COLORADO
Department of Transportation
Statewide Bridge and Tunnel Enterprise

Colorado Bridge and Tunnel Enterprise

STRATEGIES FOR ENHANCING BRIDGE SERVICE LIFE

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Acronym	**Description**
AASHTO	American Association of State Highway Transportation Officials
ABC	Accelerated Bridge Construction
ADT	Average Daily Traffic
ASTM	American Society for Testing and Materials
BIM	Building Information Modeling
BTE	Colorado Bridge and Tunnel Enterprise
CDOT	Colorado Department of Transportation
CRSI	Concrete Reinforcing Steel Institute
CVN	Charpy V-Notch
DOT	Department of Transportation
ETN	Engineering Technical Note
FHWA	Federal Highway Administration
FRP	Fiber Reinforced Polymer
HDG	Hot-Dip Galvanization
HMA	Hot Mix Asphalt
HPS	High Performance Steel
HRT	Highway Research and Technology
LMC	Latex-Modified Concrete
LRFD	Load and Resistance Factor Design
MPO	Metropolitan Planning Organization
PPC	Polyester Polymer Concrete
PS&E	Construction Plans, Specifications, and Estimate
SAE	Society of Automotive Engineers
SCC	Self-Consolidating Concrete
SF	Silica Fume
SHRP	Strategic Highway Research Program
SIA	Structure Inventory and Appraisal
SRA	Shrinkage Reducing Admixture
SSPC	Society for Protective Coatings
TPR	Transportation Planning Region
UHPC	Ultra-High-Performance Concrete

1 INTRODUCTION

1.1 PURPOSE

The Colorado Bridge and Tunnel Enterprise (BTE) is a government business owned by the Colorado Department of Transportation (CDOT) that functions to replace and rehabilitate bridges in Colorado that are identified as 'Poor'. As part of its mission, the BTE is charged with bringing innovation to the practice of bridge design and construction through implementation of innovative practices. As part of this effort BTE continues to explore the use of strategies that extend the service life of bridges that it constructs. The purpose of this document is to provide designers with a compilation of industry best practices and recommendations on when to employ the various techniques discussed herein for BTE funded bridges.

The strategies outlined in this document are not intended to take the place of a robust bridge preventative maintenance program. The combination of strategies recommended and a programmatic approach to preventative maintenance treatments will maximize the service life of newly constructed bridges. **To maximize return on investment, BTE is requiring that a bridge-specific preventative maintenance plan or "Owner's Manual", which identifies the recommended type, timing, and cost of future preventative maintenance treatments, be submitted with the final bridge PS&E package.** Background information on the Owner's Manual can be found in Section 3 – Cost/Benefit Analysis.

Additionally, construction oversight and proper quality control/quality assurance are significant factors in ensuring that newly constructed bridges achieve their intended service life. This strategies presented in this guideline will not offset impacts to long term structure durability resulting from substandard workmanship or materials.

1.2 BACKGROUND

As large bridge replacement projects continue to impact BTE funding, the program is placing added emphasis on the identification of the best use of funds for future projects. One opportunity to achieve the most long-term benefit from available funding is to design and construct bridges that can provide significantly longer terms of service, balanced with higher initial costs.

CDOT's inventory of bridges is exposed to significantly differing climate conditions and traffic demands depending on their location within the state. For the purposes of this document, the following three geographic areas have been identified:

1) Eastern Plains – characterized by rural state highways and several interstate corridors with intermittent cold and moderate deicing or anti-icing requirements.
2) Rocky Mountains and Front Range – Characterized by rural and urban corridors with more consistent cold winter temperatures and significantly higher use of deicing or anti-icing chemicals.
3) Western Slope – Characterized by rural state highways with significant freeze thaw cycles and moderate to heavy use of deicing or anti-icing chemicals.

These geographies are important to consider as the environmental conditions impact bridges differently and are mainly controlled by geographic location.

An important consideration of this document is which bridge components to enhance to best achieve longer service life. With respect to CDOT bridges, deterioration can be evident in all bridge components. However, in most cases superstructure and substructure deterioration can be attributed to deck deterioration which results in leakage that exposes all bridge components to water and chlorides. Therefore, the recommendations presented in this document are intended to address newly constructed bridge decks only.

1.3 WHAT IS 100-YEAR DESIGN LIFE?

The current AASHTO LRFD Bridge Design Specifications provide a standardized approach to bridge design and indicate a 75-year design service life is expected when the Specifications are implemented. These Specifications are applied nationwide but may not envelop microclimates across North America and more specifically, Colorado.

For the purposes of this document, 100-year design service life is the application of selected strategies that enhance the AASTHO Specifications for the purpose of limiting bridge component deterioration so that structures have the potential to perform beyond the standard 75 years, but not less than 100 years.

2 INDUSTRY RESEARCH OF BEST PRACTICES

The publication of the *SHRP 2 Renewal Project R19A Design Guide for Bridges for Service Life* (referred to herein as *SHRP 2 Design Guide*) is referenced and identifies best practices in both material application and design details. The *SHRP 2 Design Guide* was originally prepared as a national framework to identify strategies for enhancing the design service life of a bridge. Presented herein are various strategies for enhancing bridge service life in the State of Colorado, specifically those that address deterioration associated with the heavy application of deicing and anti-icing chemicals.

2.1 COLORADO DEPARTMENT OF TRANSPORTATION – CURRENT STATEGIES

CDOT routinely utilizes several strategies to mitigate and address deterioration concerns within their current design guidelines. An example is the use of integral bridge detailing. The *SHRP 2 Design Guide* identifies this as an effective strategy in addressing deterioration of superstructure and substructure elements below the deck by eliminating joints that may otherwise serve as egress points for drainage runoff laden with deicing and anti-icing chemicals. Another example is the utilization of precast deck panels; tighter design tolerances and well-controlled curing environments result in a concrete solution that may lead to better crack control. Further examples include the use of epoxy- coated reinforcement, low shrinkage concretes, weathering steel, polyester polymer concrete (PPC), and bituminous waterproofing membranes in combination with an asphalt wearing surface as a deck surface sealant.

2.2 STRATEGIES FOR ENHANCING BRIDGE SERVICE LIFE

BTE has compiled strategies for enhancing bridge design service life by reviewing the *SHRP 2 Design Guide* and interviewing various DOTs and private vendors. The results of this effort are presented in this document. Some strategies discussed were considered but not recommended for implementation either due to high potential costs, high level of maintenance, or constructability concerns. Limitations and design caveats are also included, where applicable.

The *SHRP 2 Design Guide* suggests that strategies be selected to mitigate specific obstacles that contribute to deterioration and reduced bridge service life. For example, deicing and anti-icing chemicals coupled with joint leakage are a significant contributor to bridge deterioration in Colorado.

When considering the design strategies to implement, a system of tiered performance levels has been developed based on cost-benefit analysis for each of the geographic areas described in Section 1.2 - Background. The performance levels are Tier 1 through Tier 3, with Tier 1 representing typical design with the AASHTO and CDOT Standard Specifications and Tier 3 representing the most rigorous strategies with respect to added service life. Refer to Section 4.2- Candidate Bridge Features for detailed guidance on the process to determine the appropriate bridge tier summarized below in Table 1.

Table 1 - General Tier & Strategy Descriptions

Tier	General Bridge Description	Strategy Description
1	Bridges located near populated areas or where population growth is expected. These bridges have a higher potential to require widening or replacement due to a need to accommodate increased future vehicle capacity. Funding sources for these bridges are more available due to their proximity to populated areas.	Use standard designs following FHWA, AASHTO and CDOT requirements
2	Bridges located near remote areas or where population growth is limited. These bridges have low potential to require widening or replacement within the next 100 years. These bridges are typically located in the eastern plains or western slope areas.	Strategies deploy an intermediate level of protection strategies.
3	Bridges located near remote areas or where population growth is limited. These bridges have low potential to require widening or replacement within the next 100 years. These bridges are in the mountain areas.	These bridges require more rigorous protection strategies.

The following is a discussion of each strategy considered and their recommended tier assignment, with a comprehensive summary provided in Table 3 in Section 2.2.6 – Summary of Selected Strategies. Application of any selected strategy should be documented in the bridge Structure Selection Report as appropriate for the project.

2.2.1 CONCRETE STRATEGIES

2.2.1.1 Self-Consolidated Concrete (SCC)

SCC improves the ability of concrete to flow through congested reinforcement with minimal segregation. It reduces the potential for aggregate segregation, voids, and bug holes in the concrete. The use of SCC is encouraged for Tier 1, 2, and 3 when appropriate. SCC is self-leveling and is not recommended for bridge deck concrete. High slump concrete, i.e. slump > 9 inches, should not be used in place of SCC. High slump concrete tends to segregate, with aggregates sinking and cement paste rising, when viscosity modifying admixtures are not used. In high slump concrete applications where SCC is not used, the concrete should be designed and tested for static segregation using ASTM C1610 with a maximum segregation of 10%.

2.2.1.2 Ultra-High-Performance Concrete (UHPC)

CDOT has used UHPC in a limited number of applications at the time this document was published. While durable, it is anticipated that wide use of these materials for elements such as decks, girders and substructure components would be cost prohibitive. UHPC develops a strong bond to concrete and should be considered as a complement to accelerated bridge construction (ABC) techniques for joint closures in Tier 1, 2, and 3 applications.

2.2.1.3 Shrinkage Reducing Admixtures (SRA)

SRAs are effective in minimizing cracking; however, field control of air content has shown to be an issue. SRAs have a negative effect on air entrainment as they work by reducing the surface tension of water. Air entrainers work by increasing the surface tension of water. CDOT Class DF concrete allows the use of SRAs; however, requiring the use of SRAs should be discouraged in all applications.

2.2.1.4 Corrosion Inhibiting Admixtures

Corrosion inhibiting admixtures are used to either reduce chloride penetration in the concrete or form a protective layer over reinforcing that inhibits chloride ion intrusion. Because of the reinforcing recommendations for Tier 2 and Tier 3 applications discussed in Section 2.2.2 – Reinforcing Steel Strategies, it is anticipated that there will be little to no benefit from these concrete admixtures. Corrosion inhibitors can be utilized, however, for Tier 1 applications and in accordance with applicable ASTM specifications. Designers should exercise caution when specifying these admixtures as their use during cold weather delays concrete strength gain.

2.2.1.5 Macro and Micro-Fiber Reinforcement

The distinction between micro and macro fibers is made depending on the length of the fiber. Fiber reinforcements are used to improve crack control and decrease crack widths and consist mostly of synthetic fibers added to concrete. Micro-fiber reinforcement can help reduce the plastic shrinkage cracking in concrete but offers no significant strength benefits. Macro-fiber reinforcement works as supplemental reinforcement, holding together micro-cracks caused by shrinkage, while offering the bonus of residual strength. As detailed in the CDOT Standard Specifications, CDOT Class DF concrete requires the use of macro-fiber reinforcement, specified as polyolefin fibers at a minimum dosage of 4.0 lb./cubic yard. Use of CDOT Class DF concrete should be encouraged for all tiers when appropriate.

2.2.1.6 Membranes and Asphalt Wearing Surface

CDOT has significant experience with waterproofing membranes. The CDOT Standard Specifications specify a felt sheet/bituminous or hot applied elastomeric waterproofing membrane used in conjunction with a hot mixed asphalt (HMA) wearing surface. Preformed waterproofing membranes are vulnerable to defects at critical locations such as curves, expansion joints, and drains (*SHRP 2 Design Guide*). CDOT has similar experience in that defects have been found in the felt sheet joints during removal for rehabilitation. For this reason, preformed or bituminous waterproofing membranes are assigned for Tier 1 and 2 applications only, while hot applied elastomeric waterproofing membranes are assigned for Tier 3 applications. HMA wearing surfaces require regular maintenance. The service life of the HMA can be as short as 5 years in areas with heavy truck traffic where tire chain use is routine. Although the initial cost of waterproofing membranes and HMA is relatively low, the overall life cycle cost of these treatments may exceed the cost of other higher initial cost waterproofing treatments and wearing surfaces. BTE has completed a pilot project to install a spray-on elastomeric type waterproofing membrane on a new bridge. The performance of the system will be monitored and considered for inclusion as a substitute to preformed or bituminous membranes.

2.2.1.7 Concrete Sealers

Application of concrete sealers on roadway surfaces has been eliminated from consideration because of their low tolerance to abrasion, specifically against snowplows, studded tires, and tire chains. These products have the greatest effect when applied to barriers, substructure elements, and other bridge components not exposed to traffic wear. The CDOT Standard Specifications include structural concrete coating that is an acrylic emulsion in water. Other types of sealants that should be considered for barrier faces include methacrylate, silanes, and siloxanes. Further, designers can also specify application of water repelling epoxy-based sealers to top of pier bent overhangs near exterior girders, as well as the top of girder seats vulnerable to unanticipated water leakage from deck joints above. Concrete sealers require frequent reapplication to be effective. This strategy is encouraged for Tier 1, 2 and 3 applications.

2.2.1.8 Deck Overlays

There are several types of deck overlays available, including: latex-modified concrete (LMC), PPC, silica fume (SF) modified concrete, epoxy-polymer and other dense/high strength concrete. Each of these systems aims to provide a thin (¼” to 2 ½”) protective layer over the bridge deck as a riding surface and moisture barrier. Typically, it is impractical to construct a full depth deck using these materials because their properties differ from structural concrete or it is cost prohibitive.

CDOT has discontinued SF modified concrete as it was extremely difficult to place. Further, the SF overlays tended to crack excessively and/or delaminate from the underlying concrete. Because the coefficient of expansion varies between concrete and epoxy, epoxy overlays have also shown a tendency to delaminate and should be avoided until the technology has improved. PPC overlays have shown excellent service life in Colorado and other areas with high mountain corridors such as California. CDOT is currently evaluating the performance of LMC overlays on several bridge preventative maintenance projects. Data gathered from these applications will be used to determine the viability of LMC as an alternative to membrane and overlay or PPC.

PPC is currently the preferred alternate to asphalt and waterproofing membrane. While its use is becoming more common and can provide an estimated 15 to 25 years of deck protection, initial costs of PPC as an overlay alternative remains a premium over waterproofing membrane and wearing surface combinations. Project specific discussions at preliminary design and a life-cycle cost analysis are encouraged to determine its overall benefit in new construction. Where appropriate, PPC overlays should be considered for Tier 1, 2, and 3 applications.

2.2.1.9 Cathodic Protection – Galvanic Protection and Impressed Current

CDOT has successfully used cathodic protection systems on rehabilitation projects to halt active corrosion of bridge deck reinforcing. Galvanic protection systems, specifically sacrificial anodes, are recognized as a low maintenance, cost effective solution for both reducing or stopping corrosion. Because anodes provide an estimated 5 to 15 years of corrosion protection, their use is more advantageous and economical when applied to bridge rehabilitations and widenings with active corrosion or chloride contaminated concrete. Strategies better suited to achieve a 100-year service life are encouraged in all tier applications. Impressed current cathodic systems were evaluated but are eliminated from consideration for all applications due to their high installation, maintenance, and monitoring costs. Components of these systems are also susceptible to vandalism and copper theft according to several DOTs.

2.2.1.10 Precast Deck Panels

Precast deck panels are typically considered as part of an ABC approach; however, due to higher quality control in precast facilities, precast deck panels may potentially improve service life. To date, full depth precast deck panels have been utilized in a limited number of applications, but the practice is evolving in Colorado. Partial depth precast deck panels have been successfully used in numerous applications throughout the state. Precast deck panels should be considered for Tier 1, 2 and 3 applications with full depth precast deck panels considered when warranted due to an ABC approach.

2.2.2 REINFORCING STEEL STRATEGIES

2.2.2.1 Epoxy-Coated Steel Reinforcing

Epoxy-coated steel is a common corrosion resistant strategy in states utilizing deicing and anti-icing chemicals. However, per the *SHRP 2 Design Guide*, "recent work and observations in the field have shown that the longevity desired (75 years and beyond) may not be achievable and therefore, other corrosion reinforcements are being considered." Additionally, epoxy- coated reinforcement naturally degrades in a moist alkaline environment within concrete (*SHRP 2 Design Guide*).

Recent CDOT experience with epoxy-coated reinforcement indicates that it is difficult to maintain free of defects at the time of installation. The defects in the epoxy coating accelerate corrosion when compared to plain reinforcing bars. For these reasons, epoxy coated reinforcement is recommended only for Tier 1 applications.

2.2.2.2 Low Carbon Chromium Steel Reinforcing

Low carbon chromium steel has demonstrated corrosion rates about 4 times lower than conventional black bar reinforcing. Its superior corrosion resistance over black reinforcement and its reliability over epoxy coating makes low carbon chromium steel reinforcing a viable strategy for extending bridge service life. Other DOTs, such as Virginia DOT, have completely abandoned epoxy-coated reinforcement for low carbon chromium steel reinforcement. Low carbon chromium steel should be considered for Tier 2 applications.

2.2.2.3 Stainless Steel Reinforcing

Stainless steel reinforcing has demonstrated corrosion rates that are about 1,500 times lower than conventional black bar reinforcing and is the most promising reinforcement alternative examined in the *SHRP 2 Design Guide* that balances initial cost with extended service life. To achieve an economical solution, BTE funded projects have used stainless steel reinforcing paired with AASHTO LRFD empirical design methodology to reduce the reinforcing quantity in bridge decks. Stainless steel reinforcement should avoid contact with black reinforcement, as other materials may initiate galvanic corrosion in stainless steel (*ETN-M-2-12, CRSI, 2012*).

Stainless steel reinforcement should be combined with enhanced concrete strategies to prevent concrete degradation relative to the reinforcement. Stainless steel reinforcing should be considered for Tier 3 applications only. AASHTO LRFD empirical design methodology should be considered in conjunction with the use of stainless steel rebar to achieve cost savings when appropriate. Approval of this design methodology will be on a case-by-case basis per the CDOT Bridge Design Manual.

2.2.2.4 Galvanized Reinforcing

Hot-dip galvanized steel is widely used as a means of corrosion resistance throughout numerous industries. CDOT has historically viewed the use of hot-dip galvanizing as a strategy to protect reinforcing steel in bridge decks as problematic due to damage of the protective coating from bending, transport, or construction handling. The process and materials used in ASTM A1094, *Standard Specification for Continuous Hot-Dip Galvanized Steel Bars for Concrete Reinforcement*, minimize damage to the zinc coating due to the bending of steel reinforcement. ASTM A1094 galvanizing offers an advantage over ASTM A767 galvanizing, which is prone to be more brittle, and should be considered as a substitute for epoxy-coated rebar for Tier 1 applications.

2.2.2.5 Other Strategies

Other strategies considered, but not recommended, are provided below in Table 2.

Table 2 - Reinforcement Strategies Eliminated from Consideration

Reinforcement Material Type	Reasons for Elimination
Stainless Steel-Clad	While stainless steel-clad rebar is more cost effective than stainless steel, the cladding is vulnerable to debonding from the bar, especially when bent, cut, or handled in construction, exposing these localized areas to future corrosion.
Titanium	Although titanium corrodes 135 times less than conventional black bars when exposed to a high salt solution, the cost of titanium reinforcement is approximately 6 times higher than that of stainless steel reinforcement and not cost competitive (*SHRP 2 Design Guide*).
Copper-Clad	Copper cladding retards cement hydration, and its effect on concrete structural performance, specifically bond strength, requires additional research.
Nickel-Clad	Nickel clad reinforcement is expensive and research or case studies regarding its use is scarce.
Fiber Reinforced Polymer (FRP) Bridge Decks	FRP bridge decks are an emerging technology. FRP's low skid resistance, degradation under environmental conditions, and problematic connections to crashworthy barriers eliminate its use from further consideration until further research is conducted.

2.2.3 STRUCTURAL STEEL STRATEGIES

2.2.3.1 Paints and Primers

Zinc-rich primers and paints are commonly applied as a corrosion protection measure, but their use typically correlates with high life cycle cost. Paints typically require reapplication every 20 to 30 years in moist climates (*SHRP 2 Design Guide*), or about 15 to 25 years in Colorado. If repainting does not occur, significant corrosion can initiate, requiring treatment of the steel surface to ensure chlorides are removed prior to painting. Proper maintenance is critical because contaminants are considerably more difficult to remove from rusted steel. Salt concentrations on a steel surface can be measured utilizing the *SSPC-Guide 15-Field Methods for Retrieval and Analysis of Soluble Salts on Steel or Other Nonporous Substrates*.

Due to the relatively frequent maintenance associated with paints and primers, they are considered for Tier 1 applications only.

2.2.3.2 Hot-Dip Galvanization (HDG)

HDG is a system where components are dipped into a vat of molten zinc, creating a strong metallurgical bonded coating (*SHRP 2 Design Guide*). Galvanized metals have a history of high corrosion resistance. The AASHTO Specifications have minimum thickness standards when galvanizing specific steel components. Natural galvanizing leaves a bright zinc colored finish that can be painted following proper coordination with the galvanizer.

HDG is considered the most effective protection available for structural steel (*SHRP 2 Design Guide*). Due to its high corrosion resistance, HDG is considered for Tier 2 and Tier 3 applications.

2.2.3.3 Metalizing

Metalizing is a “spray on” application of galvanizing and an alternative when structural steel shapes are too large for the HDG process. Like HDG, metalizing is considered for Tier 2 and Tier 3 applications, when appropriate.

2.2.3.4 Weathering Steel

Weathering steel has shown considerable corrosion resistance with fairly low maintenance. The steel is available in ASTM A709 Grade 50W as well as high performance steel (HPS) grades HPS 50W, 70W and 100W. A patina develops on weathering steel when subjected to wet and dry cycles that acts as a protective layer, eliminating the need for painting in most circumstances. If properly designed and detailed, weathering steel could potentially realize bridge life cycles up to 120 years with minimal maintenance (*SHRP 2 Design Guide*).

Considerations for the use of weathering steel are as follows:

1) Weathering steel placed in a consistently moist environment (i.e., high rainfalls, high humidity, and/or persistent fog) without corresponding dry cycles will not form a protective patina and may result in advanced corrosion. Conversely, steel sheltered from moisture may also fail to develop a protective patina.

2) Heavy use of deicing and anti-icing chemicals may cause issues, especially if any runoff occurs through leaking expansion joints or scuppers and drainage pipes. In cases where weathering steel is vulnerable to surface runoff, it is recommended that the weathering steel girder be painted for a length equal to 1.5 to 2 times the overall girder depth. Drip bar detailing is also recommended to prevent leakage along a girder flange and can prevent substructure deterioration and staining.

CDOT had discontinued the use of weathering steel for bridge rails. Per the *FHWA FAQ: Barrier, Terminals, Transition, Attenuators, and Bridge Railings* "bridge rails are usually close enough to the travelled way that they can be sprayed with water from passing traffic…plows can throw snow onto the rail and the abrasive action of the snow can erode the protective layer. When exposed to these environments, weathering steel never develops the 'patina' that slows corrosion as in other less aggressive environments."

Due to its potential to achieve a design service life of more than 100 years, weathering steels, exclusive of bridge rails, are considered for Tier 1, 2, and 3 applications.

2.2.3.5 ASTM A709 Grade 50CR Structural Stainless Steel

ASTM A709 Grade 50CR, formerly ASTM A1010, has been limited to coal rail cars and coal processing equipment but is gradually being implemented in bridge applications (*SHRP 2 Design Guide*). Consequently, ASTM adopted the reference ASTM A709 Grade 50CR to reflect the material's accepted and continued use as a solution to corrosion in bridge applications.

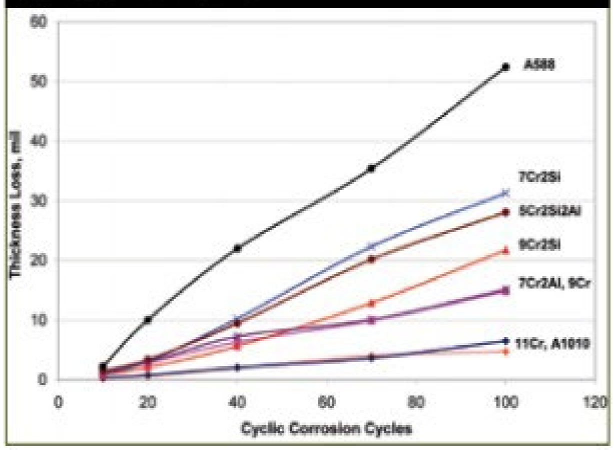
ASTM A709 Grade 50CR structural stainless steel is available in plate sizes up to 4 inches thick and can meet the strength and impact properties of AASHTO M270 Grades 50W and HPS 50W (*SHRP 2 Design Guide*). The Federal Steel Design Handbook also indicates that A709 50CR steel meets mechanical property requirements for ASTM A709 Grade 50 and Charpy V-Notch (CVN) requirements for HPS 50W. A709 50CR is weldable, but because the material is not currently included in the American Welding Society's D1.5 Bridge Welding Code, supplemental provisions are required for the manufacturer (*FHWA-IF-12-052,* November 2012).

Two structures in Oregon utilized structural stainless steel girders, one near a coastal environment. A structure in Colusa County California, constructed in 2005, also utilized a structural stainless steel superstructure. Both Oregon DOT and Colusa County DOT have indicated that their structures are performing well. A709 50CR steel has been used in Pennsylvania, Texas, Iowa, and Canada. Additionally, in 2017, Virginia DOT constructed their first stainless steel plate girder bridge and documented the material fabrication, construction process, cost analyses, and design guidance for implementation in future bridge projects in their study *Virginia's First Corrosion Resistant ASTM A1010 Steel Plate Girder Bridge (FHWA/VTRC 20-R10,* November 2019). At the time of publication, Virginia DOT was preparing to construct or rehabilitate additional bridges utilizing A709 50CR steel.

The initial cost of structural stainless steel may be more than twice the initial cost of conventional carbon or weathering steel (*FHWA-HRT-11-061,* July 2011). A more recent estimate by Virginia DOT in their publication *FHWA/VTRC 20-R10* indicates that the premium to use A709 50CR steel in lieu of galvanized weathering steel was 60%. Because stainless steel in bridge applications is underutilized, fabricators and welders unfamiliar with the material require special provisions and supplemental testing that make the material cost unpredictable.

ASTM A709 Grade 50CR structural stainless steel performs well in corrosive chloride environments and the material outperforms ASTM A588 weathering steel. Presented below in Figure 1 are results from NaCl cyclic tests (SAE J2334 Cyclic Corrosion Tests) performed on various alloys, including ASTM A588 and 50CR (ASTM 1010) steels *from FHWA-HRT-11-061 - Improved Corrosion Resistant Steel for Highway Bridge Construction.*

Figure 2. Summary of 5 percent NaCl cyclic corrosion test results.



1 mil = 25.4 μm

Table 3. Linear regression equations for thickness loss in 5 percent NaCl cyclic corrosion tests.

Steel	Coefficient, Mil Per Cycle	Predicted Life Versus ASTM A588
ASTM A1010	0.050	10.4
11Cr	0.056	9.3
9Cr	0.147	3.5
9Cr2Si	0.197	2.6
7Cr2Si	0.304	1.7
7Cr2Al	0.152	3.4
5Cr2Si2Al	0.275	1.9
ASTM A588	0.519	1.0

1 mil = 25.4 μm

Figure 1 - Results of Corrosion Tests on Steel Alloys

(Source: *FHWA-HRT-11-061 Improved Corrosion Resistant Steel for Highway Bridge Construction*)

It should be noted that of alloys considered other than ASTM A588 in this test, only the A709 50CR alloy satisfied the CVN test (*FHWA HRT-11-061*, July 2011). Structural stainless steel should not be placed in contact with carbon steel, zinc, or aluminum as these materials may initiate galvanic corrosion in stainless steel (*SHRP 2 Design Guide*). ASTM A709 Grade 50CR steel is considered for Tier 3 applications only.

2.2.3.6 Nanoparticle Coating Systems

As noted in the *SHRP 2 Design Guide*, there is continued research on steel coating systems that provide superior corrosion protection such as nanoparticle technology. While no system is currently available for inclusion in the tiered strategy system, nanoparticles are mentioned as a place holder for future discussion and should be further evaluated when its usage is further advanced in the bridge industry.

2.2.4 DESIGN DETAILING STRATEGIES

Alternative design detail strategies discussed in this section may have insignificant cost impacts but may be implemented to enhance bridge service life.

2.2.4.1 Strategic Construction Joint Placement

The *SHRP 2 Design Guide* indicates that bridge decks would likely perform better if construction joints were eliminated or placed strategically away from chemical-laden drainage runoff.

One strategy relocates the barrier construction joint above the deck surface to provide a monolithic concrete pour where there is potential for collection of drainage runoff. A sample detail is shown below in Figure 2. Due to the relatively low cost of this strategy, it is considered for all tier applications. As an alternative, a vertical neoprene water stopper can be installed with 3-inch projection from the deck. Corrosion resistant reinforcing or fiber reinforcing can also be used at barrier facia to prevent curb spalling as deemed appropriate.

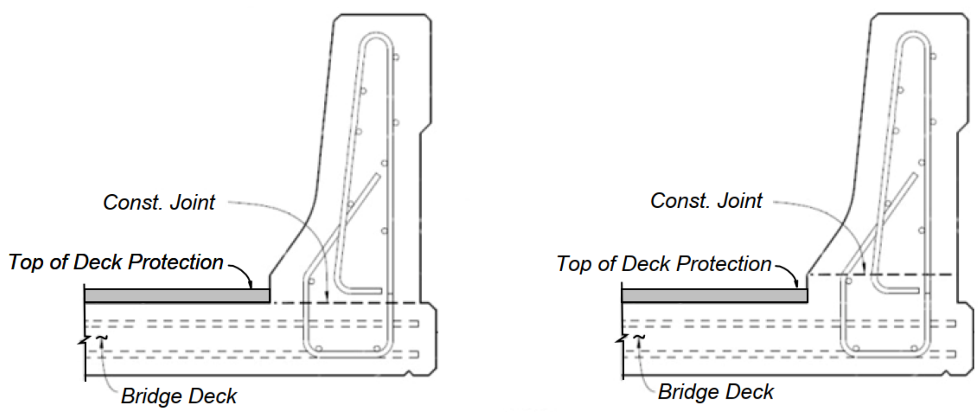


Figure 2 - Alternative Construction Joint Placement of Deck/Barrier Interface

(Source: *SHRP 2 Renewal Project R19A Design Guide for Service Life*)

2.2.4.2 Jointless Bridge Design

A low-cost strategy that reduces superstructure and substructure exposure to chloride infiltration and freeze/thaw damage includes eliminating deck joints. This requires that foundations be flexible enough to accommodate movement from horizontal loads. Due to the significant benefit of jointless bridge design, this strategy should be considered for all tier applications.

2.2.4.3 Post-Tensioning Deck Slabs

Post-tensioning deck slabs is a technique that increases the deck cracking resistance by placing the slab into compression. However, post-tensioning adds hardware and may increase long term maintenance requirements. If a loss of stressing occurs due to failure of tensioning rods, strands or anchorage devices, the slab is vulnerable to cracking and accelerated deterioration. Because the longevity of this strategy is uncertain, it should be applied in Tier 2 applications only. Detailing should be such that post-tension systems are protected from corrosion, and design should be completed so that post-tension forces are not the primary live load resisting components of the deck.

2.2.4.4 Bridge Layout: Reduce Skew and Span Balance

Bridges with high skew angles exhibit higher shear stress in the acute corners of the superstructure than bridges with reduced skew supports. These stresses may cause premature expansion joint and bearing failure, abutment cracking, and fatigue damage in steel girders. Where possible, designers are encouraged to reduce or eliminate the skews of structures in all tier applications. To further reduce undesirable stresses in the superstructure, designers are also encouraged to proportion end spans to interior spans such that negative and positive moments are well balanced, as site constraints allow.

2.2.5 CONSTRUCTION QUALITY CONTROL STRATEGIES

The CDOT Standard Specifications, supplemented with current special provisions, provide a basis for construction tolerances that complement the AASHTO Standard Specifications for providing a 75-year design service life. Construction tolerances and inspection requirements can be enhanced to provide additional quality of a final bridge product.

2.2.6 SUMMARY OF SELECTED STRATEGIES

It is recognized that combinations of strategies presented in Table 3 may complement each other while other combinations provide redundancy beyond what is required to achieve the desired 100-year design service life. Selection of a tiered grouping is intended to give designers opportunities to use combinations of strategies, while some strategies can be eliminated. **Designer discretion is required to select the appropriate strategies or combination of strategies based on project-specific considerations.**

TIER 1 STRATEGIES

CONCRETE
- ULTRA-HIGH-PERFORMANCE CONCRETE (ABC)
- CORROSION INHIBITING ADMIXTURES
- CDOT CLASS DF CONCRETE
- BITUMINOUS WATERPROOFING MEMBRANES
- CONCRETE SEALERS FOR NON-ABRASION SURFACES
- PPC OVERLAY
- PRECAST DECK PANELS

REINFORCEMENT
- EPOXY-COATED REBAR
- GALVANIZED REBAR

STRUCTURAL STEEL
- ZINC-RICH PAINTS & PRIMERS
- WEATHERING STEEL

DESIGN DETAILING
- STRATEGIC JOINT PLACEMENT
- JOINTLESS BRIDGE DESIGN
- REDUCE BRIDGE SKEW AND BALANCE SPANS

TIER 2 STRATEGIES

CONCRETE
- ULTRA-HIGH-PERFORMANCE CONCRETE (ABC)
- CDOT CLASS DF CONCRETE
- BITUMINOUS WATERPROOFING MEMBRANES
- CONCRETE SEALERS FOR NON-ABRASION SURFACES
- PPC OVERLAY
- PRECAST DECK PANELS

REINFORCEMENT
- LOW CARBON CHROMIUM REBAR

STRUCTURAL STEEL
- HOT-DIP GALVANIZATION
- METALIZING
- WEATHERING STEEL

DESIGN DETAILING
- STRATEGIC JOINT PLACEMENT
- JOINTLESS BRIDGE DESIGN
- POST-TENSIONED DECK SLABS
- REDUCE BRIDGE SKEW AND BALANCE SPANS

TIER 3 STRATEGIES

CONCRETE
- ULTRA-HIGH-PERFORMANCE CONCRETE (ABC)
- CDOT CLASS DF CONCRETE
- ELASTOMERIC WATERPROOFING MEMRBRANES
- CONCRETE SEALERS FOR NON-ABRASION SURFACES
- PPC OVERLAY
- PRECAST DECK PANELS

REINFORCEMENT
- STAINLESS STEEL REBAR (CONSIDER EMPIRCAL DESIGN METHODOLOGY)

STRUCTURAL STEEL
- HOT-DIP GALVANIZATION
- METALIZING
- WEATHERING STEEL
- A709 GRADE 50CR (STAINLESS STEEL)

DESIGN DETAILING
- STRATEGIC JOINT PLACEMENT
- JOINTLESS BRIDGE DESIGN
- REDUCE BRIDGE SKEW AND BALANCE SPANS

Figure 3 - Summary of Available Strategies for Tier 1, 2, and 3

3 COST/BENEFIT ANALYSIS

The *SHRP 2 Design Guide* identifies that a life cycle cost analysis is key in providing a more comprehensive selection process. While focus is often placed at selecting the lowest initial cost, higher maintenance costs may lead to performance issues and budget constraints may lead to "worst first" methodologies ultimately leading to a bridge structure's reduced design service life. Life cycle cost analyses factor in initial costs as well as anticipated maintenance costs throughout the design life of a bridge to identify the most cost-effective solution.

It was recognized that performing a life cycle cost analysis of strategies during the development of these guidelines may have the negative effect of prematurely eliminating strategies from future consideration, leading to an overly prescriptive approach. BTE intends to keep several life extending strategies open for consideration in each tier. Furthermore, it was recognized that due to constant market changes, initial costs of strategies will change over time. The best way to ensure valid results of a life-cycle cost analysis is to perform the analysis at the time of design. As a result, designers of BTE bridges are expected to proceed with a life-cycle cost analysis of strategies outlined in Table 3. Selection and implementation of strategies should be based on the optimal cost-effective solution.

The *SHRP 2 Design Guide* recommends that every new bridge design be supplemented with an "Owner's Manual." Within each "Owner's Manual", the design strategies and anticipated maintenance activities (including their respective costs in the life cycle cost analysis) are identified so that bridge inspection personnel can be more intensely focused on bridge elements as certain anticipated rehabilitation and/or repair milestones approach. Identifying maintenance issues earlier and allocating budgets with the aid of a life cycle cost analysis will be crucial in enhancing the service life of a bridge structure even further than selection of materials and design detailing alone.

In addition to an "Owner's Manual", tools such as Building Information Modeling (BIM) could be incorporated to map out the location of key design features or utilities. BIM may assist in rehabilitation and repair efforts. For example, BIM may better identify locations of saw cutting and removal activities to avoid incurring additional costs due to unforeseen structural or utility conflicts that were not properly identified in an as-built set.

4 WHEN TO UTILIZE ENHANCED STRATEGIES

4.1 CANDIDATE BRIDGES

When identifying bridge enhancement alternatives for selection and recommendation, a life cycle cost analysis is insufficient as a standalone selection tool. It is equally important to recognize that some bridge structures may not justify higher initial costs if they have the potential to be widened, modified, or even replaced due to factors such as increased traffic demand. To avoid potential throwaway costs, designers should therefore consider and investigate thoroughly additional factors when selecting the best bridge enhancement strategies.

For example, a structure that has potential for future widening may be eligible for deck rehabilitation. Rather than incurring a high initial bridge cost that reduces the overall life cycle cost, the deck widening, and concurrent deck rehabilitation, could be performed in lieu of costly bridge elements the future widening may impact or remove. A new life cycle cost analysis could identify benefits of incorporating enhanced features in deck rehabilitation if it could be demonstrated that the potential for future structure modification or removal remained low.

Accordingly, bridge structures located near metropolitan centers or areas of anticipated population growth may be poor candidates for high initial cost bridge enhancements. Conversely, bridge structures in remote locales with minimal population growth or difficult construction access may be eligible for higher initial costs and lower overall life cycle costs since the potential for future bridge modifications or replacement is minimal. Discussed below are candidate features used to determine eligibility for bridge service life enhancements.

4.2 CANDIDATE BRIDGE FEATURES

Candidate features for consideration when including strategies that enhance bridge service life include proximity of the bridge structure to an area of high population or high projected population growth; assessing present versus future average daily traffic (ADT) volumes; and geographic location. In determining the applicable tier assignment, designers should complete the following steps.

Step 1: Proximity to Population or Projected Growth

Determine bridge location with respect to Metropolitan Planning Organizations (MPO) or Transportation Planning Regions (TPR) based on the maps available from the following CDOT websites:

- Bridges located within an MPO boundary are candidates for Tier 1 strategies only.
- Bridges located within TRP boundaries are candidates for Tier 2 and Tier 3 strategies, subject to other criteria.

Step 2: Current ADT

Determine the ADT for the current inspection year (refer to CDOT SIA report Item 29 or CDOT OTIS Highway Data Explorer for current traffic data)

- ADT lower than 600: proceed to *Step 5*
- ADT from 601 to 1400: proceed to *Step 3*
- ADT greater than 1401: use Tier 1 strategies

Step 3: Future ADT

Determine the ADT at 20 years from current inspection year (refer to CDOT SIA report Item 114 or CDOT OTIS Highway Data Explorer for projected traffic data).

Step 4: Divide current ADT by Future ADT

- Current ADT / Future ADT > 0.75: proceed to *Step 5*
- Current ADT / Future ADT < 0.75: use Tier 1 strategies

Step 5: Geographic Location

Determine bridge location within the geographical limits defined below:

- Bridges within the Mountains or Front Range are candidates for Tier 3 strategies
- Bridges located within the Eastern Plains or Western Slope are candidates for Tier 2 strategies

Figure 3 illustrates the tiered workflow.

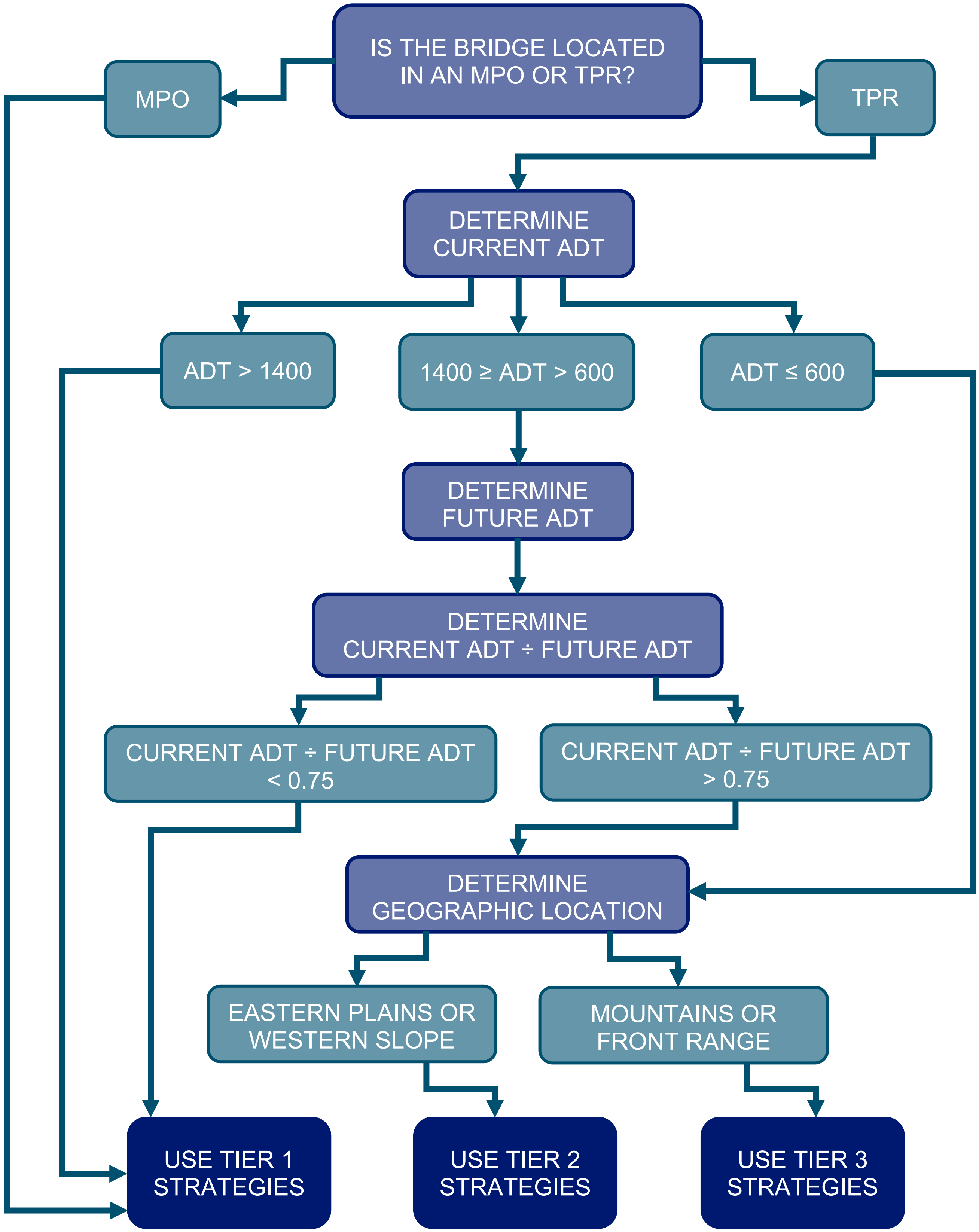


Figure 4 - Tier Strategies Workflow

5 REFERENCES

1) SHRP 2 Renewal Project R19A Design Guide for Bridges for Service Life, Atorod Azizinamini et. al., Publication, December 2013.

2) Engineering Technical Note ETN-M-2-12, Frequently Asked Questions About Stainless Steel Reinforcing Bars, CRSI, 2012.

3) FHWA Frequently Asked Question (FAQ): Barriers, Terminals, Transitions, Attenuators, and Bridge Railings. https://safety.fhwa.dot.gov/roadway_dept/countermeasures/faqs/qa_bttabr.cfm#brrs1

4) FHWA-IF-12-052-Vol. 1 Steel Bridge Design Handbook – Bridge Steels and Their Mechanical Properties, November 2012.

5) Virginia's First Corrosion-Resistant ASTM A1010 Steel Plate Girder Bridge, Virginia Transportation Research Council (VTRC), FHWA/VTRC 20-R10, November 2019. http://www.virginiadot.org/vtrc/main/online_reports/pdf/20-r10.pdf

6) FHWA-HRT-11-061 Improved Corrosion-Resistant Steel for Highway Bridge Construction (Tech Brief), FHWA, July 2011.

7) www.pavementinteractive.org/article/los-angeles-abrasion/