Long-Term Bridge Performance Program

SUMMARY REPORT

FHWA LTBP Summary—National Changes in Bridge Practices for Reinforcing Bars

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About LTBP

This research was conducted as part of the Federal Highway Administration's Long-Term Bridge Performance (LTBP) Program. The LTBP Program is a minimum 20-year research effort to collect scientific performance field data, from a representative sample of bridges nationwide, that will help the bridge community better understand bridge deterioration and performance. The products from this program will be a collection of data-driven tools including predictive and forecasting models that will enhance the abilities of bridge owners to optimize their management of bridges.

Introduction

This study was conducted as part of the Federal Highway Administration (FHWA) Long-Term Bridge Performance (LTBP) Program in conjunction with the National Concrete Bridge Council. The LTBP Program is a long-term research effort, authorized by the U.S. Congress under the *Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users* to collect high-quality bridge data from a representative sample of highway bridges nationwide that will help the bridge community better understand bridge performance.(1) The products from this program will be a collection of data-driven tools, including predictive and forecasting models that will enhance the abilities of bridge owners to optimize their management of bridges.

The LTBP Program is collecting field data from bridges constructed from 1960 to the present. Because the LTBP Program not only collects the data but also analyzes it, the data must be evaluated in its proper context. Nationally, bridge technologies have changed, and new innovations have arisen so that the state-of-the-art for bridge engineering has advanced. It is important to record when these innovations and changes in bridge technology occur in order to better interpret and understand why the performance data may differ for bridges built from 1960 to the present. For example, if a bridge built in 1965 is outperforming a bridge built in 1978 (or vice versa), it would be helpful to understand what innovations and changes in practice occurred between these two dates that could affect bridge performance.

This summary report discusses the changes in bridge practice—both technology changes and innovations—for reinforcing steel for concrete bridge members.

The Need for and Use of Reinforcing Steel

The compressive strength of concrete is significantly stronger than its tensile strength. Wherever there is sufficient tension in plain (unreinforced) concrete, concrete tends to crack. Therefore, wherever tension is present in the concrete member, designers place reinforcing steel bars, or rebars, to help carry the tensile load/stress. For reinforced concrete members, designers use only reinforcing steel. For prestressed concrete members, designers use reinforcing steel in addition to high-strength seven-wire pretensioned strands and/or post-tensioned tendons to carry higher loads and/or span greater distances.

Tensile loads occur in simple-span and multispan bridges due to prestressing and flexure induced by dead loads and live loads. Tensile loads can also occur from shear forces, lateral loads, seismic forces, thermal effects, creep and shrinkage of the concrete, and deleterious reactions within the concrete. Typically, flexure loads can be carried by straight reinforcing bars placed in the bottom of a deck or beam in simple spans and placed in the tops of these members over the supports. Truss bars (reinforcing steel that is formed in a repeating pattern of bottom reinforcement followed by top reinforcement) are still used by some States to resist flexure primarily in bridge decks. Reinforcing bars formed into open or closed hoops, called "stirrups," are placed in the concrete member to help resist shear forces. Lateral loads and seismic forces may be resisted in columns by spiral reinforcing steel or a series of evenly spaced reinforcing steel hoops called ties. Creep and shrinkage forces occur in the concrete both during the initial set of the concrete and over time; these forces can be resisted by grids of reinforcing bars that intersect locations where cracks may form.

The Need for Corrosion Protection

Bridges in much of the United States are subjected to deicing chemicals during the winter months, and bridges located in a marine environment are subjected to sea water. Many of these deicing chemicals contain chloride ions. As snow and ice melt, the water carries these chloride ions down into the pores of the concrete surface. When present in sufficient concentrations, chloride ions cause the reinforcing steel to rust and corrode. Rust causes the reinforcing steel to exfoliate, causing inner stress with the hardened concrete. As the rust expands, it cracks the concrete, and a spall can develop adjacent to the corroded rebar.

Specialty reinforcing bars were developed to address issues related to corrosion and/or to provide increased tensile strength. These specialty reinforcing bars include epoxy-coated, galvanized, dual-coated, low carbon-chromium, and stainless steel.

The following timelines describe the advancement and changes in reinforcing bars and corrosion-resistant reinforcement from 1910 to the present (see table 1 and table 2).

Table 1. Timeline of changes in national bridge practices for steel reinforcement in concrete bridges.

1910	First reinforcing bar specifications issued.[(2)]
1911	ASTM A15 published with grades 33 and 50.[(3)]
1914	ASTM A15 revised by adding grade 40.[(4)]
1924	The American Association of State Highway Officials (AASHO) issued its first standard for concrete reinforcement, AASHO M 31.[(5)]
1928	First hot-dip galvanized reinforcing bar specifications published, ASTM A123.[(6)]

Table 1. Timeline of changes in national bridge practices for steel reinforcement in concrete bridges — Continued.

Year	Event
1947	ASTM A305 published; it included rebar deformation patterns.[7]
1953	U.S. Navy uses galvanized rebar in a bridge in Bermuda.
1957	ASTM A408 published; it covered large diameter bars (no.14 and no.18 bars) in three different grades.[8]
1958	ASTM A431 published; it included grade 75 rebar.[9]
1959	ASTM A432 published; it included grade 60 rebar.[10]
1968	• ASTM A305, ASTM A408, ASTM A431, and ASTM A432 withdrawn. (See references 7–10.) • ASTM A615 published (replaced ASTM A15, ASTM A408, ASTM A431, ASTM A432, and portions of ASTM A305) with grades 40, 60, and 75. (See references 11, 4, and 7–10.)
1969	ASTM A15 withdrawn.[4]
1972	ASTM A615 revised, removing grade 75 rebar.[12,2]
1973	Epoxy-coated rebar first used in a U.S. bridge.
1974	ASTM A706 published for rebars with improved weldability.[13]
1979	ASTM A767 published for zinc-coated (galvanized) rebars.[14]
1981	ASTM A775 for epoxy-coated rebars and ASTM D3963 for handling of epoxy-coated bars published.[15,16]
1982	The American Association of State Highway and Transportation Officials (AASHTO) published the metric version of standard M31, known as AASHTO M 31M.[17]
1983	Stainless steel rebar first used in U.S. bridges.
1987	• ASTM A615 revised, reinstating grade 75.[18] • AASHTO published M 284 for epoxy-coated rebars.[19]

Table 1. Timeline of changes in national bridge practices for steel reinforcement in concrete bridges — Continued.

Year	Change
1989	ASTM A775/A775M revised to change damage threshold and add anchor profile.[20]
1990	• ASTM A775/A775M revised with provisions for repairing damaged coating.[21] • FHWA memorandum issued on certification programs.[22]
1991	The Concrete Reinforcing Steel Institute (CRSI) began a certification program for epoxy-coating applicator plants.
1992	ASTM A775/A775M revised to change the coating thickness.[23]
1994	ASTM A775/A775M revised to change the bend tests.[24]
1995	• ASTM A934/A934M published for prefabricated epoxy-coated rebar.[25] • ASTM A775/A75M revised to allow a chemical wash for surface preparation.[26]
1996	ASTM A955/A955M published for stainless steel rebars.[27]
1997	Cathodic debonding introduced in ASTM A775/A775M and A934/A934M.[28,29]
2001	AASHTO issued AASHTO M 317M/M 317.[30]
2003	ASTM A995 revised.[31]
2004	• ASTM A1035/A1035M published.[32] • ASTM A615/A615M renamed.[33] • ASTM A775/775M revised.[34] • AASHTO MP 13M/MP 13 published.[35]
2007	ASTM A955 revised.[36]
2008	ASTM A1055 published for zinc and epoxy dual coated rebars.[37]
2009	• ASTM A615/A615M revised, adding grade 80.[38] • ASTM A706/A706M revised, adding grade 80.[39] • AASHTO MP 18M/MP 18 published.[40]
2012	• AASHTO discontinued AASHTO M 284M/M 284. It was replaced by ASTM A775/A775M.[41,42] • AASHTO discontinued AASHTO M 317M/M 317. It was replaced by ASTM D3963/D3963M.[43,44]
2015	• ASTM A615/A615M revised, adding grade 100.[45] • ASTM A1035/A1035M revised.[46] • ASTM A1094/A1094M published for continuous hot-dip galvanized steel rebars.[47] • AASHTO updated AASHTO MP 18M/MP 18.[48]

Table 2. Detailed changes in bridge practices nationally for steel reinforcement in concrete bridges.

1910	Specifications for reinforcing bars were first produced by the Association of American Steel Manufacturers.[2]
1911	ASTM issued its first version of ASTM A15, *Standard Specification for Billet-Steel Concrete Reinforcement Bars.*[3] It had provisions for the following two grades: • Grade 33—Structural, with a minimum specified yield strength of 33 ksi. • Grade 50—Hard, with a minimum specified yield strength of 50 ksi. This specification was withdrawn in 1969.
1914	ASTM changed ASTM A15 and added provisions for a third grade: grade 40—Intermediate, with minimum specified yield strength of 40 ksi.[4]
1924	AASHO published its first standard for reinforcing bars, AASHO M 31, *Billet-Steel Concrete Reinforcing Bars.*[5]
1928	ASTM first published ASTM A123, *Tentative Specification for Zinc (Hot-Galvanized) Coatings on Structural Steel Shapes, Plates and Bars and Their Products.*[6] This specification covers rebars that are constructed into rebar cages/assemblies and then are hot-dip galvanized as a cage/assembly. It also covers hot-dip galvanizing for an assortment of products, including steel plates, pipes, and wires.[49,50]
1947	ASTM issued the first version of ASTM A305, *Tentative Specification for Minimum Requirements for the Deformations of Deformed Steel Bars for Concrete Reinforcement.*[7] This specification established standards for rebar deformation patterns, which improved the bond between the concrete and the rebar that met the standards in the first version of ASTM A15.[3,51]
1953	The U.S. Navy used galvanized rebar for the Longbird Bridge in Bermuda. This may have been the first use of galvanized rebar in North America.[49]
1957	ASTM first published ASTM A408, *Tentative Specification for Special Large Size Deformed Billet Steel Concrete Reinforcement Bars.*[8] This specification established standards for bars of approximately 14/8-inch and 18/8-inch diameters and designated them as 14S and 18S bars, respectively. Both bar sizes were available in three grades: structural, intermediate, and hard. The structural grade had a tensile strength of 55,000 to 75,000 psi and a minimum yield point of 33,000 psi. The intermediate grade had a tensile strength of 70,000 to 90,000 psi and a minimum yield point of 40,000 psi. The hard grade had a minimum tensile strength of 80,000 psi (and no specified maximum tensile strength) and a minimum yield point of 50,000 psi.[8]
1958	ASTM introduced its first specification for grade 75 rebar, ASTM A431, *Tentative Specification for High-Strength Billet-Steel Bars for Concrete Reinforcement.*[9]
1959	ASTM introduced its first specification for grade 60 rebar, ASTM A432, *Tentative Specification for Deformed Billet Steel Bars for Concrete Reinforcement with 60,000 psi Minimum Yield Point.*[10]

Table 2. Detailed changes in bridge practices nationally for steel reinforcement in concrete bridges — Continued.	
1968	**ASTM withdrew specifications ASTM A305, ASTM A408, ASTM A431, and ASTM A432. (See references 7–10.)** **ASTM first published ASTM A615.[11] It replaced ASTM A15, A408, A431, A432, and portions of A305, and it contained the following three grades: (See references 4, 8–10, and 7.)** • **Grade 40, with a minimum specified yield strength of 40 ksi.** • **Grade 60, with a minimum specified yield strength of 60 ksi.** • **Grade 75, with a minimum specified yield strength of 75 ksi.** **It was the first ASTM standard to specify provisions for all three of these grades of steel in one specification. It also contained provisions for deformation patterns for rebars that had previously been contained in ASTM A305.[2,7]**
1969	**ASTM withdrew specification ASTM A15.[4]**
1972	**ASTM A615 removed its provisions for grade 75 rebar.[12,2]**
1973	**Epoxy-coated rebars were first used in a U.S. highway bridge in Pennsylvania over the Schuylkill River.[52,53]**
1974	**ASTM issued its first version of ASTM A706, *Standard Specification for Low-Alloy Steel Deformed Bars for Concrete Reinforcement.*[13] The only grade specified was grade 60, with a minimum specified yield strength of 60 ksi and a maximum yield strength of 78 ksi. ASTM A706 bars are easier to weld than ASTM A615 bars due to greater controls over the chemical composition of the bars. The ASTM A706 specification also required the rebars to have a maximum carbon equivalent of 0.55 percent. The value of carbon equivalent is used in conjunction with the American Welding Society D12.1 standard to determine the minimum preheat temperature prior to welding.[54] The equation for calculating the carbon equivalent is provided in the ASTM A706 specification and includes values for the percentages of carbon, manganese, copper, nickel, chromium, molybdenum, and vanadium in the steel.[13,55]**
1979	**ASTM issued the first version of ASTM A767, *Standard Specification for Zinc-Coated (Galvanized) Bars for Concrete Reinforcement.*[14] This specification covered unassembled groups of bars and single bars. The amount of coating is not specified by thickness but by the mass of the zinc coating per surface area.[49,50]**
1981	**ASTM issued the first version of ASTM A775, *Standard Specification for Epoxy-Coated Reinforcing Steel Bars.*[15] It covered the coating application on the rebars before fabrication (subsequent bending or handling of the rebar to create the reinforcing cage). The coating thickness was set at 7 mil ± 2 mil, which would allow a minimum coating thickness of 5 mil.[15,56]** **ASTM issued the first version of ASTM D3963, *Standard Specification for Epoxy-Coated Reinforcing Steel.*[16] It covered the fabrication of epoxy-coated rebars and the handling of these rebars during transport, as well as the handling, storage, and placement of these rebars at the job site.[16]**

Table 2. Detailed changes in bridge practices nationally for steel reinforcement in concrete bridges — Continued.

1982	AASHTO published its first metric standard for rebar, AASHTO M 31M, *Deformed and Plain Billet-Steel Bars for Concrete Reinforcment [Metric].*[17]
1983	The earliest bridge deck built using stainless steel reinforcement was constructed in 1983 in Michigan using Unified Numbering System S30400 material for the east-bound deck. The deck is on the I-696 Bridge over Lennox Road in Ferndale, MI.
1987	ASTM A615 reinstated provisions for grade 75 rebar.[18] AASHTO published its first standard for epoxy-coated rebars, AASHTO M 284, *Epoxy Coated Reinforcing Bars.*[19]
1989	ASTM revised standard A775/A775M in the following ways[20,53]: • Changed the damage threshold value of the total surface area in each 1-ft length of bar from 2 to 1 percent. • Introduced an "anchor profile," which is a measure of surface roughness after blast cleaning and prior to coating. Measures for anchor profile include maximum peak height and exposed surface.
1990	ASTM revised standard A775/A775M to include a provision that states that all damage to the epoxy coating incurred prior to the shipment of rebars to the job site must be repaired.[21,52,53] FHWA issued a memorandum on certification programs that encouraged owner agencies to require certification of producers involved in federally funded projects and specifically named the CRSI's upcoming Epoxy Coating Applicator Plant Certification Program.[22]
1991	CRSI began a voluntary certification program for epoxy-coating applicator plants.[52]
1992	ASTM revised standard A775/A775M to change the coating thickness to a range of 7 to 12 mil.[23] Bars with average coating thicknesses less than 7 mil were rejected.
1994	Changes were made to ASTM A775/A775M for coating flexibility and the coating process.[24] Prior standards evaluated bend tests with a bend angle of 120 degrees. This was changed in 1994 to a bend angle of 180 degrees, which elongates the coating. If errors are made in surface preparation (including surface cleanliness and surface roughness) and/or curing of the coating, then it is unlikely that the coating will pass this bend test.[53]
1995	The following changes were made to ASTM A775/A775M: • Allowed a chemical wash for surface preparation, which could increase adhesion of the coating.[53] • Included provisions in the appendix (non-mandatory information) portion of the specification for storing the epoxy-coated rebars at the job site after delivery and prior to placement in storage.[26] ASTM issued the first version of ASTM A934/A934M, *Standard Specification for Epoxy-Coated Prefabricated Steel Reinforcing Bars.*[25] It covered the coating application on the rebars after fabrication and allowed a chemical wash for surface preparation.[52,53]

Table 2. Detailed changes in bridge practices nationally for steel reinforcement in concrete bridges — Continued.

1996	**ASTM issued the first version of ASTM A955/A955M, *Standard Specification for Deformed and Plain Stainless Steel Bars for Concrete Reinforcement.*[27,57]**
1997	**Cathodic debonding tests were introduced into ASTM A775/A775M and ASTM A934/A934M as requirements for bonding of the coating to the rebar.[28,29] This test required a sample of epoxy-coated rebar to be placed in a 3-percent sodium chloride electrolyte solution for 168 h, with a limit on the average coating disbondment radius after the test of 0.16 inches.[52,53]**
2001	**AASHTO issued AASHTO M 317M/M 317, *Standard Specification for Epoxy-Coated Reinforcing Bars: Handling Requirements for Fabrication and Job Site.*[30]**
2003	**ASTM A955 was updated to reflect the minimum 20-percent elongation value for all bar sizes and grades.[31]**
2004	**ASTM issued the first version of ASTM A1035/A1035M, *Standard Specification for Deformed and Plain, Low-Carbon, Chromium, Steel Bars for Concrete Reinforcement.*[32]** **ASTM renamed standard specification ASTM A615/A615M as *Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement.*[33]** **ASTM revised standard A775/A775M to change the coating thickness for large diameter bars (no. 6 bar and higher) to a range of 7 to 16 mil.[34]** **AASHTO issued the first version of AASHTO MP 13M/MP 13-04, *2004 AASHTO Provisional Standard Specification for Stainless Clad Deformed and Plain Round Steel Bars for Concrete Reinforcement.*[35]**
2007	**A mandatory corrosion resistance test was added to ASTM A955.[36]**
2008	**ASTM issued the initial version of ASTM A1055, *Standard Specification for Zinc and Epoxy Dual Coated Steel Reinforcing Bars.* The layer of zinc alloy is applied first by the thermal spray coating method, and then the epoxy coating is applied second using the electrostatic spray method.[37]**
2009	**ASTM added provisions for grade 80 rebar, with minimum specified yield strength of 80 ksi, to ASTM A615/A615M.[38]** **ASTM added provision for grade 80 rebar, with minimum specified yield strength of 80 ksi, to ASTM A706/A706M.[39]** **AASHTO first issued AASHTO MP 18M/MP 18-09, *2009 AASHTO Provisional Standard Specification for Uncoated, Corrosion-Resistant, Deformed and Plain Alloy, Billet-Steel Bars for Concrete Reinforcement and Dowels.*[40]**

Table 2. Detailed changes in bridge practices nationally for steel reinforcement in concrete bridges — Continued.	
2012	**AASHTO discontinued AASHTO M 284, *Standard Specification for Epoxy-Coated Reinforcing Bars: Materials and Coating Requirements*. It was replaced by ASTM A775, *Standard Specification for Epoxy-Coated Steel Reinforcing Bars*.**[41,42] **AASHTO discontinued AASHTO M 317M/M 317, *Standard Specification for Epoxy-Coated Reinforcing Bars: Handling Requirements for Fabrication and Job Site*. It was replaced by ASTM D3963/D3963M, *Standard Specification for Fabrication and Jobsite Handling of Epoxy-Coated Steel Reinforcing Bars*.**[43,44]
2015	**ASTM added provisions for the following items to ASTM A615/A615M**[45]**:** • **Grade 100 rebar, with minimum specified yield strength of 100 ksi.** • **New size—no. 20 rebars.** **The specification adds a caution when using the grade 100 rebar. It states in note 1 that the ratio of specified tensile strength to specified yield strength is less than this ratio for the lower grades of rebar.**[45] **ASTM added provisions for two additional types of rebar to ASTM A1035/A1035M.**[46] **They are type CL and type CM, which have lower chromium contents than the current type CS, and are available in grades 100 and 120.** **ASTM published ASTM A1094/A1094M, *Standard Specification for Continuous Hot-Dip Galvanized Steel Bars for Concrete Reinforcement*.**[47] **AASHTO updated AASHTO MP 18M/MP 18-15, *Standard Specification for Uncoated, Corrosion-Resistant, Deformed and Plain Alloy, Billet-Steel Bars for Concrete Reinforcement and Dowels*.**[48]

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