STRUCTURE DESIGN - CORROSION PROTECTION GUIDE

TxDOT Bridge Division

PURPOSE

The purpose of this document is to provide guidance for designers to enhance the corrosion protection measures of a bridge structure. Implementation of various measures should be based on historical performance in the area, roadway classifications, environmental conditions, collaboration with maintenance office, material suppliers, as well as engineering judgement. Not all measures are recommended for every structure: traffic volumes, frequency of de-icing agent usage, on-system vs. off-system, signature structures, etc. should be taken into consideration when selecting additional corrosion protection measures.

DE-ICING AGENTS

In areas of the state where de-icing agents are frequently used during winter storms, it is recommended that additional corrosion protection measures be incorporated into the new and replacement bridge design and details.

Special consideration should be given on a case-by-case basis for:

1. Retrofit bridge rails
2. Widenings or rehabilitations of existing structures
3. Isolated culverts with Class "S" top slabs
4. Slab replacements or re-decking
5. Projects in remote areas
6. Off-system bridges.

In these cases, consider the availability of materials, extent of corrosion damage of any existing structures, and overall cost-benefit.

ROADWAY CLASSIFICATIONS

All primary state roadways in Texas are treated in a four-tier system based on their importance for snow and ice removal.

- Tier I state roadways affect the movement of interstate commerce and receive priority for pre-treatment and de-icing;
- Tier II state roadways are of high priority locally or regionally and TxDOT identifies treatment actions in collaboration with local governments;
- Tier III state roadways are low-volume roadways that primarily service local areas that receive treatment depending on available resources; and
- Tier IV state roadways are low-volume roadways that primarily service local areas that receive treatment in problem areas.

Verify the structure's categorization based on the roadway tier classifications. Note that corrosion protection measures are not required for Tier IV structures. The statewide winter weather Tier I map is shown in Figure 1.

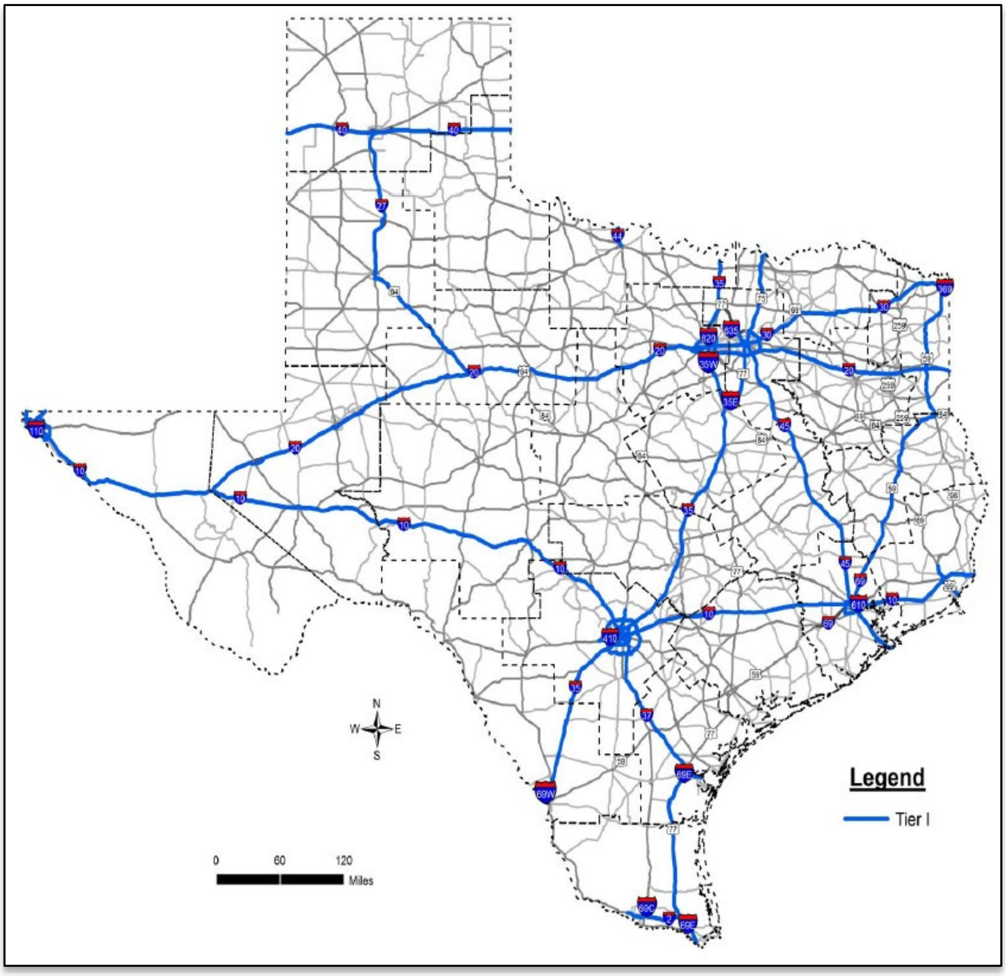

Figure 1. Statewide Winter Weather Tier I Map

ENVIRONMENTAL CLASSIFICATIONS

This guideline establishes four environmental zones based on the performance of bridge structures and considers historical weather patterns in different parts of the State:

- Mild Environment
- Moderate Environment
- Aggressive Environment
- Marine Environment

Figure 2 depicts the approximate area that each zone spans across the state. Note that structures within the marine environment are not included in the scope of this guideline and must be evaluated on a case-by-case basis at the District's discretion.

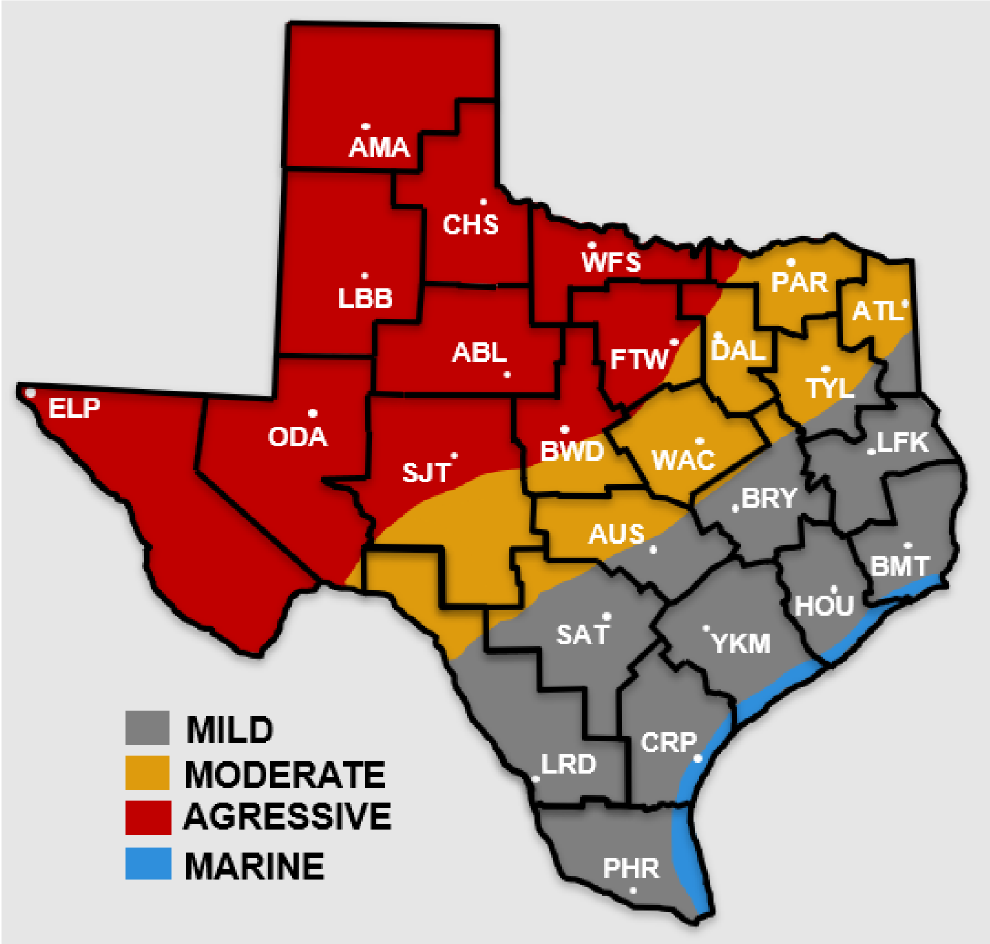

Figure 2. Statewide Environmental Classification Map

CORROSION PROTECTION MEASURES

There are several options available pertaining to improving the long-term durability potential of reinforced concrete structures. These options include improving the concrete performance, increasing concrete clear cover, using corrosion resistant reinforcing steel, and using coatings or membranes/overlays to minimize deterioration.

Mitigating Corrosion with Improved Concrete Materials

High Performance Concrete (HPC)

High Performance Concrete (HPC) is defined within TxDOT as concrete containing supplementary cementing materials (SCM) or one meeting a maximum tested permeability value. The permeability of HPC is significantly lower than that of ordinary concrete. Lower permeability concrete reduces the ability of chlorides to attack the reinforcing steel and cause corrosion. Concrete containing supplementary materials can also aid in the mitigation of ASR/DEF through the reduction of total alkali content and reduced heat generation. As can be seen in Table 8 "Concrete Classes" in Item 421, "Hydraulic Cement Concrete," the class of concrete with the

HPC designation limits the mix design options, which were developed to mitigate ASR. Mix design options 6 and 7 do not contain SCM's nor do they have a permeability test requirement. Use of HPC does not necessarily equate to a more durable structure. Item 421-4.2.6 Mix Design Options 3-5 utilize SCM's to form a ternary blend of cementitious materials; However, these mixes are allowed to contain silica fume which is highly effective in reducing concrete permeability but also make the mix problematic for flatwork construction, such as a bridge deck. Silica fume has a high water demand which can promote plastic shrinkage cracking if curing practices are not strictly followed. Use of silica fume as an SCM is not recommended in bridge decks because of the increased probability of concrete cracking, which negates the benefit of reduced permeability.

Class F fly ash has been the most prominent SCM typically used within TxDOT and is very effective at reducing permeability, even at 20% replacement of cement rate. However, Class F fly ash is becoming less available, which is making HPC more difficult and expensive to obtain. Table A, provided below, is based on the materials

Table A. Availability of Material for HPC Concrete Mix

Districts	Substructure	Bridge Deck
Abilene	Limited*	
Amarillo	Available	Not Available
Atlanta	Available	
Austin	Available	
Beaumont	Available	
Brownwood	Available	
Bryan	Available	
Childress	Limited*	
Corpus Christi	Limited*	
Dallas	Available	
El Paso	Available	
Fort Worth	Available	
Houston	Available	
Laredo	Limited*	
Lubbock	Available	Not Available
Lufkin	Available	
Odessa	Limited*	
Paris	Available	
Pharr	Available	
San Angelo	Not Available	
San Antonio	Available	
Tyler	Available	
Waco	Limited*	
Wichita Falls	Available	
Yoakum	Available	Limited*

* Class F fly ash may not be available throughout all areas of this district. When specifying HPC in reinforced concrete bridge slab, Mix Design Option 1, Item 421 is highly recommended. Other mix design options with CL C fly ash and additional SCM's is not encouraged in bridge decks. The designer must check with the district to see if the required materials are accessible for HPC concrete providers in the desired location. The designer must indicate on the plans which elements require HPC. There are specific Bid Items for HPC.

that are most readily available in each District. This table may be used by the designer to choose the best concrete mix design options for each location, although it is recommended that they contact the District for any possible updates in their area.

- Bridge Slabs, Decks, & Rails - When indicated, specify Class "S" (HPC) for bridge slab, CIP portions of decks and Class "C" (HPC) for all concrete bridge railing elements.
    - This includes all cast-in-place superstructure concrete such as cast-in-place slab spans, box culverts that require Class "S" concrete in the top slab, slabs cast on top of box beams, and slab beams.
    - If HPC is specified for the bridge slab or deck, utilizing it for the bridge approach slab is recommended.

- Substructure - When indicated, specify Class "C" (HPC) for all substructure elements.
    - Applies to all abutments, bent caps and columns regardless of their locations relative to bridge expansion joints.

- Prestressed concrete beams - Table 8 in Item 421 specifies mix design options 1-5 for Class H concrete, which is the standard concrete specified for prestressed concrete beams. As a result, there is no need to require the use of HPC in precast concrete beams.

Reinforcing Steel Considerations

Increased Clear Cover

Increased clear cover to reinforcement beyond what is normally required keeps the reinforcement further away from the chlorides on the surface of the concrete, reducing the potential for corrosion. Clearly indicate increased clear cover requirements on the plans. There is no direct payment for this work.

- Bridge Slabs – Bridge standard drawings have additional top clear cover.
- Substructure - Consider increased clear cover for substructure elements on a case-by-case basis at the discretion of the District.
    - Use primarily in areas of the state with a history of significant corrosion damage in substructure elements.
    - Specify an additional 0.5 in. of clear cover for bent caps, abutments and exposed footings by decreasing the size of stirrups. Increase the size of the bent cap, abutment, or footing by increments of 3”, when required by structural design.
    - Columns have sufficient clear cover.
    - Account for increased clear cover in the structural design.

Corrosion Resistant Reinforcing (CRR)

- ***Epoxy-Coated Reinforcing (ECR)***

  Epoxy-coated reinforcement is a fusion-bonded coating on the reinforcing steel that provides protection from oxidation. Epoxy-coated reinforcement increases the time to initial corrosion as compared to uncoated reinforcement. It is not intended to protect exposed steel, as the coating is subject to degradation from ultraviolet light. Care must be taken not to damage the coating when handling epoxy-coated reinforcement. Item 440, "Reinforcement for Concrete," and Special Provision to Item 440, SP440-004 covers the material requirements for epoxy-coated reinforcement as well as handling and repairing epoxy-coated reinforcement.

- ***Other Corrosion Resistant Reinforcing***

  Item 440 and the Special Provision to Item 440, SP440-004 contains material requirements for other corrosion resistant reinforcement, such as stainless reinforcing steel, low carbon/chromium reinforcing steel (LCCR) , continuously galvanized reinforcing (CGR), hot dipped galvanized reinforcing (HDG), or glass fiber reinforced polymer bars (GFRP).

- ***Selection of Reinforcing***

  Increased durability performance achieved by the various types of reinforcement varies and generally there is not substantial long-term testing results showing which of these will perform best. Stainless steel generally is thought to be the most corrosion resistant reinforcing but comes at the highest cost. GFRP is showing good field results and is not prone to galvanic corrosion at all. GFRP is recommended in bridge decks where dicing salts are applied, and freeze-thaw cycling is high, such as in the Pan Handle, where concrete cracking is more prevalent related to the dry and windy conditions bridge decks are subjected to during construction. GFRP has not yet been used in substructure elements in Texas though the AASHTO Design Guide Specifications for GFRP-Reinforced Concrete, 2nd Edition makes ample provisions for its use. Table B lists corrosion-resistant reinforcing options and recommendations for structures based on their districts. Consider the facility carried and functional classification while implementing these reinforcing recommendations.

  When selecting low carbon, chromium bars, Type CS are provided when required on the plans and Type CM is also permitted if specifically specified in the plans. This rebar is also unique because it is only furnished in Grades 100 & 120.

  Continuously Galvanized Reinforcing is an alternative to epoxy coated reinforcement and considered an equivalent.

  Each type of reinforcing provides additional protection from corrosion compared to black steel reinforcing bars. Engineering judgement should be used in the selection.

  - Epoxy Coated Reinforcing

- Commonly used and widely available.
- Contractor familiarity with the use and placement.
- If not properly handled, epoxy coating can be chipped and gouged; if not properly repaired, this can cause accelerated corrosion at the damaged areas and earlier onset of corrosion related damage.

- Stainless, Low Carbon/Chromium, Continuously Galvanized, Galvanized, GFRP
    - Relatively new corrosion resistant reinforcing options meaning limited actual field data to verify long term performance.
    - Initial costs for corrosion resistant reinforcement range from an increase of 2% to 4% of the total project cost but provide a benefit with reduced life cycle costs. For stainless steel the initial investment is about 10% to 15% of total project cost, with a substantial reduction in life cycle costs. See Figure 3 for a general cost vs. performance comparison of the various corrosion resistant reinforcing taken from TxDOT Research Project 0-6952.
    - Potentially more durable and less prone to damage during transportation and installation.

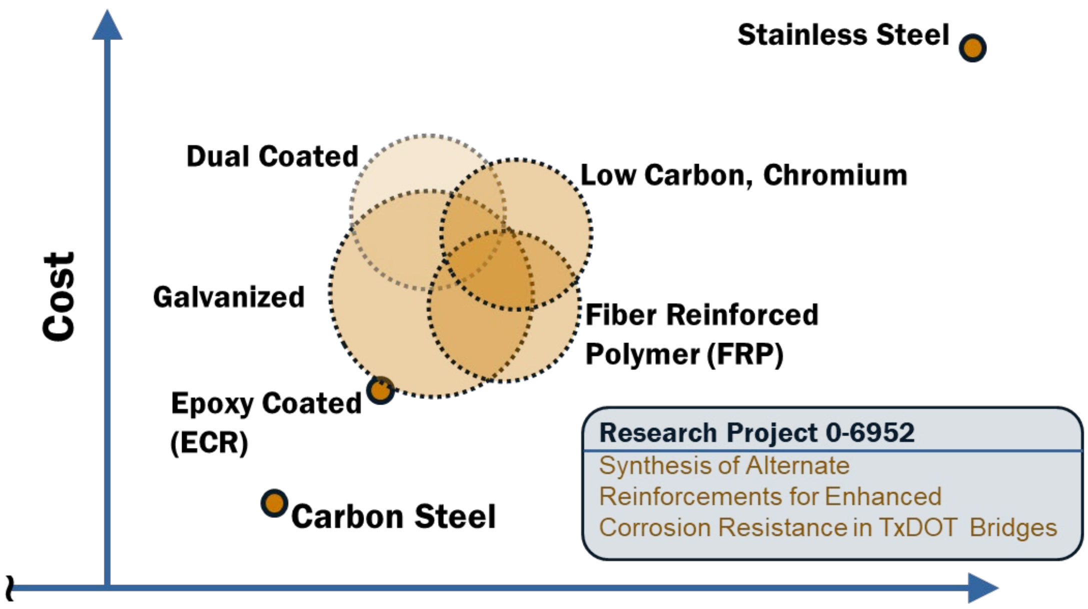

Figure 3. Cost vs. Performance for Corrosion Resistant Reinforcing.

Table B. Corrosion-Resistant Reinforcing Options and Recommendations (Non-Coastal Environment)

Districts \ Options	ECR*, CGR, HDG, GFRP**, LCCR, Stainless	
	Substructure	Bridge Deck
Abilene	Recommended	
Amarillo	Recommended	
Atlanta	Not Recommended	Recommended
Austin	Not Recommended	
Beaumont	Not Recommended	
Brownwood***	Recommended	
Bryan	Not Recommended	
Childress	Recommended	
Corpus Christi	Not Recommended	
Dallas***	Recommended	
El Paso***	Recommended	
Fort Worth***	Recommended	
Houston	Not Recommended	
Laredo	Not Recommended	
Lubbock	Recommended	
Lufkin	Not Recommended	
Odessa***	Recommended	
Paris	Not Recommended	Recommended
Pharr	Not Recommended	
San Angelo***	Recommended	
San Antonio	Not Recommended	
Tyler	Not Recommended	
Waco***	Recommended	
Wichita Falls***	Recommended	
Yoakum	Not Recommended	

*ECR is not permitted in PAR.

**GFRP is preferred in bridge decks in AMA and LBB.

***Corrosion resistant reinforcing in substructure is recommended for interstates, state highways, and other major facilities.

Note that structures within the marine environment are not included in the scope of this guideline and must be evaluated on a case-by-case basis at the District's discretion.

Provide notes on the bridge plan sheets to indicate which elements are to receive corrosion resistant reinforcement (see Bridge Design Guide). In addition, be sure to specify corrosion resistant reinforcement in the General Notes to Item 440. Notes should indicate which bridge elements require corrosion resistant reinforcement. General Notes should not conflict with notes on bridge plan sheets.

- Bridge Slabs, Decks, & Rails - When indicated, specify corrosion resistant reinforcing for bridge slabs, decks, and concrete bridge railing elements.
  - Specify corrosion resistant reinforcing in the bridge slab.

        - This includes cast-in-place slab spans, culverts that require Class "S" concrete in the top slab, as well as slabs cast on top of box beams, slab beams, or double tees.
        - Specify corrosion resistant reinforcing in the bridge approach slab if present.
        - Prestressed Concrete Panels, PCP's, used in bridge deck construction do not require epoxy coated reinforcement or epoxy coated prestressing strands.
        - By default, the bridge railing standard drawings require the use of corrosion resistant reinforcement in all concrete bridge railing elements when the bridge slab reinforcing is corrosion resistant. There has been an availability issue getting contractors to use ECR welded wire in bridge rails. It is acceptable to allow HDG welded wire as a substitute to ECR when requested.
        - For bridges that do not have a cast-in-place bridge deck such as decked slab beams, specify corrosion resistant reinforcing on the plans by providing notes in the General Notes to Item 424 "Precast Concrete Structural Members (Fabrication)" and Item 440, "Reinforcement for Concrete." Consult with BRG for guidance.
    - Substructure - When indicated, specify corrosion resistant reinforcement for substructure elements.
        - Applies to all bent caps, columns, and abutments regardless of their locations relative to bridge expansion joints.
        - The use of corrosion resistant reinforcing bars for foundation elements (i.e. piling, drilled shafts or buried footings.) is not recommended, unless in a marine environment.
    - Prestressed Concrete Beams - Corrosion resistant reinforcing bars are generally not recommended for prestressed concrete beams. Do not utilize corrosion resistant bars for the reinforcing that connect the bridge deck slab to the prestressed concrete beams even when the bridge deck slab reinforcing bars are corrosion resistant. Specifically, do not epoxy coat R-bars (I-girders and U-beams), Z-bars (box beams), H-bars (Slab beams).

Air Entrainment

Air Entraining Admixtures (AEA) have been used in concrete mix designs to improve workability and freeze/thaw (F/T) durability. The effectiveness of air entrainment for F/T is dependent on the number of saturated freezing and thawing cycles per year. Investigations have indicated most of Texas does not encounter substantial saturated F/T cycles for air entrainment to be required. In 2014, TxDOT removed the air entrainment requirement from structural concrete in all but four Districts: AMA, CHS, LBB, and WFS. The main driving reason for reducing the number of districts requiring AEA was a field issue revealing a compatibility problem between the air entraining admixtures with fly ash. The decision was made that the benefits of fly ash outweighed the benefit of AEA in lower risk F/T districts. Fly ash is the key component in producing much of the HPC in the districts. HPC is believed to produce more durable concrete and does provide some measure of F/T resistance—thought to be sufficient for much of the state, other than the four districts listed.

Corrosion Inhibiting Admixtures

Calcium-nitrite has been shown to delay the onset of corrosion. Calcium-nitrite is an approved concrete strength and set accelerator concrete admixture and has been successfully used for prestressed concrete member fabrication. Specifying it in prestressed concrete members is a low-cost option to improve the durability of these members.

Calcium-nitrite can be used in lieu of HPC reinforced concrete slab when class F fly ash is unavailable.

Other corrosion inhibiting admixtures have not consistently provided similar protection and are not recommended.

- When the use of calcium-nitrite is indicated, provide notes on the bridge plan sheets indicating that the prestressed concrete beams are to receive calcium-nitrite. In addition, specify calcium-nitrite in the General Notes to Item 425.
- When the use of calcium-nitrite is indicated for reinforced concrete slab, provide notes on the bridge plan sheets. In addition, specify calcium-nitrite in the General Notes to Item 422.
- Notes should indicate that the prestressed concrete beams are to receive calcium-nitrite at a dosage rate of 3 gal/CY. The use of calcium-nitrite in the prestressed concrete panels (PCP), used in bridge deck construction is not needed. There is no direct payment for this work or materials.

Bridge Deck Overlays (for bridge rehabilitations only)

One of the most efficient techniques of preventing deicing salts and corrosive substances from penetrating existing bridge deck surfaces is to apply protective overlays to existing concrete bridge decks.

- **Polyester polymer Concrete (PPC)**
  Polyester polymer concrete is a type of polymer concrete that has been successfully used to overlay bridge decks. PPC is comprised of a polyester-based resin binder and natural aggregate. Due to their low permeability, PPC overlays are frequently specified to protect bridge decks from corrosive pollutants that accelerate the deterioration of reinforced concrete. Special Specification 4106 “Polyester Polymer Concrete Bridge Deck Overlay” covers this overlay.

- **Multi-layer Polymer Overlays (MLPO)**
  This overlay is the most common type of thin polymer overlays used on bridge decks. Item 439 “Bridge Deck Overlay” of TxDOT Standard Specifications covers this overlay.

- **Limit Use of ACP Overlay on Bridge Decks**
  ACP overlay tends to trap salt laden moisture and thereby accelerate corrosion. Adding ACP to a bridge deck increases maintenance cost to the structure during its service life. Limit the use of ACP overlay on new bridge decks whenever possible. When replacing the ACP overlay on bridge decks, it is recommended to completely remove the ACP overlay and not partially remove leaving an underlying old layer of ACP.

- Surface preparation

  For a successful overlay installation, a good substrate and proper surface preparation are essential. The surface of the bridge deck should be sound, clean, and dry. Concrete that is weak or delaminated should be removed and replaced. Two common methods for preparing the deck surface prior to overlay installation are hydro demolition and shot blasting.

Limit Use of Specific Bridge Rails (T223, T631, and drain slots)

Deicing agents can run down the face of the outside beam through the Traffic Rails T223, T631 and drain slots in rails. Limit the use of these rail types, as well as drain slots in rails. Snow removal requirements, on the other hand, may necessitate the usage of open bridge rails.

Crack Control in Structural Design

Limiting the width of cracks in concrete reduces the ability for chlorides to penetrate to the reinforcing steel thereby reducing the potential for corrosion.

- For structures where the use of HPC or corrosion resistant reinforcing is indicated, design using Class 2 exposure condition to satisfy AASHTO LRFD 5.6.7. Control of Cracking by Distribution Reinforcement. See TxDOT Bridge Design Manual (LRFD) for further information. This applies to abutment, bent caps, and non-standard columns only. It is not required to be used on bridge slabs, beams, or standard columns.
- Internally Cured Concrete (ICC) is a concrete that contains a small amount of lightweight fine aggregates in the mix. These lightweight aggregates hold moisture and release the moisture as the concrete cures. This internal moisture reduces the drying shrinkage and thus has been shown to reduce the amount of drying shrinkage cracks typically seen on bridge decks. Contact BRG if interested in reducing deck cracking using ICC.

Shrinkage Crack Control Measures for Bridge Decks

Control of cracking due to shrinkage of concrete in the early and long term can limit the formation of cracks, which lead to the penetration of water and chlorides to attack the reinforcing steel and cause corrosion. Include notes for shrinkage control measures to the specific Item in which these apply.

- Microfibers for corrosion protection due to plastic shrinkage can be 2 lbs. to 3 lbs. per/CY depending on the corrosion potential and type of microfiber.
- Macrofibers for drying shrinkage or durability should be tested for concrete performance to meet the minimum “R” value of 160 psi flexural per ASTM C 1609. Dosage rates are fiber and manufacturer dependent.
- Provide shrinkage reducing admixtures tested by an approved testing lab and meeting the requirements for ASTM C494 Type S, except that in Table 1 length change shall be measure as: Length Change (percent of control) shall be a minimum of 35% less than that of the control. Table 1

Length (increase over control) shall not apply. Do not use expansive metallic materials in shrinkage reducing admixtures.

Contact Bridge Division for Special Specification guidance for implementing performance-based improvements to concrete utilizing fibers for shrinkage control.

Other Protection Measures

In general, we do recommend any of the following based on district specific or project specific requirements.

Concrete Coatings

Concrete coatings or penetrating sealers have been used to act as a barrier to corrosive agents at or near the concrete surface. Typical coatings/penetrating sealers have included:

- Type X epoxy waterproofing of bent caps, abutment caps, abutment backwalls, or columns. DMS-6100 specifies the material requirements of Type X epoxy coatings. The performance of epoxy waterproofing is dependent of the level of substrate cleanliness. Item 427.4.2.1 states "Clean the surface thoroughly before applying a coating by chemical cleaning, if required, and by blast cleaning." Blast cleaning will be required in almost all cases, and proper inspection and installation are vital to the epoxy waterproofing's long-term performance
- Silicone-Based Paint can provide a barrier to the ingress of water and provide protection. Item 427 "Surface Finishes for Concrete" and DMS-8141 cover the material and application requirements for silicone-based paint coatings.
- Type 10 waterproofing per Item 458 for the back side of abutment backwalls/caps.
- Silane, per Item 428, "Penetrating Concrete Surface Treatment" is recommended on exposed concrete substructure members, typically straddle caps and columns if they do not get painted.

Geometric Treatment to Promote Drainage

Top of caps at abutments, interior bents, and footings have been sloped in the transverse direction in deicing salt zones to promote runoff of drainage off the tops of caps. Reference the *TxDOT Bridge Detailing Guide* for example details.

Expansion Joint Type and Material Selection

TxDOT uses a variety of expansion joint types at the ends of bridge decks. Sealed Expansion Joints that use a strip seal are more effective in limiting drainage on substructure. Two types are available, a bonded (SEJ-B) and mechanical (SEJ-M) seal. The later is believed to provide better sealing. TxDOT offers the opportunity to hot-dip galvanize expansion joint steel hardware if specified in the general notes. In areas of deicing salt usage, such treatments can avoid long term deterioration and loosening of the steel hardware.