

Guide for Repair of Concrete Bridge Superstructures

Reported by ACI Committee 546

Repair techniques for concrete bridge superstructures are described. This includes pier caps, beams, decks, curbs, sidewalks, and rails. Special emphasis is placed on decks. Recommendations for evaluation of damage, selection of repair method, and surface preparation are given. Repair materials given primary consideration are conventional portland cement mortars and concretes, and those using latex, epoxy resins, or methyl methacrylate. Only techniques that have been documented and used extensively are included. Guide recommendations are those considered necessary for severe exposure conditions.

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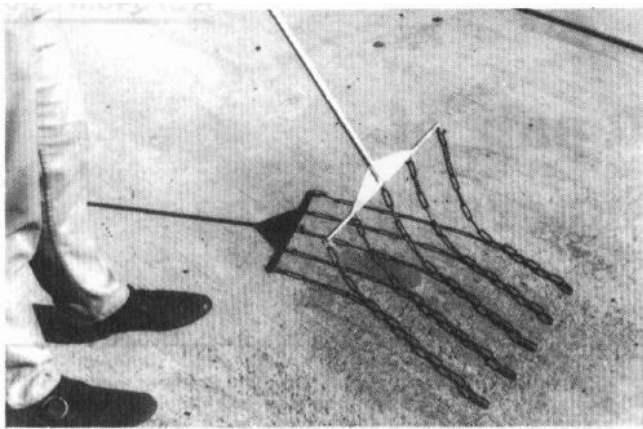


Fig. 1 – Chain drag (courtesy State of California Department of Transportation).

CHAPTER 1 – Introduction

1.1 – General

Although concrete bridges are generally durable structures that provide good service over many years with minimum maintenance, damage requiring repair does occur, and it occurs most commonly in the deck. Chlorides from salts used to prevent ice or from sea spray contribute to, or are the source of, most deterioration. Damage may also be due to poor design or construction, vehicle impact, or excessive overloading. Recommendations for the design and construction of bridge decks can be found in the report by ACI Committee 345.¹

This Guide is not intended to answer the question of whether a permanent or temporary repair should be made. Limited funds may only allow the filling of pot holes with an asphaltic material even though this may accelerate deterioration. When the state of deterioration is too far advanced to reclaim the surface, a temporary riding surface such as an asphaltic concrete overlay may be expedient. This, too, may accelerate deterioration and it will conceal that deterioration so that safety evaluations become more difficult. This Guide provides only information on recommended techniques and materials for enduring repairs.

Quite often it is necessary to keep bridges open to traffic while repairs are being made. The maintenance of safe traffic conditions can be the most troublesome and costly item in the repair program. The daytime hours between peak traffic loads in urban areas may not provide sufficient time to make repairs with portland cement concrete. Special patch materials may be justified when their cost is compared to the expense of prolonged detouring or controlling traffic through the repair zone.

1.2 – Scope

This Guide is intended for concrete superstructures of bridges, including pier caps, beams, curbs, sidewalks, rails, and with special emphasis on decks. The procedures can be used on other parts of the bridge or on other concrete structures.

Repair materials included are conventional portland cement mortars and concretes, and those utilizing latex, epoxy resins, or methyl methacrylate. Each of these materials has been used extensively in bridge repair, and their performance is well documented. Recommendations are those considered necessary for severe exposure conditions. Only proven, effective procedures are included. Procedures reported by Tuthill,² Tremper,³ Kulberg,⁴ and Felt,⁵ on restoration of deteriorated concrete provide the basic approach for the methods presented.

Other products not included have been subject to evaluation by State highway or transportation departments. A large number (over 300) of these evaluations are listed in the Patching Materials section of SPEL, Special Product Evaluation List.³⁰

Many of these materials offer the advantage of being rapid-setting materials with an accelerated rate of strength gain compared to conventional portland cement concrete mixes. Some of these materials may also have the property of very low shrinkage on setting and curing, or may expand slightly on setting and curing. Some may be susceptible to deterioration from freeze-thaw cycles or to repeated cycles of wetting and drying or to erosion from traffic.³⁴ In addition, the cost of such repair materials may be several times that of conventional portland cement concrete.³³ Each material should be evaluated for any specific intended use by laboratory tests, performance records, and total repair cost effectiveness.

Repair costs are not directly considered in this Guide. Costs will vary widely depending on type and extent of damage, its location, traffic conditions, and materials and methods of repair. Some costs are included in Reference 8. Material costs are presented in Reference 33.

Chapter 2 – Evaluation of damage and selection of repair method

2.1 – General

An evaluation of damage is essential in selecting a repair method. To evaluate damage, it is necessary to determine the extent, cause, and whether or not the cause is still active. Guidance on surveys for these determinations may be obtained from ACI 201⁷ and from ASTM C823.* The most common types of damage to bridge superstructures are defined in this chapter together with evaluation techniques. With each type of damage, applicable repair methods are suggested. Some repair material characteristics are provided. Selection of a repair material must be based on an evaluation of the damage, repair material characteristics, and local conditions.

If detailed evaluation of a damaged structure reveals that the original construction was of poor quality concrete, a lasting repair can probably be

*Applicable specifications are given in Chapter 8.

achieved with a high quality concrete or other patching material. If a high quality concrete has deteriorated, a lasting repair can only be achieved by moderating the exposure conditions and then repairing with a high quality material. Examples of exposure conditions that can be changed are drainage conditions, exposure to chloride deicing agents, and lack of mechanical protection for rails or parapets. Local patching is generally not advisable in extremely severe exposure conditions except for a temporary repair.

Repair materials must be compatible with the concrete that is being repaired. They should respond in the same way to changes in temperature and loads, and they should blend well in appearance.

The riding quality of the structure should be considered in selection of the repair method. Poor riding qualities may make an overlay of the entire deck desirable rather than patching only deteriorated areas. Skid-resistant characteristics of the patch material or overlay must be evaluated to determine if current safety requirements can be met.

If chloride contamination, corrosion, and deterioration of the concrete is extensive, patching may not be practical. In these situations, it is advisable to replace the entire slab or member. Removal of deteriorated or chloride contaminated concrete, and surface preparation operations in small areas require a considerable amount of hand labor, whereas an entire beam or deck can be removed by more economical methods.

A repair can be unsightly unless proper attention is given to factors affecting its appearance. Where appearance is important, particular care should be taken to ensure that the texture and color of the repair will blend with the surrounding concrete.

2.2 – Delaminations

Delaminations occur when layers of concrete separate from bridge decks or beams at or near the level of the top or outermost layer of reinforcing steel, generally parallel to the surface of the concrete member. Such areas give off a hollow sound when tapped with a rod or hammer. A chain drag, such as shown in Fig. 1, or other mechanical devices,¹² may be used to determine the extent of delaminations. The surface should be inspected for cracks that may have permitted penetration by surface contaminants.

The major cause of delaminations is the expansion resulting from corrosion of reinforcing steel due to intrusion of chloride ions. This is discussed in the report of ACI Committee 201.⁴⁴ It occurs with either repeated chloride deicer application or continued exposure to a marine environment.⁸ Inadequate cover over reinforcing steel will reduce the time to start of corrosion. Vehicular fires on bridges may also cause delaminations.

Depth of cover may be measured with either a hand-held¹⁵ or a rolling pachometer.¹⁶ Determination



Fig. 2 – Corrosion detector (courtesy Federal Highway Administration).

of whether or not reinforcing steel corrosion is active may be made by measuring the electrical potential using a copper-copper sulphate half-cell (ASTM C876),^{13,17} as shown in Fig. 2, and by measuring the chloride ion content of the concrete (AASHTO T260).¹⁴ When sufficient moisture and oxygen are present with a chloride ion content above 1.3 lb per cu yd (0.77 kg/m³), corrosion of reinforcement will occur in most bridge deck concrete.³⁵

Epoxy resin injection with the delaminated concrete in place may be used for repair where excessive contamination has not occurred;³¹ or delaminated concrete may be removed and repaired by the procedures followed. If a successful repair is not made, concrete above the delamination interface will eventually become dislodged and a spall will result.



Fig. 3 – A typical spalled area (courtesy National Research Council, Transportation Research Board).

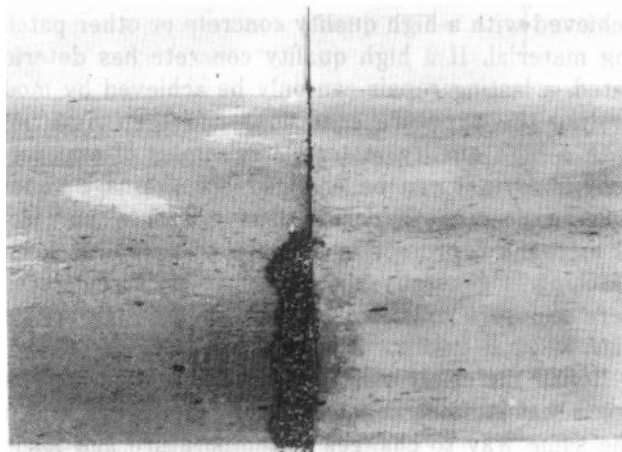


Fig. 4 – Joint spall temporarily filled with asphalt (courtesy Portland Cement Association).

2.3 – Spalls

A spall is defined as the depression resulting when a fragment is “detached from a larger mass by a blow, by the action of weather, by pressure, or by expansion within the larger mass.”^{6,7} A typical spall is shown in Fig. 3. Spalls are referred to as large when their size exceeds approximately $\frac{3}{4}$ in. (19 mm) in depth or 6 in. (152 mm) in any dimension.^{7,9}

The major cause of spalls is the same as that for delaminations. A special case of spalling that occurs at joints may be caused by corrosion of steel at expansion dams, or from traffic impact, or intrusion of material into an unarmored joint. A spalled joint temporarily filled with asphalt is shown in Fig. 4. Movements due to temperature fluctuations may allow such filler to work its way deeper into the joint resulting in forces which frequently cause increased damage.

Although the extent of spalling may be visually determined, potential spalling and the activity of causes of deterioration should be investigated as discussed in Section 2.2. Usually the area of active steel corrosion and chloride-contaminated concrete is considerably larger than the area of spalled or delaminated concrete. If only the area of spalled or delaminated concrete is removed and repaired, a continuing repair program will probably be required. However, if the concrete that is supporting active corrosion or is capable of supporting corrosion is removed and the repaired deck is properly protected with a waterproof membrane, bonded topping or overlay; a more durable repair will probably be obtained.¹⁴

Small isolated spall areas can be patched using any of the materials discussed in this Guide that do not contain coarse aggregate. Larger areas can be patched with concrete. When substantial areas are involved, overlays of dense portland cement concrete or latex modified portland cement concrete should be considered.

2.4 – Scaling

Scaling of concrete surfaces is defined as “local flaking or peeling away of the near surface portion of concrete or mortar.”^{6,7} A scaled concrete surface is shown in Fig. 5.

Light scaling refers to loss of surface mortar with no exposure of coarse aggregate. Medium and severe scaling refer to loss of mortar with increasing exposure of coarse aggregate. Very severe scaling refers to loss of coarse aggregate with the mortar.

The most generally accepted explanation of scaling involves the generation of internal pressures during freezing of the solution contained in saturated voids. To explain observed increases in severity of deterioration attributed to the use of deicing chemicals, the osmotic pressure theory has been postulated.^{7,8,9}

Also, it has been shown that deterioration closely resembling scaling from freeze-thaw action can occur without freezing when concrete is subjected either to cycles of wetting and drying or to concentrated solutions of chloride deicers. Such attack can occur beneath asphaltic concrete overlays which are usually permeable to water.^{10,11}

Although the extent of scaling may be visually determined, measurement of the chloride ion content of the concrete is advisable to evaluate future spalling potential.

Surface coatings [less than $\frac{1}{4}$ in. (6 mm) thick] have been used when scaling is in its early stages.^{18,37} Since delaminations frequently occur with such coatings, overlays of greater thicknesses are recommended.

2.5 – Cracked or fractured sections of concrete members

Only cracking that may potentially endanger the structural adequacy of the member should be considered for repair. Many cracks do not need repair. Some cracks cannot be repaired. If the crack width is increasing due to continuing overloads or due to structural settlement, complete replacement of the

member or some modification may be necessary. If the crack width is changing with temperature changes or load cycles and action is necessary, the crack should be treated as a joint and sealed.⁴⁶ Most repairable cracks are the result of impact on the member or a one-time overloading. Cracks in prestressed members should not be repaired without consultation with an engineer to determine the reason for the cracks.

It may be necessary to measure or estimate crack widths. This can be done with measuring microscopes or feeler gages. If necessary, the extent of cracking can be evaluated by pulse velocity techniques (ASTM C597) or by coring.

Fractured sections are differentiated from cracked members in that a portion of the member has become displaced. Repairable damage of this type most often occurs on parapets or fascia walls as a result of vehicle impact.

Epoxy resins generally can be used to repair cracks and bond fractured sections. It may be convenient to rout or widen cracks and then to fill with latex mortar if an overlay of latex mortar is to be used.

2.6 – Rutting

Rutting is defined as removal of concrete in wheel paths as a result of abrasion by vehicle tires. Rutting has become more prominent with the advent of studded tires. The extent of rutting is visually apparent.

Shallow rutting may be repaired with an epoxy resin coating,^{18,37} but such a repair may have a limited life. More extensive rutting, or shallow rutting combined with other damage, may make an overlay desirable.

2.7 – Repair material characteristics

Portland cement concrete used in a repair will have properties in its hardened state nearly the same as those of the older in-place concrete. However, if there is a difference in aggregate source, maximum aggregate size, or water content, properties will differ and the in-place concrete will probably have previously undergone drying shrinkage. Differential volume changes between a repair and the in-place concrete will almost certainly occur. Effects of differential volume change will generally be minimized by maximizing aggregate content, and minimizing water content within the limits of good proportioning practices and by following good curing procedures.

The inclusion of latex in a concrete or mortar may be used to reduce the water-cement ratio and with that reduced water-cement ratio, the long term properties of the hardened latex concrete will be similar to conventional concrete with the same cement content. However, chloride ion ingress into the latex modified concrete will be reduced.

Epoxy resin compounds have high adhesion, and higher tensile strength and thermal coefficient than portland cement concrete. This tends to induce failure in repaired concrete immediately below the bonded interface when subject to large temperature changes. Epoxy resins are generally compounded with agents to decrease stiffness so as to relieve stresses due to differential volume change. The inclusion of aggregate will reduce the thermal volume changes.

Methyl methacrylate polymer concrete properties are similar to those of epoxy resin concrete. The monomer can penetrate dried in-place concrete and will strengthen it after polymerization takes place.

Polymer concretes require the use of surface-dry, and preferably oven-dry, aggregate. Since the monomers for user formulated systems have very low viscosities, all forms and other boundaries of the placement must be sealed tight. Prepackaged methyl methacrylate materials that handle like mortars are available.

Portland cement and latex modified portland cement mortar and concrete repairs generally require curing for 3 to 4 days. However, Iowa has exposed partial depth patches of low slump, high cement content concrete to traffic in 3 to 4 hr.

Epoxy resins are available in a variety of formulations for use at different temperatures. The curing rate of epoxy resins is temperature-dependent so that strength development will vary. Traffic can generally be permitted in 6 hr, or less.

Rapid curing methyl methacrylate concretes may accommodate traffic 2 hr after placement. Polymerization times are affected by the formulation, ambient temperatures at placement, and curing procedures.



Fig. 5 — Scaled concrete (courtesy Portland Cement Association).

Chapter. 3 - Surface preparation

3.1- Scope

Surface preparation is defined as the process of making ready the contact surfaces of the existing concrete for, (1) repair of scaled and/or spalled areas, (2) patching of sections where sound but chloride-contaminated concrete has been removed from areas adjacent to reinforcing steel, and (3) construction of complete bridge deck overlays. Methods are recommended for preparing those surfaces so that the repair material will be properly bonded to give a structurally sound and durable repair.

3.2 - Removal of deteriorated concrete

The basic requirement for success of any repair is proper preparation of the existing concrete. Regardless of the type or position of the bridge member, or the type of repair to be made, all unsound and disintegrated concrete must be removed. Concrete contaminated with chlorides must be given special consideration for removal. Removal of all concrete that shows evidence of active or potential corrosion will more nearly guarantee a durable repair.

Top edges of the areas to be patched should be sharp but corners should be rounded to make it easier to obtain good contact between the substrate and patch material. Edges of patch areas should be undercut to eliminate feather edges and to provide a keyed patch. If a saw cut is made, the cut can be tilted by placing one wheel of the saw carriage on a plank. The saw cut should not overrun the area to be patched nor should it be so deep as to cut reinforcing. Fig. 10a shows a deteriorated area being cut out with a saw. Since the extent of unsound concrete is frequently not evident from initial sounding, saw cutting can become a tedious and expensive operation. A satisfactory patch edge can be obtained with a chipping hammer.

Chipping tools must be selected such that they will not damage surrounding areas. Where unnecessarily heavy equipment and/or sharp-edged or pointed tools are used, possible damage to the surrounding concrete can create additional areas of potential failure. Selection of equipment may be based on the difficulty encountered in removing material but it is recommended that 30 lb (14 kg) be the maximum hammer weight. Gad points are better than chisel points because they leave a rougher texture for bond and a chisel inserted in a crack is likely to cause an extension of the crack.

Where only partial-depth patching is required additional limitations on air hammer weights and special instructions to hammer operators should be made to avoid breaking through the deck or fracturing the concrete below the partial-depth patch area. Special care should be applied in removing unsound concrete from around reinforcing steel and embedded anchorages (such as for expansion joint steel

shapes) to prevent loss of bond in the remaining sound concrete.

Large areas requiring the removal of a relatively thin layer of concrete, such as in shallow scaled decks, may be more effectively treated with a scabber, scarifier, or planer than with chipping hammers. These machines are particularly effective in cleaning a deck by removing the top surface contamination of traffic oils and greases. A scarified surface is shown in the lower right portion of Fig. 6. Improper use of a scarifier may create small fractures in the base concrete.

3.3 - Reinforcing steel

Delaminated areas and spalls sometimes extend to or beyond the reinforcing steel. Care should be exercised in the use of saws and other power tools to avoid damage to the steel. If removal of material has exposed more than half of the perimeter of a reinforcing bar, it is recommended that the bar be completely exposed with sufficient clearance under the bar to assure encasement and bond. Steel should be clean. For concrete patches, loose, scaly rust must be removed; thin, tightly-bonded rust need not be removed. Bits of mortar, if hard and sound, can be left if they tightly adhere to the steel.

Steel, in areas to be patched with materials other than portland cement concrete, should be clean and dry with no loose scale, rust, mortar, or other material. Sandblasting is the most effective cleaning method.

Where reinforcing steel is to be cut and replaced, lap splices with accepted lap lengths as determined by an engineer are preferred. If welding is used, it must conform to the Structural Welding Code — Reinforcing Steel (AWS D1.4).

3.4 - Cleaning of area to be repaired

After removal of unsound concrete, the area should be flushed with high pressure water or vacuum cleaned to remove loose particles and dust. Air blowing may be effective, but the compressor should be equipped with a functioning oil trap to prevent contamination.

All concrete surfaces on which new materials are to be bonded must be clean. Tar and asphalt should be removed by mechanical methods and the surface should then be sandblasted. Any asphalt or oil will interfere with methyl methacrylate polymerization. Strong detergents, such as sodium metasilicate or trisodium phosphate, may be useful in removing surface oil contamination, however, oils that have penetrated the surface should be removed by chipping or scarification. The chipped surface often retains particles that have been broken but not dislodged. These particles should be removed by high-pressure water jetting or sandblasting.

Linseed oil mixtures are sometimes used on decks to prevent scaling. These mixtures penetrate concrete to depths of about 1/16 in. (2 mm). Scarifying