CHAPTER 6
STRUCTURE CONCRETE REPAIR AND REHABILITATION

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6 STRUCTURE CONCRETE REPAIR AND REHABILITATION

Concrete that has been properly manufactured, placed, and cured should last for an indefinite amount of time as evidenced by structures that are still in service past their 50-year design life. Some of this may be attributable to the quality of the materials and workmanship of the original construction or the absence of severe environmental, natural or user impacts. Another factor that may attribute to the structures long-life is that each structure is inspected biannually as part of the Department's maintenance protocol and needed repair and rehabilitation is typically scoped and scheduled into construction contracts.

Remedies for surface finish defects like rock pockets and plastic cracking that have always occurred in concrete construction are found in the Standard Specifications. Once a structure is placed into service, there are many ways that immediate and severe damage may occur that prohibits normal use until repaired. The most prominent causes are vehicular traffic accidents which cause damage by impact, fire, explosion, or chemical leakage, and natural events like floods and earthquakes. Damage can also occur during routine service. The use of tire chains on icy roadways causes surface rutting. Overloaded vehicles may cause cracking or failure of structural elements. Concrete materials may fail due to durability issues also. Freeze-thaw damage gradually erodes the surface away. Alkali-silica reactivity creates an expansive gel within concrete literally forces concrete to fall apart.

Structure Representatives may be called upon to repair damage such as that shown in Figure 6-1. While the details of structural damage repair are developed on a case-by-case basis, the general process is outlined in the following steps:

- Make the existing structure safe
- Isolate the damaged area for safe removal
- Remove defective materials while preserving structural materials that will remain
- Replace defective elements like columns, girders and affected deck areas

Project duties that would normally be covered by the design project manager like developing lane closure charts, detours and storm water pollution prevention plans often are covered by the structure representative as part of the emergency repair.

Figure 6-1. Initial Damage Assessment.

Note: If you are involved in the initial damage assessment in an emergency situation, such as after an earthquake, refer to the OSC emergency operations documents, the Emergency Response Handbook and the Emergency Operations Plan for initial response procedures.

The repair and rehabilitation efforts covered in this chapter are the "bread-and-butter" types that occur regularly during construction and periodically during a structure's life span. Active construction inspection and periodic maintenance inspections after construction are needed to minimize the impacts of defects as they appear by repairing or rehabilitating structures before significant deterioration can occur. The practices described in this chapter are those that experience has shown to be the most effective in obtaining an acceptable final product, but they should not be followed blindly. If there are doubts as to the procedure to be followed, consult the construction engineer before proceeding.

In general, the size and location of the defect will determine the method of repair. For instance, large voids may require removal of unsound concrete. Extensive removal may warrant the installation of formwork prior to replacing concrete. In most cases, however, the defect will be such that it can be repaired satisfactorily either by placing a mortar patch or by "dry-packing" 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.

The procedural steps required to repair a defect are listed below and described in this chapter:

- Assess the defect and determine the cause
- Determine the limits of defective concrete
- Determine if repairs are required
- Determine which repair method will be used
- Remove defective concrete as needed for the repair
- Place the repair
- Cure the repair

Additional material in this chapter covers specific repairs that occur regularly as part of the construction or structure rehabilitation:

- Construction defects that often occur such as rock pockets, bulges, and finish irregularities (these defects are relatively minor and correction is often made without removal of placed concrete)
- Bridge deck cracks caused by plastic shrinkage
- Structural repairs that require replacing portions of structural elements
- Bridge deck overlays

Concrete Repair Process

Assess the Defect and Determine the Cause

Typically, defective concrete is found by a visual inspection of the concrete surface. However, the area surrounding the visible defect should be probed 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. A thorough investigation of the defect will result in a more effective repair solution. Repairs that ignore environmental influences or usage patterns cannot be expected to endure. Also, there may be multiple causes for damage, such as, structural deficiency, low strength concrete and improper placing techniques that may have been used during construction. Chemically caused deterioration such as chloride or sulfate attack may appear as cracked or broken surfaces; repairing the surface alone does not remedy the underlying cause. Distorted or irregularly shaped structural elements indicate movement that could be caused by chemical attack, excessive loading overloads, or seismic loading. Notable defects fall into several categories:

- Surface imperfections like soft surfaces or surface voids
- Cracking
- Scaling
- Spalling
- Delamination
- Abrasion or surface wear
- CIDH pile anomalies (Refer to the OSC Construction Records and Procedures Manual and the Foundation Manual for pile mitigation and acceptance procedures)

Surface Imperfections

Voided surfaces, like those shown in Figure 6-2, caused by rock pockets, honeycombing, and cold joints are caused by any of the following:

- Improper mix design
- Poor placing
- Improper consolidation
- Leaky forms
- Excessive form deflection
- Or any combination of the above conditions

Soft surfaces are usually caused by improper treatment of wooden forms prior to 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 parent concrete. Excessive bleed water will carry fine materials to the surface, resulting in laitance or sand streaking. (Refer to Chapter 5 for additional plywood, forming and placing information.)

Figure 6-2. Rock Pocket Damage.

Cracking

Because of concrete's low tensile strength and the volume changes that accompany changes in temperature and humidity, cracking is a concrete characteristic that can occur at any time during the life of a concrete structure. In new construction, cracks occasionally occur as a consequence of 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 in 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 too rapid 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 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 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 a cracking problem as well. The contract remedy for 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.

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, by filling the cracks (by pressure injection) with an epoxy adhesive.

Corrosion of embedded bar reinforcing steel 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 reinforcing steel also occurs in structures located in a marine environment. 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 lead, eventually, to complete disintegration of the concrete. Typical map cracking is shown in Figure 6-3.

Figure 6-3. Map Cracking.

Scaling

Scaling is the flaking of surface mortar, often accompanied by the loosening of surface aggregates. Scaling occurs as the 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 paste. Cracking and fracturing continues with each repeated freeze cycle. Eventually the paste disintegrates to the point where the aggregate particles are no longer bonded together and are easily eroded away. In cases of severe scaling, the mortar fraction of the concrete is completely broken down and loose aggregate can be scooped out by hand.

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-cementitious 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 6-4. Severe Bridge Deck Scaling, Small Pothole.

Spalling

A spall is a chip or fragment of concrete that has broken away from a larger concrete mass, examples are shown in Figure 6-5. 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 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 6-5. Spalling

Spalling is 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. Spalls may also occur as a result of vehicle collision, as shown in Figure 6-6.

Figure 6-6. 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. 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 about 13 times the volume of the original metal, and pressures exceeding 4,500 psi have been measured under laboratory conditions. However, much smaller pressures are suffic ent 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 bar, but because there is little resistance above the bar, the upward acting forces eventually lift the concrete from the bar. This causes a vertical crack to form over the bar (or enlarges the crack if one already exists at this location) and causes a horizontal crack, or delamination, extending outward from the bar.

As corrosion continues, the expansive pressure increases, enlarging the vertical cracking and extending the horizontal delamination. Eventually, concrete above the bar may break loose, forming a conical spall, while the delaminated area enlarges until it reaches a similar delamination produced by an adjacent corroding bar.

Delamination

Delamination of the concrete at or near the level of the top mat of reinforcing steel 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 hastened by additional pressure developed by ice forming 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, concrete above the top mat of 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 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 chain over the bridge deck and marking the affected area. Other sounding devices worked by percussion, like 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.

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.

Determine Limits of Defective Concrete

As part of the assessment, include an estimate of how fast damage is occurring. Cracking caused by alkali-silica damage may appear similar to freeze-thaw damage, but there may well be a significant difference in the rate subsequent damage occurs. The use of rock hammer or surface chaining are often used techniques for determining unsound concrete. Nondestructive test methods like ultrasound or x-ray imaging may also be used to efficiently assess internal damage. A Schmidt rebound hammer, a device that measures impact recoil or coring samples will assist the assessment of concrete strength. The damaged area may be large enough that it warrants development of a repair map to help determine quantities and repair strategies. In the example shown in Figure 6-7 the repair layout could be translated to a map of the deck repairs with each area keyed to a spreadsheet line where the repair quantities are tabulated and summed.

Figure 6-7. Delaminated Deck Surfaces Identified for Replacement.

Determine if Repairs are Necessary

Concrete surface cracks in bridge decks may not exceed the treatment thresholds given in the Standard Specifications and may be subsequently ignored. Minor damage may deteriorate so slowly, that the service life of the structure will never be affected. 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.

Choose the Repair Strategy

After assessing the nature and extent of a defect, selecting the repair method and materials which will restore the structure to its intended purpose and durability at the most economical price is the next step. Repair options are doing nothing, partial replacement with drypacked mortar, conventional concrete, shotcrete, an overlay, surface treatment with a sealant and total replacement.

In the situation where the amount of significant cracking on a newly constructed bridge deck exceeds a specified threshold, methacrylate treatment is the specified treatment. In some circumstances, specifications may require that other coatings such as paint or sealants be used to seal the surface. Defective concrete may be patched, or removed and replaced with fresh concrete. Damaged bridge decks may receive methacrylate treatment or an overlay. In severe instances, the top 2 to 3 inches of concrete may be removed and a complete new riding surface placed. Cracks in walls may be sealed and injected with epoxy to bond the pieces together.

Many of the prepackaged products described herein in generic terms are available commercially under one or more brand names. When using rapid set proprietary products, the field engineer should verify its acceptability by checking the manufacturer's lot number with the Materials Engineering and Testing Services (METS) Structure Materials Representative. Rapid set patching materials may be classified chemically as either cementitious or polymeric substances. The cementitious materials include Portland cements, magnesium phosphate, alumina, and sulfoaluminate cements. The more commonly used polymeric materials include epoxies, methacrylate, polyester-styrene, and urethane.

Rapid set patching materials share many common characteristics. Some harden within minutes, and most within 1 to 2 hours. Most are self-leveling and self-curing. They are available commercially as prepackaged products, or can be manufactured at the job site using readily available component materials. Considering the intended purpose of a rapid setting material, most are relatively inexpensive, and all are easy to use.

Cementitious Materials

Although Portland cement is not a natural 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. Specifications may permit chloride-free accelerators, Type C accelerator 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 line 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 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 cements with good surface bonding qualities. Magnesium phosphate reacts with aluminum, so aluminum finishing tools should not be used. Cementitious materials are described in Chapters 1 and 2.

Polymeric Materials

Polymers are a large class of materials that includes natural and synthetic molecules. Although generally not used in construction, polymers such as epoxy, polyester-styrene and methacrylate are commonly used in bridge repair/rehabilitation work. 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 adequate bond at the polymer/substrate interface. Polymer patching materials are self-curing, and most will reach about 80% 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. Rounded aggregate will improve workability and dry nonabsorptive aggregate will decrease the total resin demand.

Polymers formed by linking monomers together, without losing material 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.

CAUTION
Appropriate safety precautions must be observed when working with polymers. The applicable manufacturer's Material Safety Data Sheet should be furnished with the polymer material reviewed before the material is used. While polymer patching materials are not toxic when used in accordance with current practice for deck rehabilitation work, many have strong fumes which are irritating to some people and inhalation protection may be required. Also, as a general rule, skin contact should be avoided when using polymer materials.

Thermoplastic/Thermoset

Synthetic polymers can be classified as thermoplastic or thermosetting, according to the effect of heat on their properties. Thermoplastics grow softer as temperature increases, eventually melting and 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 acrilonitrile 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.

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 (T_g), which varies with the particular resin system and quality of preparation methods. Above the T_g, 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 T_g, the original material properties return. Polyethylene, a thermosetting plastic is based on repeating units of ethylene.

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 3×10^6 to 6×10^6 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.

Free Radical Polymerization

Materials like methacrylate and polyester concrete that are currently used on Caltrans projects use free radical polymerization to create polymer chains. Free radicals characteristically have an unpaired electron and readily attack other molecules in efforts 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 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.

Key Variables

Methacrylate and polyester polymers are initiated by mixing with a free radical and possible promoters and accelerators and create polymers that grow by chain growth; the reaction rate is controlled by temperature and the amount of initiator. Epoxy and urethane polymers consist of resins and hardeners that cross link to form solid substances; reaction rates are controlled by selection of resins and hardeners and temperature. The required application temperature range is typically 50 to 80°F, because temperature affects the speed of the polymerization. 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 for lower temperatures.

The contractor must prepare a test patch before the full-scale placement of polymer-based-concrete. A test patch demonstrates that the contractor's polymer resin formulation will harden in an appropriate time period; given that the conditions (like substrate, temperature and mixing proportions) match those under which the polymer concrete will actually be placed. If conditions change, a new test patch should be constructed.

An excessive initiator dosage results in an accelerated reaction and lower average weight polymers. Inadequate initiator or an excess of resin will result in an under-cured, softer material that may never solidify.

A key component of polymer overlay specifications, including methacrylate bridge deck treatments is moisture content; there must be dry conditions and low humidity. The ambient humidity must be below 80% and the aggregate moisture content must be less than 0.5% moisture. Polyester concrete uses synthetic resins rather than mineral-based cementitious materials to bind aggregates. Unlike cementitious materials, the chemical reaction that hardens polymer concrete is not based on the introduction of water to initiate a chemical reaction. As a matter of fact, the exact opposite is true in polymer concrete: the presence of water, even minute quantities, will cause the chemical reaction to fail and the polymer will not form. Thus, the aggregate condition of saturated-surface-dry criteria does not apply to polymer overlays.

Since these polymer concretes are typically applied on a previously hardened concrete, the concrete surface receiving the polyester concrete must be clean. Cleaning is usually specified by mechanical means, typically shotblasting, in order to remove any extraneous surface materials that may be deleterious to a solid bond between the underlying concrete substrate and the polymer concrete.

With a binding agent that is totally different from those used in a typical Portland cement concrete (PCC) bridge construction, a different mindset is needed to appreciate the rigorous and exacting polymer concrete specifications. Successful use depends on the contractor's expertise and quality control practices and rigorous implementation by the inspector of the specification and quality assurance standards, based on a sound understanding of the technical basis of the technology.

Methacrylate

Methacrylate can be used to bind aggregates together to form a 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. Current specifications allow a maximum of 5 minutes from mixing to application, 10 additional minutes for squeegee/brooming materials from grooves, and 10 additional minutes before application of sand; the minimum working time by specification is 25 minutes. Current specifications limit the concrete surface temperature to a range of 50 to 100°F. Depending on the manufacturer, typical working times range from 30 to 60 minutes and application temperatures range from 40 to 130°F. Exercise caution when applying methacrylate as the fumes can present a health hazard and can also be ignited by a spark or open flame.

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 6-8.

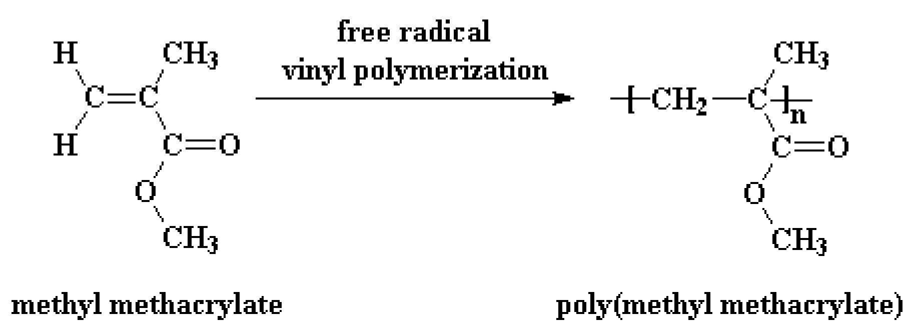

Figure 6-8. Methyl Methacrylate Polymer.

Methyl methacrylate is very viscous. 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

OSC 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 6-8, 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 Caltrans viscosity specification of 25 centipoise. The high weight molecules also reduced volatility and virtually eliminated the possibility of a bridge deck fire.

Polyester Concrete

Polyester-styrene concrete is a versatile construction material used extensively for bridge deck overlays and as an excellent patching material. Physical properties are similar to that of methacrylate except 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 a 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 relative high cost in high-quantity applications, the most common application of polyester concrete in Caltrans are thin (3/4" 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 cause the styrene monomers to crosslink with the polyester polymers within a paving mix to form a polymer matrix around the aggregate. The polyester resins molecules shown in Figure 6-9[1] are the first component of the polymerization reaction. Within the polyester resin, carbon atoms are bound together with double covalent bonds, shown in Figure 6-10. The in reactive sites on the polyester molecule shown in Figure 6-9 are identified as “B” in Figure 6-10. 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 6-11.

1. Systems for Use in Fibre-Reinforced Composite Materials
http://www.azom.com/details.asp?articleid=986 (visited June 9, 2010)

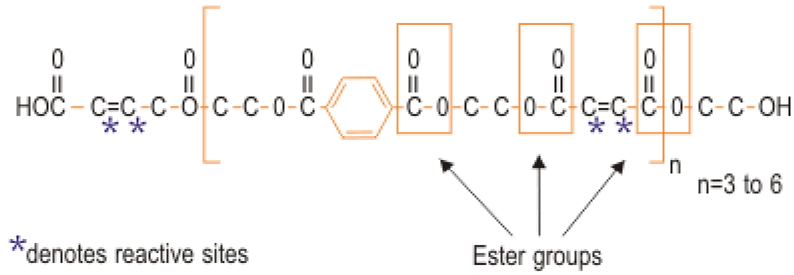

Figure 6-9. Idealized Polyester Resin

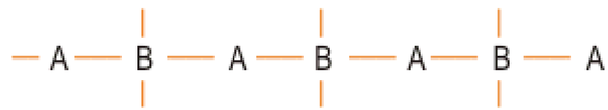

Figure 6-10. Schematic of Polyester Resin (B = Carbon bond).

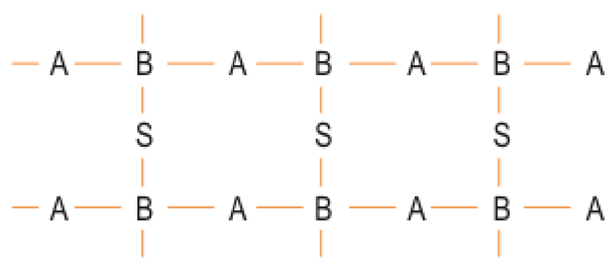

Figure 6-11. Schematic of Cured Polyester Styrene Thermoset.

Urethane

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, urethanes have been replaced 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 set time is surface temperature; a warmer temperature will accelerate set time.

Rapid setting urethanes may 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 is placed, the urethane resin was poured over the aggregate, filling the voids between the aggregate particles and forming a solid mass. Only coarse aggregates are used because urethane resins expand appreciably when mixed with fine materials, such as graded concrete sand.

Epoxy

Epoxies are used extensively in Caltrans as adhesives (for traffic markers, rebar dowels, concrete), crack sealers (vertical wall repairs), and as binders of aggregates to form polymer concrete. Epoxy is one of the oldest and most vesatile, 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, there are many reaction mechanisms that may occur; consequently, different epoxy compounds may have widely differing properties and characteristics. Epoxy resins provide:

- High strength
- Low shrinkage characteristics
- Good adhesion properties
- Resistance to water, chlorides and sulfates

Epoxies for construction use 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% 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 - broadcasted 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 has become the 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.

Before injecting, the cracks are sealed at the surface with a quick setting epoxy paste which can be applied to the concrete with a small masonry trowel or similar tool. Injection ports, which are usually small sections of plastic tubing 1 to 2 inches in length with a plastic flange at one end, are spaced along the crack at 1 to 2 foot intervals. The flange is set on the concrete and anchored in place with the epoxy paste.

Typical injection equipment consists of a positive displacement pump and 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. For convenient operation and easy movement, pump, mixer, and epoxy component storage tanks are usually mounted on the same platform.

After mixing, the epoxy is pumped through a flexible plastic tube to the injection ports. For a normal operation, injection begins at one port and continues until no more epoxy can be injected or until epoxy is observed coming out of one or more adjacent ports. The first port is plugged, and injection resumes at an adjacent port. The operation continues until all ports are injected.

Pumping pressures average about 25 to 30 psi for normal injection work, but the pressure is somewhat dependant on crack width, with smaller cracks requiring higher injection pressures. Pressures of 60 psi or more may be required for very small cracks or cracks that have become contaminated with dirt or other foreign matter.

Filling cracks in concrete by pressure injection of epoxy adhesive is a proven procedure, with many obvious benefits and no disadvantages. When properly performed, epoxy injection will completely restore the structural integrity of a cracked concrete member.

Epoxy Mortar

Since even thin sections of epoxy materials have high strength, epoxy mortar is especially well-suited for use at tapers or at 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 an epoxy concrete. 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 aggregate used in epoxy mixes must be 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 adequate bond between the epoxy patch and the parent concrete substrate, the concrete surface must be clean and dry when the patch is placed. Sandblasting is the specified cleaning method. For best results, the surface should be sandblasted and then air-blown to remove all sandblast 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.

Prior to placing the patch 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 that 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 about 80°F. Conversely, many epoxies will not cure at all at temperatures below about 50°F. Ideally, the best results will be obtained when the parent concrete and the epoxy patch material and atmospheric temperatures are all within a range of 60 to 80°F.

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°F. For temperatures between 40°F and 60°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. Class A epoxy for temperatures below 40°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 mix 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. In view of past experience, this practice is not recommended.

Remove Defective Concrete

Before repair work may be started it is necessary to remove the defective material. In a rock pocket area, sufficient material must be removed to expose sound concrete. Depending on the extent and nature of the defect, sandblasting, hand chipping or the use of smaller air-operated chipping hammers will be appropriate. 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 produces small fractures in the underlying sound concrete as the defective material is removed.

Although visual inspection will reveal most defects, in some cases it will be necessary to check for delamination which is not apparent from an examination of the surface. The most efficient method of locating such defects is to “sound” the concrete by striking the surface with a hammer or 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 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.

Edge treatment requires special consideration. For voids to be filled with a patch material, either as a permanent repair or as an initial step prior to the construction of a deck overlay, the edge should be saw cut approximately 1 inch deep to avoid a weak feather edge. The best practice is to work with the contractor, agreeing that the saw cut will be performed as a last step. The contractor would remove the initially marked area, the inspector resounds the concrete to verify delaminations have been removed. At that point the final saw cuts are laid out and 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.

Chip to the depth necessary to remove all defective concrete; however, the minimum depth of removal depends on the repair procedure to be employed. For "dry-pack" mortar repairs, the minimum depth should be at least 1/2 inch. One-half inch minimum depth is also satisfactory for shotcrete applied without adding aggregate. For other repair procedures, including the use of any material containing aggregate of pea gravel size or larger, a 1-inch minimum depth is recommended.

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. To meet this restriction on equipment use, it has been common practice to limit the size of equipment to 65-pound jackhammers for removal of large masses of concrete above the level of the reinforcing steel, and to 30-pound jackhammers, and sometimes 15-pound chipping tools, for removal of concrete below the reinforcing.

A clean, sound substrate is required for any concrete repair, so that the minimum amount of concrete to be removed will include all concrete that is structurally unsound, which will be all the concrete above a delamination. Some judgment is required when determining whether to remove additional concrete, beyond the areas of delamination, that is encasing corroded reinforcing steel, but 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 substance 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 contaminating substances adhering to a concrete surface. This is normally done by sandblasting, followed by blowing with compressed air to remove sand and dust particles. Sandblasting has the added benefit of removing any fractured aggregate particles remaining in 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 should 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 prior to placing the replacement material.

A concrete surface that has been chipped, sandblasted, 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 actually leaves a residue of fine material on the surface. To ensure bond between a sawed surface and new concrete, a sawed surface should be cleaned by sandblasting.

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

Place Repair Materials

Removing unsound concrete is the first step in a two-step repair process. The second step is filling the voids that result from the concrete removal with a suitable replacement material. The procedure depends on the extent and depth of concrete removal as discussed in the following sections.

Cure The Repair

Hydraulic cements require moisture for strength development. The chemical transformation that occurs as cement hydrates cannot occur without water. When pozzolanics like silica fume are also included in the repair mix design, curing becomes even more critical as the pozzolanic reaction requires products of the hydration reaction. Curing the repair is the standard method for maintaining moisture while the patch is hardening.

Repairing Minor Construction Defects

Construction defects are usually the result of improper placing methods or techniques. Concrete placement practices are discussed in Chapter 5. When the area to be repaired is relatively large, judgment is necessary to determine whether the resulting void may be patched or whether a structural repair is indicated. As a guideline, a patch will be appropriate when the repair is “cosmetic” only; that is, when the replacement material is merely filling a void in the concrete mass and is not necessary to maintain or ensure the strength and structural integrity of the concrete element. On the other hand, structural repair is necessary when the designed intent of an element is compromised.

Dry-Packing

Dry-packing consists of filling a void with a relatively dry (not fluid) sand/cement mortar and pressing the mortar in place. Dry packing is particularly suited to the repair of rock pockets, since rock pockets usually 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 equivalent, in strength and durability, to the original concrete.

Surface preparation is as important for dry-packing as for other repair procedures. All defective material must be removed and the exposed surface must be sound and thoroughly clean. Either neat 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 permit placing and compacting.

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 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. White cement may be added to trial batches until the correct color is obtained.

For exposed surfaces, at least 3 days of continuous water cure is recommended for dry-pack patches. If the patch is not visible to the public, a membrane cure may be used.

Conventional Concrete Patching

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. In most cases pea gravel will be used as the aggregate fille . 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. For those locations where a conventional mortar patch would otherwise appear feasible, dry-packing is the preferred method.

Concrete patches in surfaces that require a Class 1 surface finish should be water cured. For other surfaces, either water or the curing compound curing method may be used.

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.

Shotcrete for new construction is covered in Section 53 of the Standard Specifications. All specification provisions governing materials, placing and finishing, will apply to shotcrete used to fill voids created by the removal of defective concrete. For repair work, the following requirements will also apply:

- All defective concrete shall be removed as previously described, except that the edges should be tapered inward on a 1:1 slope, rather than cut perpendicularly, to avoid inclusion of rebound material. If pea gravel will be used in shotcrete applied by the wet-mix process, the minimum depth of removal shall be 1 inch.

- The exposed concrete surface shall be cleaned by sandblasting followed by blowing with compressed air.

- The surface to receive the shotcrete should be visibly damp, but significant amounts of free water should not be present. A bond coat is not required.

- Shotcrete should be applied slightly full and the finish surface trimmed with an appropriate float or straight edge to the lines of the parent concrete.

Shotcrete surfaces are cured and protected in accordance with applicable specification requirements for new construction.

Commercial Patching Materials

There are a number of proprietary products marketed commercially as concrete patching materials. 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 a satisfactory repair under certain conditions. However, these products are self-leveling, and therefore will not be appropriate for vertical or overhead surfaces in most cases.

Rapid set patching materials are used in the bridge deck rehabilitation section. While these products are useful when repairing deteriorated concrete, they are not recommended for rock pocket repair in new construction, except under very unusual circumstances.

Epoxy Mortar Patches

Because it is relatively expensive, difficult to work with, and darker in appearance than concrete, epoxy mortar is not widely used as a concrete patching material in new construction. However, the use of an epoxy mortar or concrete may be appropriate at locations where a highly viscous rapid setting material is required. Epoxy may be particularly suitable for patching small voids in vertical and overhead surfaces where appearance is not a factor.

Repair Testing

Following the cure period, patches should be visually inspected and, if deemed necessary by the engineer, tested for structural adequacy. An impact hammer (Schmidt hammer) may be used to determine the approximate strength of patches made by dry packing or with a conventional Portland cement concrete patching material. Tapping the patch with a rock hammer will reveal areas that have failed to bond properly (unbonded areas will produce a hollow sound) but this procedure does not give any strength indication. Because epoxy is a resilient material, epoxy mortar patches cannot be tested with impact tools. Epoxy patches should be examined visually for evidence of obvious defects, such as porosity and/or lack of sufficient resin at the surface.

Large Defect Repair - Concrete Replacement

When the area of defective concrete will result in large voids in primary load carrying members such as slabs and girder stems, it may be necessary to recast the member using replacement concrete of the same mix design as the original concrete to ensure integrity of the structural element. In general, a structural repair (rather than a patch) should be required when the integrity of the member is threatened by the defect. This will include voids that extend entirely through a member, voids where the main reinforcing steel is exposed to the extent that bond is jeopardized, or any void which, if unfilled, would reduce or impair the load carrying ability of the member in any way. Obviously, this is a subjective determination, but if there is any doubt, the engineer should require a structural repair.

Preparation

Detection and removal of defective concrete, surface preparation and application of a bond coat as discussed in preceding sections are applicable to structural repair. When a structural repair is indicated, it will be necessary to remove the defective concrete to a definite line, and this may require removal of concrete that is otherwise satisfactory. In general, removal limits should be straight and square with the structural element being repaired. If, after identifying the limits of the defective concrete, less than about 18 inches of sound concrete remains between the area to be repaired and the top or end of a wall or girder, this sound concrete should be removed as well.

Main bar reinforcing steel should not remain partially embedded in concrete; enough concrete should be removed to provide at least 1 inch clear around all main bars.

Care must be taken to ensure that no void area remains between the top of any concrete placed as a structural repair and the undisturbed sound concrete above. Methods to prevent inclusion of voids listed below:

- Chipping the top surface of the void area on a 3:1 upward slope toward the concrete placing side.

- Form a “chimney” chute above the void to be filled with replacement concrete. Place concrete through the chute to provide a head on the fluid concrete.

Placing

In most cases the same concrete mix will be used for the replacement concrete as used for the original concrete. However, to facilitate placing and further ensure that the entire void area is filled, consideration may be given to the use of a water reducing admixture to increase the fluidity and workability of the replacement concrete, even though a water reducer was not used in the original mix.

All specification requirements for furnishing, placing, curing and protecting new structure concrete will also apply to replacement concrete used in a structural repair.

If it is necessary to make a structural repair in concrete that is to be prestressed, keep in mind that the replacement concrete must attain the specified compressive strength before prestressing forces are applied, and this could delay the stressing operation.

Occasionally, concrete must be removed for aesthetic reasons, such as might be the case after a form failure. The procedures previously discussed for repair of rock pockets will also apply to removal and replacement of aesthetically-defective concrete as well.

Repairing Defects In New Bridge Decks

Defects occurring in new bridge decks fall into two general categories:

- Those which impair the riding quality of the finished deck surface, but which 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 which for some reason were improperly finished (too high, too low, or too rough) where the condition is serious enough to require remedial work other than grinding. Repair of 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. (Cracking that exceeds the crack intensity threshold as defined in the specifications is repaired with methacrylate treatment.) In general, repair procedures for new bridge deck repairs are similar to those described earlier in this chapter of the Concrete Repair Process section. An additional requirement for bridge decks is that the surface must be finished in accordance with current bridge deck finishing specifications

Filling Shallow Voids

When the voids in the deck are scattered, or are shallow and do not extend below the level of the reinforcing steel, current practice calls for filling of the voids with overlay material, regardless of the type of overlay to be constructed. This includes polymer overlay materials. In such cases, mixing and placing of the replacement material will be done concurrently with the overlay, following the methods and procedures specified for overlay construction. The edge should be chipped inward on a 1:1 slope to prevent the formation of pockets of entrapped air at the edge as the overlay is placed.

Filling Deep Voids

Where concrete has been removed below the level of the deck reinforcing over a large area of the deck to expose substantial amounts of reinforcing steel, the voids will be filled with concrete of the same quality as the original construction. If the rehabilitation strategy includes a Portland cement concrete overlay, the voids may be filled when the overlay is placed, using the overlay material. For a polymer concrete overlay, the deck will be reconstructed with Portland cement concrete as a separate operation before the overlay is placed.

When a concrete overlay is to be constructed, determining whether to reconstruct the deck with normal Portland cement concrete or with the concrete overlay material is usually a question of economics, since either method is satisfactory from a structural standpoint. Portland cement concrete is less expensive, and may be easier to handle, than the overlay material, and therefore will be the most economical material to use. Some of the saving is illusory, however, because of the higher labor costs associated with a two-step operation. When the deck section is restored prior to placing an overlay, the usual practice is to use a concrete mix design conforming to applicable specifications for structure concrete. Even though the deck will be covered with an overlay, air-entrainment is advised.

When normal Portland cement concrete is used, an epoxy bond coat will be specified. The epoxy adhesive may be applied by brush or by spray equipment. Application should be uniform over the concrete surface, but it is not necessary to completely coat the exposed bar reinforcing steel.

When the deck section is restored with a concrete overlay material, bonding requirements for the replacement material will be the same as specified for the overlay itself.

Bonding Agents

Of the many available bonding agents, only 2 are acceptable for repairing concrete structures. They are neat cement paste and 2-component epoxy adhesives specifically formulated for bonding new concrete to old concrete. Single-component repair products, even though they may be marketed as epoxy products, are not effective and are not to be used as bonding agents for structure concrete repair work.

Neat cement paste (a mixture of Portland cement and water) may be used to bond patches up to about 1/2 square foot in area and 3 inches in depth, provided no reinforcing steel is exposed. When neat cement is used as a bonding agent, the concrete to be repaired should be kept wet for several hours before patching, but the surface should be dry when the neat cement paste is applied; this is similar to keeping aggregate in the saturated surface dry condition.

Larger patches (or any patch where reinforcing steel is exposed) require a two-component epoxy-bonding agent. The complete removal of all foreign materials from the surface to be patched is particularly important when an epoxy adhesive is used as the bonding agent. Even a thin layer of dust will prevent bonding.

The composition, physical characteristics and directions for use of State specification epoxy adhesives for bonding new and old concrete are found in Section 95 of the Standard Specifications. Epoxy adhesives should be furnished and applied in conformance with the manufacturer's recommendations and, at the engineer's discretion, applicable provisions in Section 95 of the Standard Specifications as well.

To ensure satisfactory results, the concrete surface should be thoroughly dry when the epoxy adhesive is applied, and ambient and surface temperatures should be within the range recommended by the manufacturer. For best results, the contact surface of the concrete should be completely covered with a thin coat of the epoxy adhesive, and the epoxy should be worked onto the surface with stiff brushes. If spray equipment is used, care must be taken to prevent the epoxy from ponding in depressed areas of the concrete. The patching material must be placed before the epoxy adhesive begins to set and within the time limit specified by the manufacturer for the type of epoxy used.

Small Area Repair (< Two Inches Deep)

These areas may be filled with a proprietary concrete patching material that is suitable for deck rehabilitation work, or with epoxy mortar.

For an epoxy mortar repair, the area to be patched should be chipped down square around the edges to a minimum depth of 1/2 inch, and then air-blown clean. If the epoxy patch is placed promptly, no further cleaning will be required. However, if patching is delayed and the exposed surface becomes contaminated, sand blasting will be necessary to ensure an adequate bond. The epoxy patch should be placed in accordance with applicable specifications.

Certain proprietary patching materials, that would be unacceptable for repairing rock pockets in new concrete, may give satisfactory results when used to fill very small voids in bridge decks. This is the case because appearance is not a factor and, for the small volume of material used, shrinkage is not a problem. In general, any proprietary product that is satisfactory for use in bridge deck rehabilitation work can be used for filling small voids in new decks as well.

Large Area Repair (> Two Inches Deep)

When the finished deck surface is too high or too low, the concrete in the affected area must be removed to a minimum depth of approximately 3/4 inch to ensure adequate thickness for a structural patch. These areas are to be restored with a combination of Portland cement mortar and aggregate filler or with Portland cement concrete, as appropriate for the size and thickness of the defect.

Concrete removal is usually accomplished with hand held air-operated impact tools; however, if the defective area covers a large portion of the deck surface, the use of power scarifying equipment may be appropriate. Concrete removal using any type of impact tool or equipment will leave fractured concrete fragments that are still adhering to the surface. To ensure a sound, fracture-free substrate, the area to be patched must be thoroughly sandblasted. After sandblasting, the surface should be air-blown to remove dust and loose particles remaining from the chipping and sandblasting operations. Replacement concrete must be bonded with an epoxy adhesive.

For thin sections (i.e., patches up to 2 inches in thickness) the concrete proportions shall be 658 pounds per cubic yard, 45 to 50% pea gravel aggregate, concrete sand, and just enough water to produce a workable mixture. The pea gravel aggregate should pass a 1/2 inch sieve with 95% being retained on the No. 16 sieve. Sand should meet the specification requirements for fine aggregate. For sections over about 2 inches in thickness, a regular bridge concrete mix may be used. With the exception of the special mix design for thin sections, all contract requirements applicable to original construction will also apply to the concrete used to restore the bridge deck surface.

If air-entrained concrete was specified for the original concrete, an air-entraining admixture must be used in the replacement concrete. Other admixtures may be used if they are considered desirable.

Immediately after depositing, the concrete should be consolidated, and then struck off to the required grade and textured to match the adjoining deck surface. Curing shall conform to applicable contract provisions. Patched surfaces must meet profile, texture and cracking requirements included in the bridge deck finishing specification

Filling Cracks by Epoxy Injection

The 1999 Standard Specifications were the last specifications that included epoxy injection in the bridge deck finishing specification (Section 51). The specification provides that when the "surface crack intensity" exceeds the specified threshold value, all cracks within the affected area "...shall be filled with pressure injected epoxy." The intent of this specification is to restore the structural integrity of new bridge decks in those cases where excessive cracking has occurred during construction. Pressure injection with an epoxy adhesive was specified because it was the only commercially feasible repair procedure that rebonded cracked concrete. The current specified treatment is methacrylate.

Bridge Deck Rehabilitation

Caltrans structural elements such as concrete bridge decks exist in severe use conditions under potentially harsh environmental conditions. Our structures are subject to continuous surface wear and high live-load stresses, including both impact and fatigue. For the most part, they are exposed to alternate wetting and drying and, in many locations, alternate cycles of freezing and thawing and severe temperature differentials as well. Bridge decks contain a congestion of reinforcing steel, making the use of highly workable concrete essential. Because of finishing requirements and bleeding, the worst concrete in the deck is at the surface. In view of 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 civil engineering structures.

Depending on such variable factors as traffic, degree of exposure to adverse environmental conditions, and quality of initial construction, bridge decks on structures completed during the early years of the freeway building era in California (1950s and 1960s) are beginning to deteriorate, and many will soon be nearing the end of their useful service life. As deck deterioration accelerates, the need to maintain a smooth riding surface and/or the required load-carrying capacity will become an increasingly important highway planning consideration.

Additionally, in recent years in many parts of the country, including California, problems associated with deck deterioration have been exacerbated by corrosion of embedded bar reinforcing steel occurring as the consequence of the deliberate application of deicing salt. 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 will prevent corrosion damage, California has many hundreds of structures in freeze-thaw areas that were built before the advent of epoxy coated reinforcing steel. All of these structures have chloride-contaminated decks, and all have some degree of corrosion damage. Most have experienced at least some deterioration.

To mitigate the adverse effects of corrosion damage, California began a deck rehabilitation program in the early 1970s. Today, deck deterioration remains a problem, however, because many of the repairs done during the 1970s and early 1980s were intended only to preserve the deck riding surface; they were not a "permanent" repair.

Accelerating bridge deck deterioration statewide, together with the need to restore the structural integrity of the many remaining salt-contaminated bridge decks in freeze-thaw areas, will require an on-going deck rehabilitation effort for the foreseeable future. Accordingly, bridge deck rehabilitation will remain an important part of the Department's construction program for many years to come.

The factors contributing to deck deterioration have been previously discussed. In summary, they are:

- Cracking
- Scaling
- Spalling
- Delamination
- Abrasion or surface wear

As a rehabilitation strategy, the objective of a deck overlay is to extend the service life of an existing bridge deck at a significantly lower cost than total deck replacement. Thus the ideal overlay will completely restore the bridge deck riding surface with a strong, durable material, provide sufficient additional protection to the existing deck reinforcing steel so that further corrosion will not occur, and be constructed of materials that are relatively easy to produce and install.

Over the years, many overlay materials and construction techniques have been employed in an effort to extend the service life of a bridge deck. These include asphalt concrete in combination with a protective deck membrane; conventional Portland cement concrete; low-slump concrete; polymer-modified concrete; superplasticized concrete; and polymer products currently in favor like methacrylate and polyester concrete. Asphalt concrete overlays have been more or less successful in restoring the deck-riding surface, although the overlays have a relatively short service life. Concrete, in general, will provide a durable riding surface, but many concrete systems are not totally impervious and thus cannot prevent future corrosion of the deck reinforcing. Furthermore, most concrete products that have the strength, durability and impermeability characteristics that are essential to the ideal overlay are expensive to produce and difficult to work with in the field

Even so, and in spite of their high cost and inherent construction difficulties, concrete overlays using specialized materials and placement techniques have been considered a viable rehabilitation procedure by many states and the FHWA. Concrete overlays have not been widely used in California, because during the early years of the deck rehabilitation program, the concrete overlays were viewed as experimental, primarily because the two specialized concrete overlay systems in general use throughout the 1970s (the so-called "low slump" system and the latex-modified concrete system) have many construction drawbacks. Today, the preferred treatment is with methacrylate overlays to "heal and seal" surface cracks and polyester concrete overlays that provide bonded wearing surfaces and also serve to correct for variations in the bridge profile.

Surface Preparation

The actual depth of removal depends on the condition of the existing concrete. Where the deck is in generally good condition except for isolated areas of unsound concrete, removal to a depth of about 1/8 inch will be sufficient to remove surface contaminants and weathered aggregate particles. Deeper removal (up to 1/2 inch or more) may be specified where scaling has occurred or where design considerations require removal to a greater depth. For the typical deck rehabilitation project, the deck preparation item will include removal of a specified depth of concrete over the entire deck area, and cleaning of the area to receive the overlay.

In most cases when the rehabilitation strategy requires only a thorough cleaning of the deck surface, sandblasting may be specified. Sandblasting is a cost-effective means of removing surface contaminants and weathered aggregate particles, and will assure a clean, sound substrate for the 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, while the dust generated by sandblasting a bridge deck is not considered hazardous, under certain environmental conditions it can be an objectionable atmospheric contaminant, and this may cause a problem in urban areas.

To mitigate some of the problems associated with sandblasting, current overlay contracts, primarily those involving construction of polymer concrete overlays, have specified the use of shotblasting equipment for the deck preparation work when only a minimal depth of concrete removal was necessary. Shot blasters are self-contained units that use small-diameter (1/16 of an 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.

Shotblasting is the most effective means of assuring a clean, sound concrete surface. Shotblasting equipment was originally developed to clean concrete floors prior to 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. If shotblasting is specified, it is essential to use the appropriate equipment; otherwise, the intended results will not be obtained.

When more than surface cleaning is required (i.e., when it is necessary to remove more than about 1/8 inch of concrete) the means by which the concrete is removed will, in most cases, be left to the contractor doing the work. Although various types of abrasive impact and/or cutting equipment have been used in the past, today most contractors use milling equipment (roto-milling machine or equivalent) for this purpose. This equipment is effi ient and cost-effective, but it leaves a micro-fractured surface that may adversely affect overlay bond unless the fractured particles are removed before the overlay is placed. For this reason, the specifications will require sandblasting (or shotblasting) of the entire deck area before placing the overlay, but after completing all other preparatory work.

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 early1980s. 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. The effectiveness of 15,000 psi equipment is currently being evaluated and may be optional by change order in the future. When the proper equipment is used, a water blasted surface will expose sound coarse aggregate particles with excellent bonding characteristics.

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 sandblasted 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.

Low-Slump Portland Concrete Overlays

Low slump concrete was originally developed as a repair material for Portland cement concrete pavement, and during the 1960s was widely used for this purpose by many mid-western states. Although low slump concrete was first used as a deck overlay material in Kansas in 1969, its use was actually pioneered in Iowa during the early 1970s, and the system is often referred to colloquially as the “Iowa” method of overlay construction.

In the Iowa method, a low water-cement ratio concrete is placed on a prepared deck surface. The typical application involves the following steps:

- Remove surface concrete to a depth of approximately 1/4 inch
- Remove all remaining unsound concrete
- Sandblast the concrete and any exposed reinforcing steel
- Apply a mortar-bonding agent to a dry concrete surface
- Place the low-slump overlay. Nominal overlay thickness is 2 to 2 1/2 inches
- Cure the concrete using burlap and water

Most authorities recommended a mix design with cement content between 750-850 pounds per cubic yard and a water-cement ratio between 0.32 and 0.34. To achieve this, a water-reducing admixture was used.

The mortar-bonding agent consisted of approximately equal parts of fine sand and cement mixed with sufficient water to form slurry of creamy consistency. The bond coat was applied to the deck in a thin, even coat using stiff brooms. Typically, the neat cement (mortar) was mixed in a mortar mixer and delivered to the point of application by pumping through a flexible hose. The rate of delivery was controlled to prevent drying prior to applying the overlay material. A number of mixing methods were used, ranging from mobile, continuous mixers to jobsite paving mixers to transit mixers. All were capable of producing satisfactory results, although transit mixers required larger admixture dosages than the other mixers.

Because the relatively stiff concrete mix could not be pumped, the mixed concrete was delivered to the point of placement using buggies, or by direct discharge from a transit mixer. Conventional deck finishing equipment was too light to handle the stiff, low-slump concrete; consequently, a finishing machine specifically designed for use with low-slump concrete was used. Such machines, which were much heavier than conventional drum finishers, were equipped with two transverse screeds, one of which was a vibrating screed. In their normal configuration, the finishing width was limited to about 13 feet. Although the units could be extended, the practical limit was about 3 feet because of the weight and rigidity of the equipment.

Vibrators were used ahead of the finishing machine to level and consolidate the overlay material, and to bring grout to the surface to facilitate finishing. Even so, some hand finishing was required behind the finishing machine to smooth irregularities and to seal surface cracks. Surface texturing was usually accomplished with a tined wire-grooving tool.

The overlay surface was covered with wet Burlene® as soon as possible after texturing. Curing compound was not used because the thin overlay is susceptible to both plastic and drying shrinkage, particularly when placed during warm weather. Also, because of the initial low water content, it was necessary to apply water to the surface to ensure that sufficient water will remain in the concrete to hydrate the cement.

Low water-cement ratio overlays used the relatively inexpensive materials normally associated with Portland cement concrete construction. However, the work is labor intensive and required specialized equipment for placing and finishing, and sometimes for mixing as well. Success was greatly dependent on the ability and experience of the construction crew, and on rigid adherence to specification requirements. The few low-slump overlays constructed in California have generally performed well and have been relatively maintenance free. This may be attributed to the fact that the projects were quasi-experimental in nature and therefore were the subject of considerably more engineering attention and involvement than is typically the case. California concluded that low-slump overlay installation required more expertise than most contractors have, and therefore continued success would necessitate a higher degree of State involvement than was considered appropriate. Accordingly, the construction of low-slump overlays was discontinued. Other states have apparently reached this same conclusion, as the use of the low-slump system is far less prevalent today than it was in the past.

Latex-Modified Concrete Overlays

Latex-modified concrete is conventional Portland cement concrete with the addition of approximately 15% latex solids. The latex, which is a polymeric material, is added as an emulsion during the mixing cycle. Polymeric latex is a colloidal suspension of synthetic rubber particles in water. The particles are stabilized to prevent coagulation, and antifoaming agents are added to prevent excessive air entrapment during mixing. The water in the emulsion hydrates the cement, and the latex polymer provides additional binding due to the adhesive and cohesive properties of the latex. This results in a superior concrete having very good strength and durability properties, and low permeability.

In theory, the structural properties of latex modified concrete (LMC) make it an ideal material for bridge deck overlay construction. In practice, however, the properties of LMC overlays vary widely depending on the type and amount of the latex used, the type of cement and aggregate used, the cement factor and the water-cement ratio. Additionally, LMC is sensitive to temperature variation, and is difficult to place and finish under all but the most benign environmental conditions. For these reasons, the desirable properties of LMC are not always obtained under field conditions.

Placement procedures for LMC overlays differ in many respects from the procedure used for low-slump concrete overlays. The principal differences are:

- The deck must be kept wet for at least 1 hour before placing the overlay
- The mixing equipment must have a means of storing and dispensing the latex emulsion into the mixture
- The LMC mix is not air-entrained
- A separate bonding agent is not used
- The nominal overlay thickness is usually 1 to 2 inches
- The LMC mixture has a high slump
- Conventional deck finishing equipment may be used
- A proper cure requires a combination of water curing and controlled air drying

Almost without exception, latex-modified concrete is produced in mobile, continuous mixers that are fitted with an additional storage tank for the latex emulsion. While in storage, the emulsion temperature must be kept between 45°F and 85°F. This may present some difficulty, particularly during the summer months.

The bond coat consists of the mortar fraction of the latex-modified concrete, which is worked onto the deck using stiff brooms. If additional mortar is needed, it is easily obtained directly from the mobile mixer by cutting off the aggregate flow for a short period of time.

Mix proportions differ from low-slump concrete in that relatively more fine aggregate is used and the cement content seldom exceeds 650 pounds per cubic yard. The final mix design is selected after trial batches using various cement and aggregate combinations. This procedure is necessary because the latex is sensitive to, and may react differently, when different brands of cement and different aggregate sources are used.

The LMC mixture is highly fluid and usual slump (or penetration) requirements do not apply. Although the mixture is fluid, the water-cement ratio is relatively low, ranging from about 0.35 to a maximum of 0.40. The fluid nature of LMC makes for a workable, nearly self-leveling mixture, but this property also makes it difficult (and often nearly impossible) to maintain grade and thickness control on decks having even a moderate (say 6%) cross fall.

No special finishing procedures are required, and conventional finishing equipment can be used. For curing, wet Burlene® is applied as soon as possible after finishing, and left in place (and kept continuously moist) for 24 hours. This initial period of wet cure is necessary for the hydration of the cement and to prevent shrinkage cracking. After 24 hours the Burlene® is removed, and the overlay is permitted to air dry for the remainder of the curing period. Air drying is necessary to permit the latex to dry out, which then enables the latex particles to coalesce and form a continuous film within the overlay. The latex film, which fills cracks and pores within the mortar matrix, gives LMC its structural properties of high strength and low permeability. However, the film forming characteristics of latex are temperature sensitive, and develop very slowly at temperatures below 55°F. Curing at a lower temperature will require an extended curing period. (Note that all latex polymer manufacturers recommend air drying for at least 72 hours, and additional drying time during periods of cold weather.) Film formation ceases altogether at about 45°F.

The Department's experience with latex-modified concrete, although limited, suggests that a properly constructed LMC overlay will provide adequate deck protection and a relatively maintenance-free riding surface during a long (probably 25 years or more) service life. However, LMC overlays have not been considered, in California at least, to be a practical deck rehabilitation strategy, for several reasons. To begin with, the LMC mix design is dependent on trial batches which are evaluated by the latex manufacturer. Trial batches are needed to verify compatibility of the latex polymer with the cement and aggregate to be used in the LMC, which normally will be the cement and aggregate being used for other concrete on the project. However, there have been cases when it was necessary to change the brand of cement or the aggregate source, or both, to assure that the materials were compatible.

The time required for trial batch evaluation and mix design, which can take several months, must be factored into the project schedule. Furthermore, LMC overlays can be placed only during a very narrow construction window, since the material cannot tolerate hot, cold, dry, wet or windy weather conditions. After placement, it is necessary to prevent moisture contamination during the period specified for air drying. As previously noted, LMC is quite fluid when first mixed, and therefore is impractical for overlay placement on decks on a steep grade or decks with highly super-elevated cross slopes. These factors, along with a relatively high initial cost, suggest that LMC, based on realistic considerations, is not a practical material for deck-overlay construction.

Conventional 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 is a conventional air-entrained bridge mix with a cement content of 650 pounds per cubic yard, with minor modifications. The specified mix design provides for 50 to 55% fine aggregate; the maximum size for coarse aggregate is 1/2 inch; the water-cement ratio is limited and a water-reducing admixture is 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 have specified a water-cement ratio of 0.40 maximum.) Nominal reinforcing (epoxy-coated #3 bars at 12 centers in both directions) is provided, and the concrete is 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.

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. And while rehabilitation technology now favors thin polymer concrete overlays, other factors being equal, Portland cement concrete still is an appropriate choice where the deck configuration or other design considerations dictate the use of a thicker overlay than is economical with the polymer systems.

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.

Methacrylate Overlays

High molecular weight methacrylate, a low viscosity polymer resin, is a healer/sealer. Methacrylate flows by gravity into cracks less than 0.02 inches wide to seal cracks, on Caltrans bridge decks and as a prime coat for polyester concrete overlays. As a healer, methacrylate fills cracks from the bottom up, preventing water from entering cracked concrete. After setting, cracked concrete will be restored to 75-90% of original strength. Methacrylate is not a wearing surface; it is quickly abraded by vehicle traffic. A recent METS program checked cored samples of methacrylate work; one of the cores is shown in Figure 6-12. 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 6-12 is the same core under regular lighting. Under regular lighting, it is difficult to see more than 4 inches of crack depth, but under ultraviolet, it can be seen that the crack extended at least 5 inches deep.

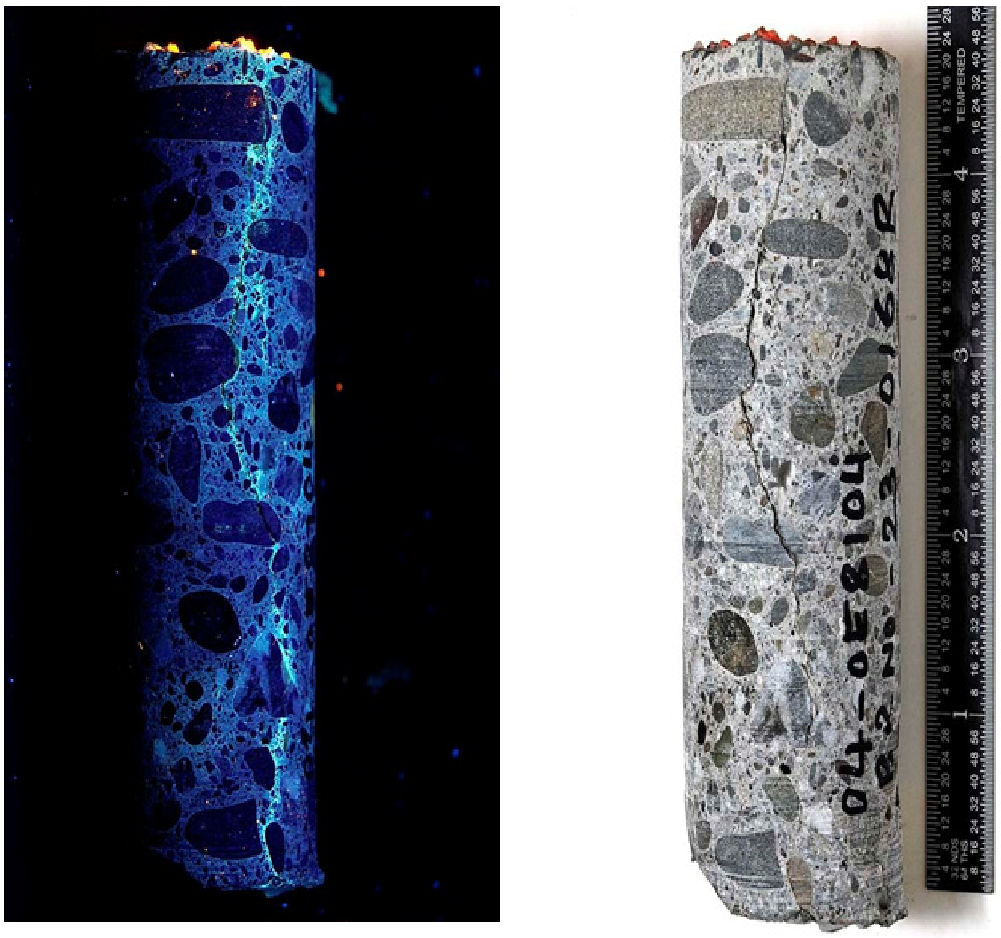

Figure 6-12. Methacrylate Treated Bridge Deck Cores.

Methacrylate lots are tested by METS; test results are available through the Materials Engineer. Methacrylate resin will not start the polymerization process without an initiator like cumene hydroperoxide or methyl ethyl ketone peroxide and a promoter like cobalt naphthenate or cobalt octoate. Initiator and promoter should only be combined in resin; mixing the two together without resin will result in a fire or explosion. In an example of how not to transport hazardous materials, Figure 6-13 includes a 250 gallon container of methacrylate, 4-gallon boxes of cumyl-hydroperoxide and 5-gallon buckets of promoter. In the event of an accident, the materials in the truck bed could mix with explosive results.

As part of the placing plan required by specifications, the contractor should explain how the materials will be safely transported.

Figure 6-13. Methacrylate Components.

Prior to bead blasting the bridge deck, the deck is sounded with a chain to identify delaminated concrete, which is removed and replaced with a rapid setting patch. When patching is complete, the entire deck is bead blasted to remove approximately 1/8 inch of material and then swept clean of dust. Note, if magnesium phosphate patching materials are used, there must be a 72-hour wait before placing an overlay.

Specifications require a test panel prior to actual placement to verify under field operating conditions, that the contractor has control of the process, that the work can be finished within a work window and that the surface will meet skid resistance requirements. From a contract administration perspective, the test panel should not be waived because it could then be argued that risk transfers to the structure representative. If field conditions such as materials in use, crew leadership, or time of operation are changed by the contractor, another test panel would be warranted. As part of the test panel installation, a certified industrial hygienist will perform air quality testing. The air quality report must be accepted by the structure representative before the contractor can proceed with the contractual deck overlay.

Respirators may be required when applying methacrylate, all personnel should be fitted with and possess respirators while on the job site. Avoid physical contact with polymeric materials. 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 the traveled way.

Applied materials should be pushed forward with a squeegee and the area swept with a broom to minimize material in grooved surfaces. The average coverage is about 1 gallon for an area of about 90 square feet. Fresh methacrylate is slippery, like walking on ice; if you must walk on the surface, tread carefully. Before the methacrylate sets, sand must be spread over the surface to increase friction for vehicles. After set, loose sand should be swept away.

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 has been spread to absorb wax and accelerate set time.

Polyester Concrete Overlays

A relatively new construction material, polyester concrete, was first used as an overlay in California in 1983. (A typical polyester overlay is shown in Figure 6-14.) Polyester concrete and PCC are similar in that before setting, they are plastic materials, capable of being cast as structural elements. Both materials consist of aggregate and a binder. Where PCC initiates hydration with water, the polymeric reaction of polyester resin is initiated with promoter and initiator like used in methacrylate.

When compared to PCC with 750 pounds of cementitious per cubic yard, polyester concrete has twice the flexural strength and compressive strengths are nearly equal, abrasion loss is 10%, and chloride permeability is 20% of PCC. Polyester concrete is also used as a patching material and as expansion dams when replacing joint seals.

Figure 6-14. Newly Applied Polyester Concrete Overlay.

The first polyester concrete overlays were placed as a multilayer system, also called broom and seed, where a layer of polyester was spread over the bridge deck and followed by a layer of aggregate. The process continued until the specified thickness was developed. Current practice is to mix aggregate and polyester and place the material in one lift, like concrete either in small batches by mobile mixer or with volumetric trucks, as shown in Figures 6-15 and 6-16. After placing, grading could be controlled with a "Texas" screed, or a laser-guided screed as shown in Figures 6-17 and 6-18.

Polyester materials may be used after being checked by the Caltrans Materials Engineering and Testing Service (METS). Test results can be obtained from the local METS Structure Materials Representative.

As with methacrylate overlays, a test panel is required along with the air quality report from the Certified Industrial Hygienist before the contractual overlay can proceed.

Figure 6-15. Mobile Mixer Operation.

Figure 6-16. Volumetric Operation (Note HAZMAT Placard ID # 1866).

Figure 6-17. "Texas" Screed with Ski Controlled Grading.

Figure 6-18. Laser Guided Screed.

Much of the preparatory work is similar to that when placing methacrylate.

- Surface preparation consists of removing any existing overlay material
- Removing and replacing unsound concrete
- Bead blasting the surface
- Removing all dust and placing a methacrylate primer coat

The bridge deck must be clean and dry when the methacrylate primer coat is placed. If magnesium phosphate patching materials are used, there must be a 72 hour wait before proceeding with the overlay. Polyester overlays will not bond to dirty or wet bridge decks or freshly placed mag-phosphate patches. A recent overlay on the I-580 in Oakland failed 3 months after being placed on a deck that was still damp from grinding. In another overlay failure, the spalling shown in Figure 6-19 is attributed to inadequately applied material (1/4 inch instead of a 1-inch thickness) placed over a wet surface.

Figure 6-19. Polyester Overlay Spalling.

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 the contact according to the material safety data sheet for decontamination.

Grade control under direction of the engineer, is required when placing material in the traveled way. Figure 6-20 is a photo of a rail guided system. Other methods could include a laser-guided screed like Figure 6-18 or a ski like Figure 6-17. Prior to approving the placing method, determine the nature of the overlay. If there is a profile correction, a ski would not correct the profile. If the purpose of the overlay is to provide a wearing surface, and the existing deck has an adequate profile, then a ski may be appropriate if allowed by specifications.

Polyester concrete cures in approximately 3 hours; work is often broken into segments that can be completed in single work shifts. Small operations with mobile mixers and "Texas" screeds can place 200 linear feet of overlay in a shift. Combining volumetric mixers with polyester paving machines can result in 1,000 linear feet in a shift.

Figure 6-20. Rail Grade Control.

When placed, the material must achieve 97% compaction in accordance with CT 552. Proper compaction and resin content is physically indicated by a surface sheen which occurs when resin rises to the surface. As with all overlays, the surface must pass profilograph testing and friction testing. Paving machines generally pass profilograph testing while the surface left by a "Texas" screed may require grinding to meet smoothness specifications.