inadequately applied material (1/4 inch instead of a 1-inch thickness), placed over a wet surface.

[1] Caltrans internal use only

Figure 5-55. Thin Layer of Polyester Concrete Overlay that Failed

Per *Standard Specification* Section 60-3.04B(3)(c), *Construction – Placing Polyester Concrete,* after the application of the methacrylate prime coat, polyester concrete must be placed **immediately** on the bridge deck. It should be noted that other DOTs have different time requirements for when polyester concrete can be placed after the application of methacrylate primer, and this might create confusion for out-of-state Contractors.

The placement method of polyester concrete has evolved over the years. The first polyester concrete overlays were placed as a multilayer system, also called the "Broom and Seed Method", where a layer of polyester was spread over the bridge deck, followed by a layer of aggregate. The process continued until the specified thickness was developed. This placement method was also called the "Drop-In" or "Brookhaven Method". Per *Standard Specifications* Section 60-3.04B(3)(c), *Placing Polyester Concrete,* the current practice is to premix polyester resin and the aggregate in a volumetric truck as shown in Figure 5-56 and Figure 5-57. This method was originally developed in the 1970's by Oregon DOT and later modified by Caltrans. As such, this method is known as the "Pre-mix" or "Oregon Method".

In the past, there have been misunderstandings about the different types of equipment used for making and dispensing polyester concrete. It is worth noting that this equipment can be labeled/described in the following three ways:

1. "Continuous mixer" by the *Standard Specifications*
2. "Volumetric proportioning plants" (i.e., commonly known as "volumetric trucks") under [California Test](#) (CT) 109, *Method for Testing of Material Production Plants* (per specifications, mixers must be certified under CT 109).
3. "Mobile mixer" by the industry.

In other words, as the labels/descriptions imply, these premixing trucks measure the proportions of the polyester concrete components by volume, employ an auger screw to continuously mix the components, and are mobile while dispensing the material into the pavers. It should also be noted that the trucks need to be recertified every 6 months; Section (C) *Proportioning Systems Calibration and Approval,* of CT 109 states, "If the device, system, or control is not included in the current list, CT 109 should not be performed". For further information about the certification process and the current list of certified plants, refer to the Material Plant Quality Program.

Figure 5-56. Volumetric Operation (Note HAZMAT Placard ID # 1866)

Figure 5-57. Volumetric Operation (Note Display/Computer/Printout System)

Earlier, in Section 5-3, *Materials That Can Be Used for Concrete Repair*, the components of polyester resin were discussed, and the chemistry of polymerization was explained. For a quick reference, it is worth providing a brief description of each component for field identification and to summarize the purpose of each material, as follows:

1. **Styrene resin monomer**- This is a colorless liquid material. It is the building block of making the long-chain polyester resin polymer.
2. **Initiators**- They are also known as hardeners. They are either cumene hydroperoxide (CHP) or methyl ethyl ketone peroxide (MEKP). Both chemicals are colorless liquids. CHP is a flammable material. MEKP is a combustible and reactive liquid that may burn slowly at first, but after heating can burn violently and explosively. MEKP is a severe skin irritant and can cause progressive corrosive damage or blindness. This material starts the polymerization process by decomposing into free radicals (i.e., this material initiates the crosslinking of the resin). These materials are consumed during the reaction. It should be noted that some literature and at times even the industry incorrectly describe these materials as a catalyst; however, "initiator" is the appropriate term (see Wikipedia for additional information on synthetic resin).
3. **Promoter**- It is generally a metallic soap (i.e., metallic salt of fatty acid) such as cobalt naphthenate (CoN) or cobalt octoate (CoO). Cobalt naphthenate is a brown amorphous or bluish-red solid that is commonly used diluted in mineral spirits or mineral oil. Both are moderately toxic substances that can cause a range of acute and chronic conditions, and they are also carcinogens. Cobalt octoate (CoO) is a purple appearing liquid, which is flammable. Promoters are not consumed by the reaction; they are catalysts. Promoters can reduce the critical temperatures of peroxide initiators, thus forming free radicals at ambient temperatures.
4. **Additives**- In addition to the above three primary components of polyester resin, other chemicals can be added to fulfill a specific need. Below, a few of them will be discussed:
   a. Colorants may be added for aesthetic reasons.
   b. Antioxidant may be added to stop or slow oxidation.
   c. Accelerators are added to increase the rate of the polymerization process by enhancing catalyst activity. Without a catalyst, an accelerator would not affect the reaction rate. (See Promoter or Accelerators link for additional information).
   d. Wax specified to lower emission levels. Specifications currently limit the polyester resin binder static volatile emission to a maximum of 60 g/sq m.
      i. Refer to Rule 1162 SCAQMD, and paraffin wax BYK-S740 for additional information.

e. Silane coupling agent used to improve bond between polymer and mineral surfaces (i.e., aggregates).

To make polyester concrete, a volumetric truck continuously mixes the components per one of the following sequences, as illustrated in Figure 5-58 and Figure 5-59. As mentioned previously, be aware of the risk of explosion due to incorrect mixing sequence, as illustrated in Figure 5-60.

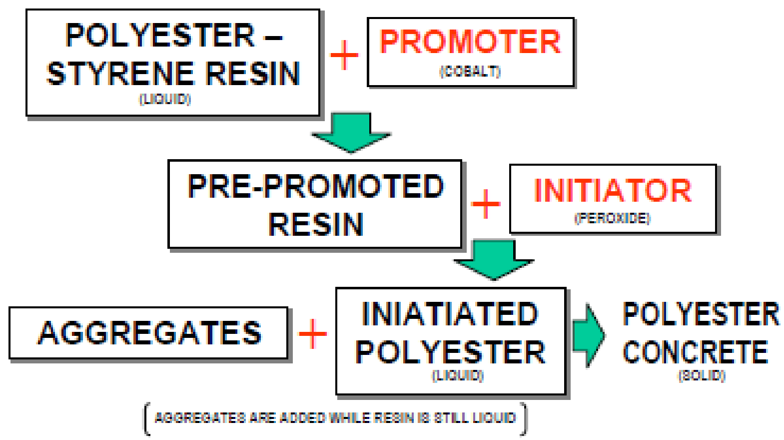


Figure 5-58. A Sequence Used to Produce Polyester Concrete

Alternatively, the following sequence might be used:

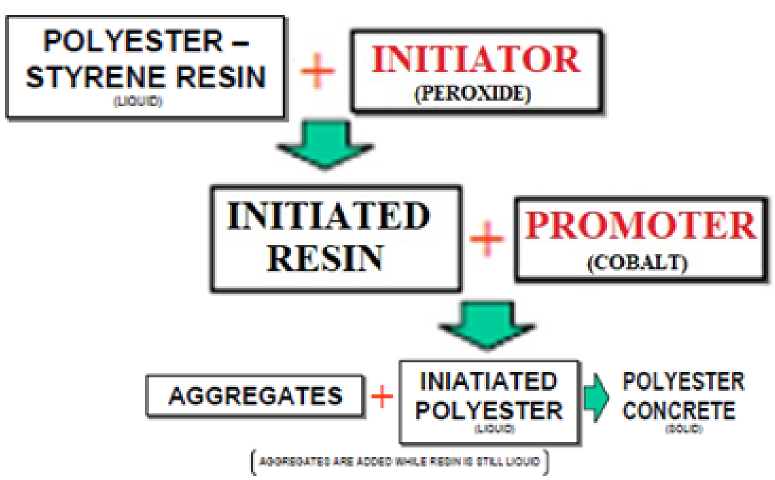


Figure 5-59. Alternative Sequence to Produce Polyester Concrete

Figure 5-60. Risk of Explosion Due to Incorrect Mixing Sequence

The free-radical process of polymerization (using initiators/promoter systems) is an independent reaction (that is, independent of the resin) where the peroxide is catalyzed by the cobalt. Consider the independent reaction between cobalt and peroxides - if they are combined directly, they decompose very rapidly, resulting in fire or violent thermal reaction. The resin is used to insulate or dilute this effect.

After the polyester concrete is premixed, it is dispensed from the mixer into a paver. Per contract requirements, the polyester concrete must be placed before gelling can occur and within 15 minutes of adding the initiator. Pavers accomplish the following tasks:

1. Provide a finished surface that is smooth and at the proper grade
2. Consolidate the polyester concrete.

In the past, to finish the polyester concrete, a “Texas Screed” may have been used for placing overlays; see Figure 5-61 below. This equipment was used when the bridge deck profile needed no correction (i.e., the thickness of the overlay was kept constant). Note that in the past, the term fixed or movable “ski control” was used, compared to current “skid-supported”. However, this equipment is no longer allowed per *Standard Specifications* Section 60-3.04B(3)(c), *Placing Polyester Concrete*, as stated in the following excerpts:

1. The use of fixed-height skid-supported strike-off equipment is not allowed; the equipment must be capable of adjusting for a variable thickness overlay. The equipment must have automatic screed controls and sensing devices that control the thickness, longitudinal grade, and transverse screed slope.
2. The equipment is not allowed to advance with a winch or a pulling device; the finishing equipment must be self-propelled.

Figure 5-61. "Texas" Screed with Fixed Ski Controlled Grading

In addition to being self-propelled with automatic grade control, the finishing machine must be at least 12 feet wide. Since a traffic lane is also 12 feet wide, this allows for overlaying a complete traffic lane without a seam. Figure 5-62 shows an example of a paving machine that is self-propelled and has automatic grade control, meeting specification requirements. The finishing machine can be controlled in several ways to create a smooth surface. One method is by following a smooth profile/elevation given by the Engineer (as an example, a smooth string line can be created based on the Engineer's elevation, and the machine can follow the string line). The following figure illustrates an example of a laser-guided screed that is used to follow a smooth profile in creating the polyester-finished surface.

Figure 5-62. Paving Machine with Laser Guided Screed

Alternatively, the Engineer can simply provide the minimum requested polyester thickness and allow the finishing machine to automatically adjust the grade to create a smooth finished polyester surface. See Figure 5-63 below for an example of a self-propelled paving machine with movable (i.e., not fixed) ski control.

Figure 5-63. Sample Paving Machine with Automatic Screed Control

Using the above method, even when the underlying surface is not even, the machine can still provide a very smooth surface; see Figure 5-64 for a picture of the finished surface.

Figure 5-64. Completed Paving Surface using Appropriate Paving Machine

When placed, the polyester material must achieve 97 percent compaction in accordance with California Test CT 552, *Method of Test for Relative Compaction of Polymer Concrete Utilizing Nuclear Gages*. Proper compaction and resin content are physically indicated by a surface sheen, which occurs when resin rises to the surface. After the placement of the polyester concrete by the paving machine, the surface must be textured by longitudinal tining and sand must be applied before gelling occurs; this is done to achieve a surface coefficient of friction of at least 0.35, as required by the contract specifications.

After the initial cure of the polyester concrete, all joints are sawcut. The specifications do not provide a set time of when the polyester concrete must be sawcut. The time of saw cutting will be dependent on temperature and other factors affecting the setting of the polyester concrete, which can typically range from 30 to 90 minutes. The Contractor needs to determine the time so that the saw cutting does not cause random cracking and raveling.

The Contractor needs to protect the overlay from moisture and not allow traffic or equipment on the overlay per the following:

1. For a minimum of 4 hours cure time after final finishing.
2. Until each rebound test result for the final finish shows a reading of at least 28 when tested under American Society for Testing and Materials (ASTM) C805.

The cure time must be extended if ordered. The rebound test may not be used to reduce the 4-hour cure time of the overlay.

When inspecting this work, SC field inspectors need to read BCM 60-3.04B&C, *Existing Structures – Structure Rehabilitation – Deck Overlays – Polyester Concrete Overlays and Expansion Dams*. It is important to emphasize the need for a clean and sound substrate, suitable repair material, and protecting the treated area while it cures. Accordingly, verify the repair material meets all contract requirements; seek METS Rep assistance as needed.

As with every inspection, SC field staff need to prepare before the start of the field work. However, for polyester overlay work, more than the usual amount of preparation is required. Below is a quick (not comprehensive) list of items that SC staff need to prepare for:

1. Safety- Inspectors need to read and understand Caltrans' and Contractor's Code of Safe Practices (COSP).
2. Respirators are required for all Caltrans employees when working within 50 feet of the polyester concrete operations. Avoid physical contact with the materials; if contact occurs, treat according to the material safety data sheet for decontamination.
3. Have appropriate personal protective equipment (PPE) including mask, eye protection, etc.

4. Verify that the Contractor is prepared to clean up accidental material spills or splatters (keeping in mind these materials are sticky and not easily washable by water)
5. Review the plans and submittals. Understand the Contractor's plan.
6. Locate any drainage inlets and/or joint seals.
7. Provide sufficient prior notice to METS for testing.
8. Verify that equipment(s) is calibrated (per CT 109).
9. Provide the polyester overlay finish grade.

SC field staff also need to verify that an acceptable trial overlay has been completed and-authorized prior to the start of actual overlay work. It is very useful if the same SC field staff(s) inspect both the trial and the actual overlay work; this will allow SC staff to become familiar with the Contractor's placement operation before the start of the actual overlay, and to resolve any questions and concerns in a timely manner.

When performing field inspection of this work, SC field staff need to be aware of the following required tests:

1. Test for air/deck temperature and humidity/dryness- Bridge deck and air need to be tested for temperature to verify compliance with the contract requirements and manufacturer's specifications. The air humidity must also be tested, and the deck surface must be verified to be dry.
2. Test for airborne emissions- If contract documents require airborne emissions monitoring, SC staff need to verify that a Certified Industrial Hygienist is present during polyester placement to monitor the air.
3. Test for the strength of the concrete – If a new bridge deck or approach slab is overlaid, SC field staff need to verify that the concrete has reached the required strength before polyester overlay can occur; this is accomplished by making and testing concrete cylinder samples. However, the time needed for concrete to reach a specified strength often cannot be determined exactly. As a result, typically a sufficient number of concrete cylinders need to be made so that if concrete cylinder test results fail to meet required strength (after an estimated curing time), there are additional concrete cylinders for testing later, to allow the concrete to cure and gain further strength.

   In order to assist in this process and minimize the number of cylinders to make, there is a tool called a Schmidt hammer that can be used. A Schmidt hammer, as illustrated in Figure 5-65, can be used as a nondestructive test (NDT) for concrete strength. However, *Standard Specifications* Section 90, *Concrete*, does **not** reference using this tool (due to the limited accuracy of this testing method). As such, the Schmidt hammer test is for reference only. Additional testing will be needed to verify the actual strength of concrete (for compliance with strength requirements in section 90) when the results from Schmidt hammer testing might suggest sufficient concrete test strength has been achieved. In other words, this tool can be used to make a preliminary assessment of the concrete strength before making the required and conclusive test, using concrete cylinders.

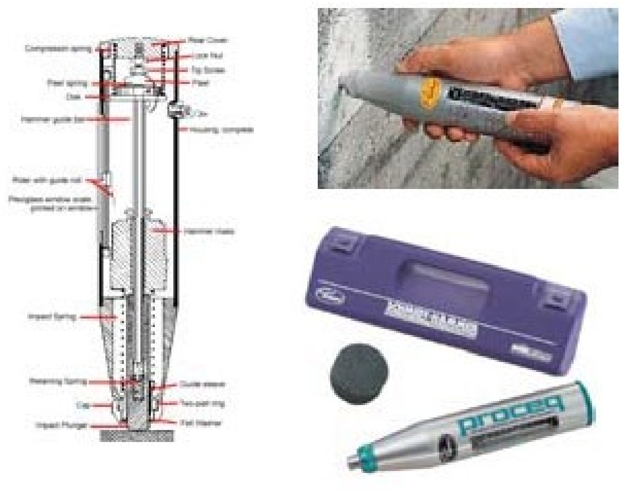


Figure 5-65. Schmidt Hammer

4. Testing for compaction- As previously mentioned, when the polyester overlay is being placed, SC staff need to verify that it is compacted to 97 percent per California Test (CT 552). The relative compaction test must be taken immediately after the polymer concrete has been placed and finished, and before any surface sanding or texturing. Resin flushed to the surface is usually a good indication of adequate compaction. If required corrective actions do not result in higher compaction numbers and the overlay appears to be compacted, coring, or pull-out testing (as shown in Figure 5-66) may be necessary.

Figure 5-66. Illustration of a Pull-out Test

5. Pull-out test cores- Test cores as shown in Figure 5-67 should be examined for uniformity from top to bottom. Unit weight should be investigated.

Figure 5-67. Pull-out Test Cores

6. Test for friction- SC staff need to arrange for the coefficient of friction test, CT 342, *Method of Test for Surface Skid Resistance with the California Portable Skid Test*. Refer to BCM 51-1.01, *Concrete Structures – General*, for details of skid testing.
7. Schmidt hammer testing- Per ASTM C805, a Schmidt hammer test of polyester concrete is required before traffic can be allowed on the polyester concrete overlay. A rebound reading of at least 28 is required per *Standard Specifications*, Section 60-3.04B(3)(c), *Placing Polyester Concrete*.

It is important to note that polyester concrete work is expensive. SC staff inspecting this work need to verify that polyester is placed within the limit shown on the contract plans. For polyester concrete work, there are two contract items: one item is for furnishing the material, and the other is for placing the polyester. The item for placement is a final pay item and cannot be adjusted without creating a Change Order. As a result, to avoid changes to pay items, SC staff need to verify that the limit of work is not changed. For material furnished to the job site, it should be noted that the pay item is field measured and subject to adjustment of item if quantities exceed certain limits (set by the contract specifications). Accordingly, SC staff need to verify that the polyester surface grade provided to the Contractor will result in the thickness of polyester that complies with contract requirements, in an effort to avoid a pay item adjustment. To avoid disputes with the Contractor on the amount of polyester placed, SC field staff need to track resin quantities of material delivered to the job site. Resin is delivered in tank trucks in drums and is tagged at the source. Resin can be off-loaded from the tank truck into 500-gallon poly tanks for storage in the yard, as shown in Figure 5-68.

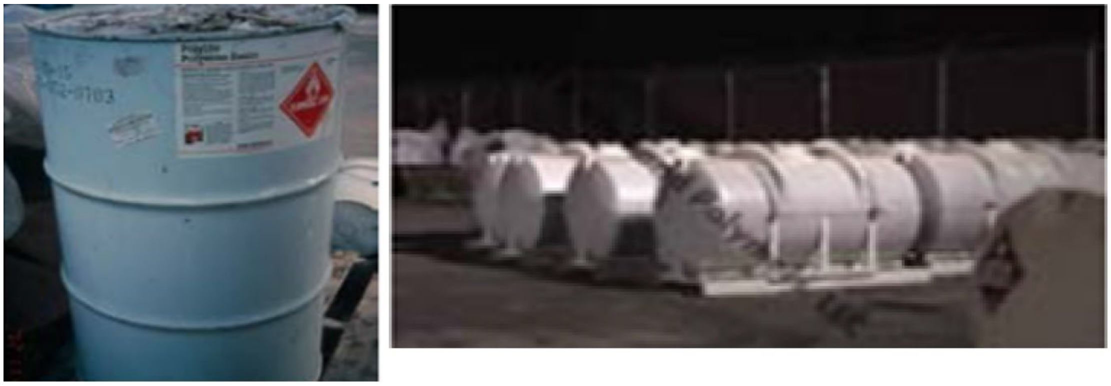


Figure 5-68. Resin Stored in Drums and in Poly Tanks

5-7.04 Portland Cement Concrete Overlays

During the late 1960s and early 1970s, California's construction strategy for new structures located in frost areas included deck protection consisting of a preformed or liquid membrane covered with a 3-inch asphalt concrete overlay. Where the approach pavement was concrete, the decks were depressed 3 inches to make the new deck surface (after placing the asphalt concrete (AC) overlay) match the pavement profile. When the membrane/AC systems reached the end of their service life (usually 10 to 15 years after installation), the repair strategy for those structures built with depressed decks included the use of conventional portland cement concrete to fill the space originally occupied by the AC overlay. Typically, the concrete used was a conventional air-entrained bridge mix with a cement content of 650 pounds per cubic yard, with minor modifications. The specified mix design provided 50 to 55 percent fine aggregate; the maximum size for coarse aggregate was 1/2 inch; the water-cement ratio was limited and a water-reducing admixture was required. Initially, the water-cement ratio was limited to 0.36, but this resulted in a stiffer mix than was considered desirable. More recent projects had specified a water-cement ratio of 0.40 maximum. Nominal reinforcing (epoxy-coated #3 bars at 12 inches on center in both directions) was provided, and the concrete was placed on an epoxy-bond coat. This successful rehabilitation technique for structures with depressed decks led to the use of conventional concrete overlays at other locations as well.

It is interesting to note that the first deck rehabilitation project in California, in 1968, included a 2-inch nominal concrete overlay placed on an epoxy-bond coat. The overlay concrete was a 7-sack air-entrained mix with pea gravel aggregate, and no special quality control measures were employed. Fractures below the overlay, which were either undetected when the overlay was placed or developed subsequently, were filled by epoxy injection in 1978. No other maintenance has been necessary; the deck-riding surface remains in good condition and the overlay shows no signs of failure, all of which indicates that overlay construction using conventional portland cement concrete may be a more viable rehabilitation strategy than most authorities once believed.

Portland cement concrete has many advantages for overlay construction. It is relatively inexpensive when compared to other rigid overlay materials, and it can be produced, delivered, placed, and finished using conventional equipment and procedures. While rehabilitation technology now favors thin polymer concrete overlays, portland cement concrete may at times be an appropriate choice.

When portland cement concrete overlay is used to rehabilitate a bridge deck, the contract plans will provide details of the concrete overlay work, including the limit of work, the amount of existing deck removal, the thickness of the overlay, and the material quantity. Figure 5-69 shows an example of contract plan details for a concrete overlay project.

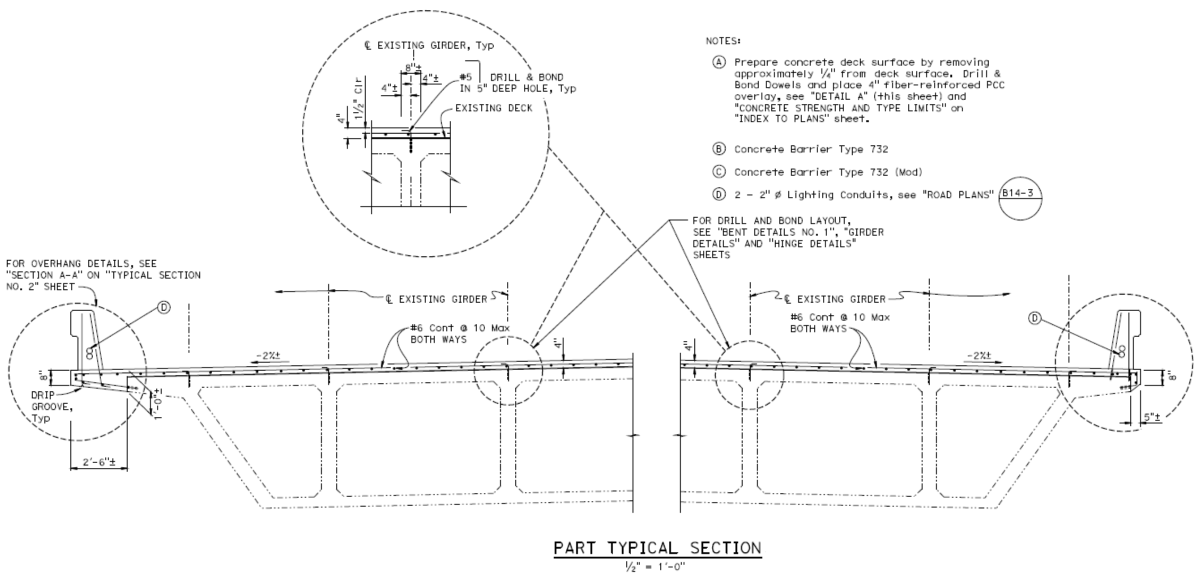


Figure 5-69. Sample Plan Detail of Concrete Overlay

Standard Specifications Section 60-3.04D, *Existing Structures – Structure Rehabilitation – Deck Overlays – Concrete Overlays*, describes requirements that must be complied with when performing this type of work. The specifications for this section are a mere 2 sentences long and reference Section 51, *Concrete Structures*. Similarly, a review of the *Contract Specifications* shows no additional requirements. Therefore, the main requirement for placing a concrete overlay is the same as placing concrete for other types of structural members. The requirements in Section 51, *Concrete Structures,* will not be covered; the reader is referred to the *Concrete Technology Manual* for further details on common concrete work. However, the contract *Special Provisions* might include unique and project-specific requirements. For example, here are some of project-specific requirements previously seen in the *Special Provisions* of concrete overlay projects:

1. Lowering of bridge load rating and special traffic load limit- depending on the amount of existing bridge deck removal, the load rating of the bridge may be reduced until the overlay concrete has gained sufficient strength.

2. Placement of temporary support- to avoid a reduction in load rating, after partial removal of existing bridge deck, the *Special Provisions* and contract plans might require placement of temporary supports.
3. Work plan submittal requirement- the Contractor might be required to provide a work plan to describe how they intend to perform the work, including equipment, schedule, and details of operation.
4. Requirement to construct trial overlay- the Contractor might be required to construct a trial overlay before performing the actual work. The purpose of the trial overlay is for the Contractor to demonstrate that, under field operating conditions, the work can be completed within the time constraints and in compliance with contract specifications.
5. Requirement to use “accelerated compressive strength”- the requirement for this type of concrete is different than for Rapid Strength Concrete. Careful planning, good preparation, being attentive, and quick thinking are all critical when using any type of concrete that rapidly gains compressive strength; there would be very little time to take corrective actions if any mistakes occur during concrete placement.

When inspecting this work, SC staff need to read BCM 60-3.04D, *Existing Structures – Structure Rehabilitation – Deck Overlays – Concrete Overlays*. It is important to emphasize the need for a clean and sound substrate, suitable repair material, proper curing, and protecting the concrete while it sets (i.e., gains sufficient compressive strength); these factors are critical for constructing a durable repair. Accordingly, verify the repair material meets all contract requirements; seek METS Rep assistance as needed.

5-7.05 Combining/Modifying Repair Methods

To rehabilitate or repair a bridge element, one or more repair methods might have to be used. For example, a bridge deck might have unsound concrete as well as small cracks. In such a situation, two repair methods would be used to rehabilitate a bridge deck; one repair would be to patch the bridge deck after all unsound concrete is removed, and the second repair would be to treat the same bridge deck with methacrylate to repair the cracks.

See Figure 5-70 for an example of a contract plan showing both rapid-setting concrete (patches) and methacrylate bridge deck treatment.

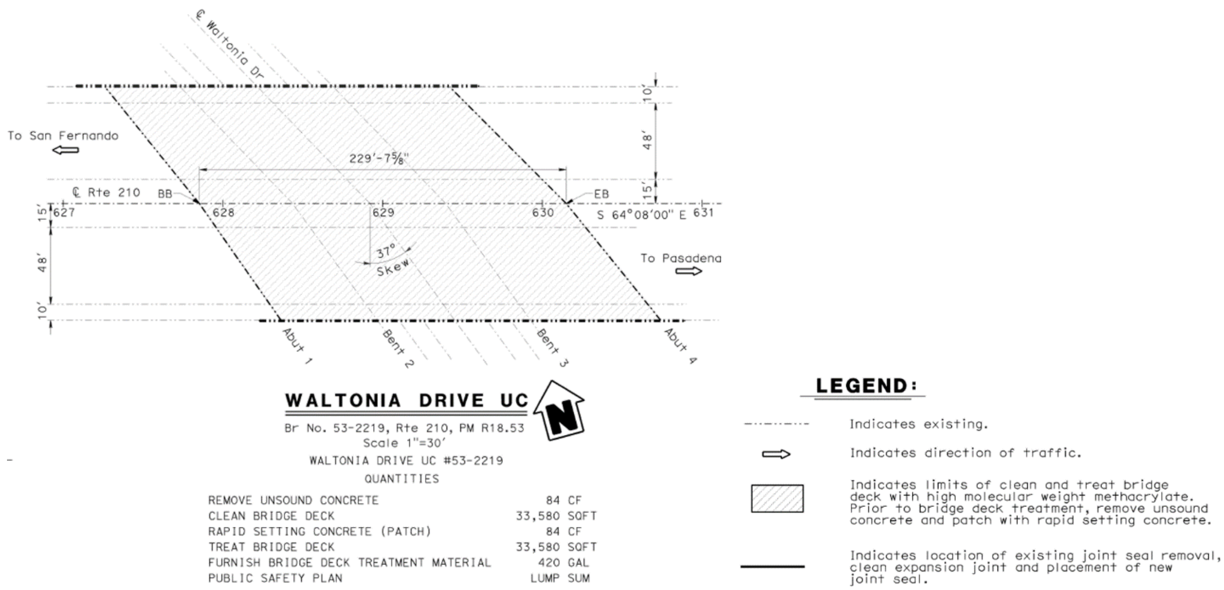


Figure 5-70. Sample Plan with Spall Repair and Methacrylate Resin Treatment for a Bridge Deck

Repair methods can also be modified to do more than one type of repair. For example, in rehabilitating a bridge deck, typically rapid setting concrete is used first for patching (when unsound concrete is removed), and then polyester concrete is used for an overlay. Sometimes polyester concrete is used for both patching and overlay; this would be a faster and more efficient way to complete a repair. However, it is important to note that in rehabilitation projects, modifications to the typical repair methods must be specified/allowed by the contract documents, as shown in the following example. See Figure 5-71 for an example of a contract plan detail that allows placement of polyester concrete for both patching and overlay; note that the patch depth is limited to 3 inches.

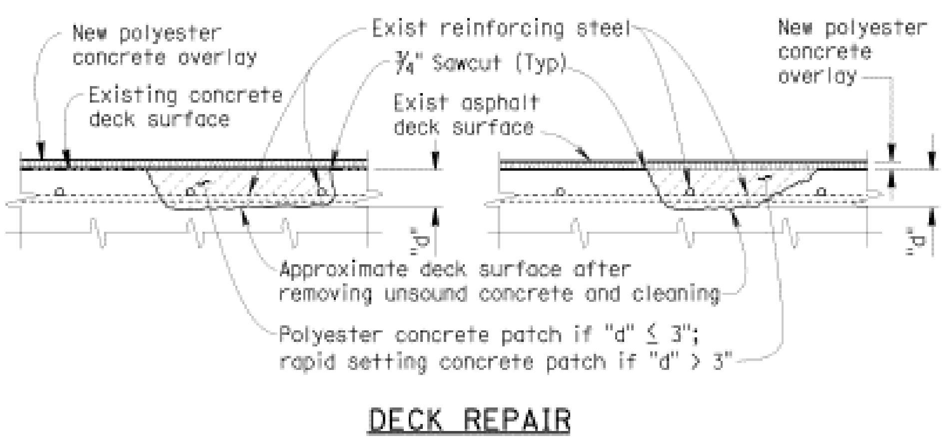


Figure 5-71. Sample Plan Sheet Permitting Polyester Concrete for both Patching and Overlay

The reader is referred to prior sections of this manual for guidance when repairs are combined or modified.