

Reinforced Concrete Bridge Repair Methods

Patching concrete is the most common repair on the bridge inventory, and one of the most often redone. A patch that debonds, cracks or sets off new corrosion around its edges a few years later costs more than the original work, plus a second lane closure. This course walks through the full repair sequence for reinforced concrete bridge members: evaluating and categorizing the damage, removing concrete and treating the reinforcement, preparing the substrate, choosing a repair material, placing and curing it, and accepting the work. It also covers the ring-anode (halo) effect, which makes chloride-contaminated members corrode faster next to new patches, and the tools used to limit it, such as embedded galvanic anodes. It also covers crack injection, deck repairs, hydrodemolition and inspection of the finished work. The main sources are TxDOT's Concrete Repair Manual (Chapters 2 and 3, read online), the Michigan DOT Construction Manual Section 712 on concrete bridge rehabilitation, ACI TechNote 364.6T-02 on concrete removal around corroded reinforcing steel, the FHWA Bridge Preservation Guide (Spring 2018) and the FHWA/NHI Underwater Bridge Repair, Rehabilitation, and Countermeasures reference manual (FHWA-NHI-10-029). Agency-specific values are reported as that agency's requirements, not as national rules. Worked numbers in the examples are illustrative and were computed for this course, not taken from a real bridge. The ACI 546R and ACI 345.1R guides in the catalog are paywalled and were not reviewed, so no requirement is quoted from them.

Learning objectives

- Evaluate damage before repair
- Prepare surfaces and reinforcement
- Select repair materials
- Avoid the ring-anode effect

Why patches fail

A concrete patch is a small composite structure. New material is bonded to old concrete and to reinforcement that has already been corroding, and the joint between them must carry shrinkage, temperature and load stresses for years. When patches fail, the cause usually falls into one of a few groups:

- **Bond failure.** TxDOT's Concrete Repair Manual (CRM) calls debonding between the repair material and the substrate "one common cause of early failure" in deck repairs. It notes that thin repairs over large areas "tend to build up very high stresses at the bond line." Dirty, smooth, dry or over-wet substrates and poor curing all weaken the bond.
- **Incomplete removal.** Delaminated or chloride-laden concrete left at the patch edges keeps deteriorating and soon shows up as a new spall around the old one.
- **Material incompatibility.** The CRM's commentary on major spall repair says bond-line failures come from "loading, differential thermal expansion, drying shrinkage and contraction between the repair and parent material." It calls a comparable coefficient of thermal expansion and a comparable or lower modulus of elasticity "critical" where significant stresses are likely.
- **Electrochemical incompatibility (the ring-anode or halo effect).** Chloride-free patch material next to chloride-contaminated concrete creates a potential difference along the continuous reinforcing bar, so corrosion speeds up just outside the patch.

- **Wrong repair type.** The CRM warns that "partial-depth repairs are often implemented when full-depth would have been more appropriate," and that rapid-setting materials chosen for speed often shorten service life.

Each step in this course targets one or more of these failure modes. The CRM puts it simply: "Each step in the repair process (preparation, proportioning, mixing, application, and curing) is critical in the overall performance of the repair material."

Step 1: Evaluate before you repair

Repair begins with finding out why the concrete failed and how far the damage extends. The patch limits drawn on the plans are only an estimate. MDOT's Construction Manual Section 712 notes that plans typically show general deck patching areas, "but the final areas will be determined by sounding the concrete."

Map the extent

- **Sounding.** Chain drag on decks and hammer sounding on other members locate delaminations by their hollow sound. MDOT tells inspectors to make sure the saw-cut perimeter "extends to sound concrete to ensure all delaminated concrete is removed." The CRM's full-depth deck procedure adds about 3 in. beyond the sounded boundary in both directions unless the plans say otherwise.
- **Soffit and adjacent surfaces.** The CRM tells inspectors to check the deck soffit at partial-depth repair locations, because "bridge deck distress oftentimes progresses full depth, as evidenced by cracking in the deck soffit."
- **Previous repairs and overlays.** When a deck has already been overlaid, MDOT says to inspect patch edges for signs that the delamination extends past the proposed patch, and to enlarge the patch if needed.

Identify the cause

The right repair depends on the mechanism. ACI TechNote 364.6T says that when corrosion problems are found, "the chloride ion concentration and the depth of carbonation in the existing concrete should first be determined." It defines a high risk of continuing corrosion whenever, at the reinforcing steel level, "the acid-soluble chloride content by weight of cement exceeds 1% (ASTM C114) or cement paste is carbonated." Chloride profiles from cores or powder samples, and carbonation depth from a phenolphthalein spray on a fresh fracture, tell the structural engineer whether the problem is limited to the visible spall or runs through the whole member.

Corrosion-driven spalls in salted or marine exposure call for removal behind the bars and attention to the halo effect. Spalls from an impact or a construction defect in chloride-free concrete may need only a well-executed cosmetic or structural patch. Distress from ASR, freeze-thaw or sulfate attack (covered in BR-C01) may make patching a stopgap at best, because the mechanism continues in the concrete around the patch.

Decide whether patching is the right answer

Patching is a local fix. The FHWA Bridge Preservation Guide lists "Concrete Deck Repair ... in Conjunction with Overlays, CP Systems or ECE Treatment" as a condition-based maintenance activity, which recognizes that on a contaminated deck patching alone does not address the chlorides still in the deck. When delaminations and high chloride levels are widespread, the options grow to include deck overlays after hydrodemolition, cathodic protection, electrochemical chloride extraction or replacement. That choice is an asset-management decision, but it should be made before the repair contract is written, not after the third round of patches.

Step 2: Categorize the damage

The TxDOT CRM sorts spalls by severity, because "appropriate repair materials and methods differ significantly depending on the spall depth, size (area), cause(s) and configuration (horizontal, vertical, or overhead)." It stresses that these are general definitions and the Engineer may categorize a spall differently. Its categories (Chapter 2, Section 1) are:

Category	TxDOT definition (summarized)	Typical repair material (TxDOT)
Minor	Less than 1 in. deep and under 12 sq in. in area. A deeper spall (2 in. maximum) can count as minor if it does not go beyond the outer layer of reinforcement. If more than 50% of a bar or strand circumference is exposed, the spall is Intermediate.	Neat epoxy or epoxy mortar (TxDOT Type VIII)
Intermediate	Exposes more than 50% of the outer-cage bar or strand circumference, or is more than 2 in. deep. Maximum depth 6 in. No significant service-load stresses expected in or around the repair.	Preapproved proprietary bagged repair material (DMS 4655), preferably extended with coarse aggregate; batched concrete where practical
Major	Damage extends well beyond the outer layer of reinforcement. Significant service-load stresses are likely in or around the repair.	Batched concrete matching the parent concrete

The CRM spall definitions exclude the riding surfaces of bridge decks, which have their own repair section (partial-depth, over precast panels and full-depth). The key idea carries over to any agency's system: **non-structural** repairs should avoid attracting load, while **structural** repairs must restore capacity and therefore need material that behaves like the original concrete.

Configuration matters too

Horizontal (top-surface), vertical and overhead repairs place material differently. The CRM notes that most contractors use trowel-applied material for vertical and overhead work, with a maximum lift of 2 in. or the supplier's maximum, whichever is less. Form-and-pour is usually better for horizontal repairs because the material can be extended with coarse aggregate, which "significantly reduces the potential for shrinkage cracking." Pneumatically applied concrete (shotcrete) is a third option for large vertical and overhead areas. The CRM does not cover it and refers to TxDOT Item 431.

Step 3: Remove the concrete

Outline and saw-cut the perimeter

Repair boundaries should be simple shapes with straight edges. MDOT notes that "a square or rectangular patch is less susceptible to shrinkage cracking than patches with sharp angles or many corners," and requires patches spaced less than 1 ft apart to be combined into one larger patch. The perimeter is saw-cut so the patch has a square edge rather than a feathered one, which would be too thin to survive. Agencies set somewhat different depths:

- TxDOT deck repair: saw-cut the perimeter about 1/2 to 3/4 in. deep without cutting existing reinforcing steel. For intermediate spalls, saw-cut "to eliminate feathered edges and to ensure that the repair material will be applied in depths no less than 1/2 inch." Where practical, undercut the perimeter at about 30° so the profile helps hold the material in place.
- MDOT: verify the saw can make a 1 in. deep cut. Saw-cut substructure patches 1 in. deep, taking care not to cut reinforcement. Saw cuts are also required on the deck underside for full-depth patches, and may need to be shallower there if the bottom mat is high.

Any bar cut by the saw becomes the contractor's responsibility to supplement. MDOT notes that if there is no room for a lap splice, the bar may need to be epoxy-anchored into adjacent concrete to develop it.

Chip out unsound concrete without damaging what stays

Breakers that are too heavy cause microcracking ("bruising") in the concrete that remains, creating a weak layer just under the bond line. Agencies limit hammer size accordingly:

- TxDOT spall repairs: hand tools or power-driven chipping hammers of the 15-lb class maximum unless the Engineer approves otherwise.
- TxDOT deck repairs: hammers up to 30 lb for the bulk of the work, but 15-lb or smaller hammers at the base and perimeter.
- MDOT: patches directly above prestressed beam top flanges must be chipped with hammers of 60 lb or less. Hydrodemolition touch-up uses pneumatic hammers of 60 lb or less.

The CRM warns that an intended partial-depth deck repair can "unintentionally become full-depth" if equipment is too heavy, and that the contractor is not paid extra for full-depth repairs its own operations caused. If perimeter sounding after removal shows damage beyond the intended boundary, TxDOT requires the repair to be extended to include it.

Depth: get behind the steel

Once corroded reinforcement is exposed, the removal must continue behind the bar. ACI TechNote 364.6T gives the general rule: remove concrete around the bar "leaving in all directions a clear distance of at least 1/4 in. (6 mm) plus the dimension of the repair material maximum size aggregate," and continue along the bar "until the bar is essentially free from corrosion products." Agencies turn this into fixed dimensions:

Source	Clearance behind exposed reinforcement
ACI 364.6T-02	At least 1/4 in. plus the maximum aggregate size of the repair material, all around the bar
TxDOT CRM, intermediate spalls	3/4 in. or 1.5 times the largest aggregate size in the repair material, whichever is greater
TxDOT CRM, partial-depth deck	Minimum 3/4 in. below the top layer of steel, even if the defect stops above the bars
MDOT 712	At least 3/4 in. behind the bars, including sound concrete if necessary. With MDOT's patch mix (26A aggregate, 1/2 in. maximum), this lets the aggregate engage the steel and consolidate

The CRM's field rule of thumb: clearance is adequate "when you are able to wrap your fingers around the bar."

When should the bar be undercut? The CRM triggers full removal around the bar for intermediate spalls "if more than 1/2 the perimeter of any mild reinforcement is exposed or if the exposed bar exhibits significant corrosion." For minor spalls with less than 4 in. of exposed steel, it says the steel should not be removed and sound concrete behind it should not be excavated unless more than half the circumference is exposed. ACI 364.6T ties the decision to contamination: significant chloride or carbonation at bar level may require removing the surrounding concrete. That avoids leaving a bar partly passive and partly depassivated around its circumference, "a combination that may lead to accelerated corrosion."

Prestressing steel is different

The CRM says not to chip around prestressing strand exposed anywhere away from the immediate end of a member, and to consult the Engineer instead. When chipping near strand is necessary, avoid striking it or causing wire breaks. At member ends where strand is exposed in a spall, the strands are recessed at least 3/8 in. by torch or another approved method so they are not left as protruding dowels exposed to moisture and chlorides. Prestressed member damage is covered further in BR-P02.

Step 4: Treat the reinforcement

Clean the steel

Exposed reinforcement is blast-cleaned to remove rust and scale. The CRM calls for abrasive blasting of non-epoxy-coated bars and of epoxy-coated bars with failed coating. MDOT requires the abrasive blast to remove "loose rust and scale from the exposed reinforcing steel." On hydrodemolished decks, MDOT accepts the water-jet pressure as meeting the blast-cleaning requirement.

Judge section loss and supplement

After cleaning, the remaining section is checked:

- **TxDOT deck repair:** replace bars "when cross-section is reduced greater than 25 percent." New or added reinforcement is lapped at least 6 in. and tied at no more than 18 in. spacing (the CRM's provision for reinforcement installed in the repair).
- **MDOT 712:** replace exposed transverse bars and supplement any exposed bars that have lost 1/4 or more of their original bar diameter. Supplemental steel is lapped at least 35 bar diameters, tied within 3 in. of each end of the lap, and tied at every third bar intersection.

Note the difference: TxDOT's trigger is a *cross-section* loss over 25%, while MDOT's is a *diameter* loss of 1/4 or more. A 25% loss in diameter is roughly a 44% loss in area, since $(0.75)^2 \approx 0.56$. The engineer should know which measure the governing specification uses. For load rating of members with section loss, see BR-L04.

Epoxy-coated bars

Where epoxy-coated bars are blast-cleaned, the CRM requires an approved epoxy coating applied around the full circumference, extending at least 3 in. from the repair perimeter into the repair area, and repair of minor coating damage. MDOT notes a conflict with galvanic anodes: if new epoxy-coated bars are added to a structure with deteriorated epoxy-coated or plain bars, part of the new coating should be removed so the new and existing steel connect electrically, and continuity should be confirmed with a multimeter so any anode works. MDOT also says epoxy coating repair material "is not an acceptable alternative for anodes and should only be used in small repairs."

Anchoring the patch

Exposed reinforcement usually provides the mechanical tie between patch and parent concrete. Where none is exposed but the spall is thick enough to need cementitious material, the CRM requires anchors at no more than 6 in. on center each way (or as the Engineer requires). These are stainless steel expansion anchors, or 1/2 in. minimum rebar or threaded stainless pins set in Type III anchoring adhesive with at least 4 in. embedment. Cover over anchors must be at least 1/2 in. for stainless and 1 in. for non-stainless steel. The CRM points out a common mistake: anchors that do not protrude far enough leave most of the

patch thickness unanchored. For major repairs with supplemental bars set in adhesive, the CRM calls for at least 6 in. embedment and 1-1/2 in. cover.

Adhesive anchor installation is sensitive to workmanship. The CRM requires holes 1/8 to 1/4 in. larger than the bar, cleaned by brushing and oil-free compressed air, dried, about one-third filled with adhesive, and the bar twisted in. It warns that too little adhesive reduces pullout resistance and too much can leak onto the substrate and act as a bond breaker.

Step 5: Prepare the substrate

Most bond failures start with the surface the repair is placed on. Three things matter: roughness, cleanliness and moisture condition.

Roughness

A rough, chipped surface gives the patch a mechanical key. The TxDOT CRM sets targets by repair type and refers to the International Concrete Repair Institute (ICRI) Concrete Surface Profile (CSP) scale:

- Intermediate spalls: "a minimum surface roughness profile of 1/8 inch or CSP (Concrete Surface Profile) 6 per ICRI," which the CRM admits is "difficult to quantify and measure."
- Partial-depth deck repairs: "a uniformly rough surface with a chipped appearance (1/4 inch minimum surface profile or ICRI Concrete Surface Profile 9)."

The ICRI profile chips themselves were not reviewed for this course. The CSP numbers are given as the CRM states them.

Cleanliness

The substrate must be sound and free of laitance, oil, dust and debris. The CRM requires blasting the repair area with high-pressure air "equipped with filters to remove all oil from the compressed air" just before repair. Unfiltered compressor oil is itself a bond breaker. For deck repairs, the CRM calls for high-pressure water blasting to remove loose particles, followed by a high-pressure air blast for final cleaning. For substructure patches, MDOT requires abrasive sand blasting of the prepared cavity to remove loose material and contaminants and to clean the exposed steel.

Timing matters as much as method. Dust settles back and surfaces dry out, so cleaning should be done immediately before placement, not the day before. The FHWA/NHI underwater repair manual describes the same idea for marine work: primary surface preparation first, then a final cleaning just before placing repair material, because silt and marine growth build up quickly.

Moisture: saturated surface-dry (SSD)

Dry concrete pulls water out of a cementitious repair material, weakening the paste at the bond line. Standing water dilutes it. The target in between is saturated surface-dry. The CRM quotes ACI's terminology: SSD is the condition of a porous solid "when the permeable pores are filled with water and no water is on the exposed surfaces." The CRM adds a practical description: the substrate is saturated to a depth of about 1/8 to 1/4 in. but the surface has no free water, "as if it had been dried with a towel."

How agencies get there:

- TxDOT intermediate spalls: soak the surfaces for 2 to 24 hours, or pressure water-jet for at least 15 minutes just before application. The surface may be damp but must be free of standing water.

- TxDOT decks: achieve SSD by high-pressure water blasting at least 15 minutes before placement, and remove all ponded water just before placing.
- MDOT: flush the patch with clean pressurized water and remove excess or ponding water with an air blast immediately before placing concrete, so the existing concrete does not "rob moisture from the green patch concrete."

For major repairs, the CRM says that if the parent concrete is no longer SSD when the forms are ready, the forms come off and the surface is re-sprayed.

Bonding agents and scrub coats

Many proprietary materials bond best to an SSD surface with a scrub coat: a thin layer of the repair mortar brushed hard into the damp substrate to fill all voids, with the patch placed while the scrub coat is still wet. The CRM says not to use a proprietary epoxy bonding layer instead of an SSD substrate unless the Engineer approves. If a bonding agent is approved, it must be a TxDOT-approved Type V or Type VII epoxy, and the repair is placed while it is still tacky. A bonding agent that has cured before the patch is placed becomes a smooth, glossy bond breaker. Epoxy repairs are the exception to SSD: for Type VIII neat epoxy and epoxy mortar, the CRM says "surface must be dry and clean."

Step 6: Select the repair material

Material choice is a balance among compatibility, constructability, schedule and cost. The TxDOT CRM sets out a hierarchy that applies broadly.

Strength: enough, not more

The CRM states that "it is a common misconception that higher compressive strength equals a better repair. In reality, excessively high compressive strength can lead to early failure as a result of excessive loads being transferred into the repair material." Higher strength usually means a higher modulus, so a stiff patch in a more flexible member attracts load and stress at its bond line. For intermediate (non-structural) spalls, the CRM advises materials with "only enough strength for the intended use," noting that lower-strength materials "typically perform better since they also have a lower modulus of elasticity, and therefore greater ductility."

Speed: slower is usually better

The CRM says that "in general, slower strength development means better long term performance," and that contractors often choose rapid strength-gaining materials when they are not needed. For decks it is blunt: "The faster the return to service, the shorter the anticipated service life of the repair," and "re-repair of previously repaired decks occurs frequently when the rapid strength gaining materials are used."

Material families

Material	Typical use (per sources reviewed)	Watch-outs
Neat epoxy / epoxy mortar (TxDOT Type VIII, ASTM C881 Type I or IV)	Minor, thin spalls. High bond; neat epoxy seals small exposed steel areas	The CRM says not to use it for structural repairs or where significant movement is expected, because its thermal expansion coefficient "varies significantly from the concrete substrate." Epoxy mortar depth limited to 1 in. unless approved

Proprietary bagged cementitious mortars and concretes (TxDOT DMS 4655)	Intermediate spalls, vertical and overhead work, congested or thin areas	Use neat for up to 2 in. thick and extended with coarse aggregate above 2 in. (CRM). Working time is often 15 to 30 minutes. No retempering
Batched (ready-mix) concrete	Major spalls, structural repairs, large deck repairs	Best match to parent concrete. The CRM says to batch at least 1 cu yd even for smaller repairs to get a proper mix, and to use the original mix design where known
Rapid and ultra-rapid deck repair materials	Deck repairs that must reopen within hours	Shorter expected life, as noted above
Latex-modified (LMC) and silica-fume-modified (SFMC) concrete	Deck patches and rigid overlays (MDOT)	MDOT notes these mixes are "very dense and less permeable than standard concrete mixes and therefore slow the corrosion of the reinforcement"

Aggregate size and extension

Coarse aggregate reduces shrinkage. The CRM notes that extending bagged material with coarse aggregate "can significantly reduce the potential for shrinkage and cracking," and that most trowel-applied materials lack coarse aggregate, so they can crack from drying shrinkage if not applied and cured properly. Aggregate must still fit: the CRM limits maximum aggregate size to 1/3 of the clear space between reinforcement or the cover, and for major repairs to 1/3 of the smallest dimension including reinforcement clearance, removing large aggregate by wet sieving if necessary. That is why the clearance behind bars is tied to aggregate size.

Deck repair material by return-to-service time (TxDOT)

Needed return to service	TxDOT material
3 hours	Type B Ultra-Rapid Repair Material (DMS 4655)
6 hours	Type A Rapid Repair Material (DMS 4655)
24 hours	Class K concrete (specialty ready-mix, Engineer-approved mix design)
2 to 4 days	Class S concrete (new-deck mix), which offers "the best likelihood of long term serviceability." Moist cure 72 hours (absolute minimum 48)

The CRM also says to use material extended with coarse aggregate for deck repair depths over 3 in. Unless the plans say otherwise, it requires at least 3,600 psi compressive strength before opening to traffic. These are TxDOT categories and values. Other agencies use different product classes and opening criteria.

Marine and underwater repairs

The FHWA/NHI underwater repair manual gives mix guidelines for repair concrete placed in water: at least 600 pcy cement, a maximum water/cement ratio of 0.40 and at least 4,000 psi. It recommends Type II or V cement in brackish or sea water for sulfate resistance, typically 20 to 25% fly ash and 5 to 7% silica fume replacement for low permeability, and anti-washout admixtures for underwater placement. It notes that repair mixes often use 1/2 or 3/8 in. maximum aggregate because of small spaces and pump lines, and that "opinions vary on the effectiveness" of corrosion-inhibiting admixtures.

Step 7: Mix, place and cure

Mixing

A good material can be ruined in the bucket. The TxDOT CRM's mixing rules are worth adopting anywhere:

- Measure components with graduated containers. "Do not estimate the proper amounts while adding the different components."
- Mix mechanically (drill and paddle or mortar mixer), never by hand. For Type VIII epoxy, use a low-speed drill (400 to 600 rpm) for at least 3 minutes for whole batches.
- Do not add water to make the mix workable. The CRM warns that contractors often measure water with "5-gallon" buckets whose actual volume "can vary significantly," and says to check the real volume.
- Do not mix until surface preparation is complete, and mix only what can be placed right away. Many materials have 15- to 30-minute working times, and some set in under 15 minutes in hot weather.
- Retempering of bagged mixes is not permitted. The CRM explains that over-mixing material that has started to set "can reduce the compressive strength and increase the permeability."
- In hot weather, use cooled or iced mix water. The CRM notes that product data sheet set and working times are based on a 70°F laboratory.

Temperature limits

For cementitious spall repairs, the CRM requires the repair material and substrate to be between 40°F and 95°F at application. It does not allow placement when the ambient shade temperature is below 40°F and falling, but allows it at 35°F and rising. It requires shading above 100°F, and insulation when temperatures will drop below 50°F during curing. If artificial heat is used, the air around the repair (or the repair material, for batched concrete) must not exceed 130°F. Formwork should preferably not be hotter than 90°F, to avoid flash set.

Placement

- **Trowel-applied (vertical and overhead):** place over the wet scrub coat in lifts of at least 1/2 in. and no more than 1-1/2 in. unless approved (CRM, intermediate spalls). Roughen each lift before it reaches initial set, let it reach initial set so it does not sag, and wet it before the next lift.
- **Form-and-pour:** build tight forms before mixing so grout does not leak, place while the substrate is still SSD, and consolidate without over-vibrating. Do not vibrate self-consolidating products. MDOT's substructure practice uses forms no taller than 4 ft per section and "birds' mouths," funnel-shaped openings at least every 4 ft, so material can reach the top of tall patches.
- **Decks:** consolidate with immersion vibrators using vertical insertions. The CRM warns against dragging the vibrator, which "may cause segregation and loss of entrained air." Texture the patch surface (MDOT).

Curing

The CRM states that "failures often occur in cement-based repair materials due to inadequate curing." Patches are small, have high surface-to-volume ratios and are often made with rich, shrinkage-prone mortars, so they lose moisture quickly. Plastic shrinkage cracking occurs before the material gains tensile strength, and drying shrinkage stresses the bond line later.

- TxDOT spall repairs: moist cure exposed surfaces for at least 72 hours (wet mats, spray or ponding). Leave forms in place for at least 72 hours on form-and-pour work. Curing compounds only with the Engineer's approval, with residue removed afterward.

- TxDOT batched concrete repairs: cure at least 72 hours, usually by leaving forms in place and covering openings with wet mats.
- TxDOT decks: "Although 72 hours of curing time is ideal, that is seldom practical in deck repair applications. Even a few hours of moist curing can be beneficial."
- MDOT: follow the specified curing for the patch material without interruption. MDOT's commonly used Bridge Deck Joint Repair special-provision material requires a 7-day wet cure, but may be opened at 2,000 psi verified by compressive (not flexural) testing.

Epoxy repairs are different. The CRM says moist curing is not required, but cure time increases significantly below about 50°F.

The ring-anode (halo) effect

What happens

The FHWA Bridge Preservation Guide describes the halo effect in decks. It occurs when a delaminated area, caused by reinforcement corrosion from chlorides and moisture, "is removed and repair material (containing no chlorides) is put in its place. If a high concentration of chlorides remains in the area surrounding the replaced concrete, the corrosion potential will lead to rapid corrosion in the area surrounding the repair."

The FHWA/NHI underwater repair manual explains the electrochemistry. After a patch, the reinforcing steel "is embedded in and runs between chloride free repair concrete and contaminated concrete. The interface areas experience a large local change in corrosion potential between the new and remaining concrete which accelerates corrosion at the boundaries of the repair, hence the term 'ring corrosion.'" Steel in the new, alkaline, chloride-free patch becomes a large passive cathode. Steel in the contaminated concrete just outside the patch, which had been corroding at a moderate rate as part of a broader corrosion field, becomes a concentrated anode driven by that large cathode. The result is new delaminations ringing the old patch, often within a few years.

ACI TechNote 364.6T describes the same condition: "When a portion(s) of the electrically continuous reinforcing bar is exposed to a chloride-free repair material and the rest of the bar remains in contact with chloride-contaminated and/or carbonated concrete, corrosion in areas adjacent to the repair may be accelerated." The ACI note applies the same reasoning around a single bar's circumference, which is why it recommends undercutting a bar in contaminated concrete rather than leaving one side bedded in old concrete.

Ways to manage it

1. **Remove more contaminated concrete.** Extending removal behind and along bars into concrete below the chloride threshold reduces the potential difference. The FHWA/NHI manual says removal "should extend behind all reinforcing steel in order to remove chloride contaminated concrete" and notes that cost estimates often allow up to 20 percent more removal than the visible distress. Full removal of contaminated concrete is often impractical, however, because chlorides at the bar level may extend across the whole deck.
2. **Embedded galvanic anodes.** Small zinc anodes tied to the cleaned reinforcement around the patch perimeter corrode sacrificially and supply protective current to the steel just outside the patch. MDOT requires galvanic anodes on uncoated reinforcement throughout substructure and deck patches, "spaced as indicated in the plans, but do not exceed 24 inches between the anodes," installed under its specification Section 712.03.Y. Anodes only work if the steel is electrically continuous, so MDOT calls for multimeter continuity checks between new and existing bars.

3. **Cathodic protection (CP) of the whole element.** Galvanic or impressed-current systems protect a full deck, pier or pile, not just a patch edge. The FHWA/NHI manual states that cathodic protection "will stop corrosion even in a salt contaminated structure," and names CP within a repair as one technique to mitigate ring corrosion.
4. **Electrochemical chloride extraction (ECE).** The FHWA Bridge Preservation Guide lists ECE alongside CP as a condition-based activity paired with deck repair. ECE uses a temporary applied current to draw chloride ions away from the steel. Its design and limits were not covered in the sources reviewed for this course.
5. **Low-permeability overlays and sealers.** These slow further chloride and moisture entry after the repair. MDOT notes that LMC and SFMC overlays "slow the corrosion of the reinforcement."

The engineer's job is to match the remedy to the contamination. A few isolated impact spalls in a dry, chloride-free pier need none of this. A salted deck at 30% delamination needs a strategy, not a patch list.

Galvanic versus impressed-current protection

The FHWA/NHI underwater repair manual (Chapter IX) gives the basis for choosing between the two kinds of cathodic protection. Galvanic protection relies on the natural potential difference between metals. Its table of typical potentials (copper-copper sulfate reference) lists zinc at -1.10 V, carbon steel at -0.68 V and copper at -0.43 V. Zinc's more negative potential makes it the anode, so it corrodes in place of the steel.

	Galvanic (sacrificial)	Impressed current
Power source	None. Driven by the anode metal's potential	External DC rectifier
Advantages (FHWA/NHI)	Simple, self-regulating, little maintenance, minimal risk of hydrogen embrittlement of prestressing steel	Current can be adjusted to suit demand and is not limited by anode potential. Long-life anode systems available
Limitations (FHWA/NHI)	Limited current output and finite anode life, which ends when the zinc is used up	Needs power, monitoring and maintenance. Excessive current can cause hydrogen embrittlement of high-strength prestressing steel

Patch-perimeter anodes are a galvanic system on a very small scale. They protect a band of steel around the patch for a limited number of years, the anode life. They do not stop corrosion elsewhere in the member. Owners should record where anodes were installed so later inspectors know why a patch is performing well, or recognize when the anodes are probably used up.

The NHI manual also notes that stainless steel reinforcement in a repair "will not increase the corrosion rate of the carbon steel." That is useful when a designer wants corrosion-resistant supplemental bars in a splash-zone patch but is concerned about dissimilar-metal effects.

Crack repair by epoxy injection

Not every repair is a patch. Structural cracks that are dormant, meaning no longer moving, can be bonded by pressure-injecting low-viscosity epoxy. The TxDOT CRM (Chapter 3, Section 5) covers the practice:

- **Material:** TxDOT Type IX epoxy, which meets ASTM C881 Type IV, Grade 1, a low-viscosity, load-bearing grade.
- **Crack width:** cracks as small as 0.002 in. can be injected, but the CRM notes that this is very difficult below about 0.005 in. and that very narrow cracks may not justify the cost.
- **Ports:** entry ports spaced no farther apart than the crack depth, so epoxy reaches the full depth between ports.

- **Sequence:** on vertical or inclined cracks, inject from the lowest port upward, moving to the next port when epoxy appears there.
- **Surface preparation:** clean the crack face. Do not V-groove or grind it open, because that spreads debris into the crack.

Epoxy injection restores monolithic behavior but does not fix the cause. Active cracks, from ongoing movement, thermal cycling or continuing ASR, will reopen next to or through the injected crack. They need a flexible sealant or a structural fix to the cause instead. Injection also does nothing for corrosion that has already started at a crack, so chloride testing still applies.

Deck repairs and hydrodemolition

Bridge decks receive most of the patching volume. TxDOT recognizes three deck repair types: partial-depth, partial-depth over precast panels and full-depth. MDOT uses shallow and deep patches (deep removal extends below the top mat).

Partial depth versus full depth

- MDOT shallow patches: remove concrete only to about the middle of the top mat, roughly 1-1/2 in. deep on its typical decks. MDOT deep patches: remove to 3/4 in. below the top mat.
- TxDOT partial-depth: remove to at least 3/4 in. below the top layer of steel. TxDOT says a repair should go full-depth if removal reaches the bottom mat, if more than half the deck thickness is removed, or if the soffit shows distress. Full-depth repairs require forming the underside. MDOT warns that saw cuts on the underside must avoid the bottom mat.

MDOT also says to protect traffic and property below. For full-depth work and hydrodemolition, MDOT requires "false decking" or shielding under the deck.

Hydrodemolition

High-pressure water jets remove deteriorated concrete selectively, because weak and delaminated concrete erodes faster than sound concrete. They also clean the reinforcement and do not bruise the concrete that remains. MDOT's Section 712 practice:

- Calibrate the equipment on about 30 sq ft of sound concrete and then about 30 sq ft of unsound concrete, adjusting so deteriorated concrete is removed while sound concrete is removed only to the specified depth. For deep removal, aim for about 75% of the top bars to be visible.
- Collect and filter runoff water, and keep it out of storm sewers and streams.
- Touch up with hammers of 60 lb or less, and remove remaining loose material and slurry before placing the overlay or patch.
- Do not scarify (mill) deeper than 1 in. above the top mat. MDOT discourages using scarifying alone to remove deteriorated concrete before an overlay, because it can miss delaminated concrete at the bar level.

Joint headers

Expansion joint headers are a common deck-edge repair. MDOT notes the Bridge Deck Joint Repair special provision material mentioned under curing. Joint replacement and joint systems are covered in BR-B02.

Inspection and acceptance

A patch should be accepted on evidence, not on how it looks.

- **Sounding:** the CRM accepts intermediate spall repairs by hammer sounding once the material has cured. Hollow areas are removed and replaced. Do the same for deck patches with a chain drag.
- **Cracking:** shrinkage cracks at the perimeter or across the patch suggest curing, mixing or material problems. Fine cracks may be sealed. Wide or debonded cracks mean the repair should be redone.
- **Strength:** verify opening strength by cylinders or cubes as the specification requires. TxDOT uses 3,600 psi for decks unless the plans say otherwise. MDOT's joint repair special provision uses 2,000 psi by compressive test.
- **Records:** document location, depth, area, material, anode use and date. These records become the baseline for future inspections (see BR-I10 on inspection reports).

Patches are also an inspection concern for years afterward. Inspectors should look for ring cracking and delamination around old patches, the visible sign of the halo effect.

Worked example: planning a pier cap patch (illustrative)

All numbers in this example are illustrative and were made up for this course. They do not come from a real bridge.

A pier cap under a leaking deck joint has a spall about 18 in. by 30 in. Sounding finds hollow concrete in an area about 24 in. by 40 in. Several #6 bars (0.75 in. diameter) are exposed, with more than half their circumference visible. Lab results from powder samples at bar depth show acid-soluble chloride of about 1.6% by weight of cement.

1. **Category:** more than 50% of bar circumference is exposed, so this is at least Intermediate under TxDOT's definitions. If the cap's bearing seats or flexural zones are involved, it may be Major.
2. **Corrosion risk:** 1.6% is above ACI 364.6T's 1% threshold, so there is a high risk of continuing corrosion and the halo effect should be addressed.
3. **Outline:** saw-cut a rectangle around the full sounded area plus a margin, for example 28 in. by 44 in., about 1 in. deep, without cutting bars.
4. **Clearance behind bars:** if the repair material has 3/8 in. maximum aggregate, ACI 364.6T gives at least $1/4 + 3/8 = 5/8$ in. TxDOT's intermediate rule gives the greater of 3/4 in. or $1.5 \times 3/8 = 0.56$ in., which is 3/4 in. Use 3/4 in. under a TxDOT-style specification.
5. **Steel:** blast-clean and measure. If one bar is down to 0.55 in. diameter, its area ratio is $(0.55/0.75)^2 \approx 0.54$, a 46% section loss. That is more than TxDOT's 25% trigger, and the 27% diameter loss is more than MDOT's 1/4-diameter trigger, so supplement the bar with a lap splice per the governing specification.
6. **Halo mitigation:** install galvanic anodes on the continuous bars around the perimeter, no more than 24 in. apart if following MDOT practice. Check continuity with a multimeter.
7. **Material:** vertical face, about 4 in. deep, so a form-and-pour bagged mortar extended with coarse aggregate (or batched concrete if Major) is a better choice than hand-troweled lifts.
8. **Cure and accept:** keep forms on and moist cure for 72 hours, then hammer-sound after curing.
9. **Fix the cause:** the leaking joint is the source of the chlorides. Without repairing or replacing it, the cap will be patched again.

Key takeaways

- Find the cause and the full extent (sounding, soffit checks, chloride and carbonation testing) before drawing patch limits.
- Categorize the damage; non-structural repairs should not attract load, structural repairs need material that behaves like the parent concrete.

- Saw-cut simple, square outlines, chip with light hammers at the perimeter, and get behind corroded steel (ACI 364.6T: 1/4 in. plus max aggregate; TxDOT and MDOT: 3/4 in. or more).
- Clean the steel, measure section loss against the governing specification, and supplement or anchor as required.
- Prepare a rough, clean, saturated surface-dry substrate; choose the lowest-strength, slowest-setting compatible material that meets the schedule; moist cure.
- Patching alone does not remove the chlorides around a patch; manage the halo effect with anodes, CP, ECE or a broader rehabilitation where contamination is widespread.

References

1. ACI 546R-14, Guide to Concrete Repair
2. ACI 345.1R-16, Guide for Maintenance of Concrete Bridge Members
3. TxDOT, Concrete Repair Manual, Chapter 2 (Damage Assessment and Repair Types) and Chapter 3 (Repair Materials and Procedures), txdot.gov/manuals/brg/crm.html (online manual, read October 2026)
4. Michigan DOT, Construction Manual, Section 712 — Bridge Rehabilitation, Concrete, mdotwiki.state.mi.us/construction (read October 2026)
5. ACI TechNote 364.6T-02 (reapproved 2011), Concrete Removal in Repairs Involving Corroded Reinforcing Steel, American Concrete Institute
6. FHWA, Bridge Preservation Guide: Maintaining a Resilient Infrastructure to Preserve Mobility, Spring 2018
7. FHWA, Underwater Bridge Repair, Rehabilitation, and Countermeasures, NHI Course 130091A Reference Manual, FHWA-NHI-10-029

Study text only; the final quiz is taken online. Verify all references against the edition your agency has adopted.