

DECEMBER
2018

AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete

2ND EDITION



AMERICAN ASSOCIATION
OF STATE HIGHWAY AND
TRANSPORTATION OFFICIALS

AASHTO



American Association of State Highway and Transportation Officials
444 North Capitol Street, NW, Suite 249
Washington, DC 20001
202-624-5800 phone/202-624-5806 fax
www.transportation.org

Cover photos: **Top:** Mile road bridge deck pour with GFRP Bars, courtesy of Doug Gremel, Owens Corning Infrastructure Solutions LLC. **Lower Left:** Maui Sea Wall Pour, courtesy of Doug Gremel, Owens Corning Infrastructure Solutions LLC. **Lower Right:** KDOT State Ave I635, courtesy of Doug Gremel, Owens Corning Infrastructure Solutions LLC

© 2018 by the American Association of State Highway and Transportation Officials. All rights reserved. Duplication is a violation of applicable law.

ISBN: 978-1-56051-717-7

Pub Code: GFRP-2

This is a preview. Click here to purchase the full publication.

AASHTO EXECUTIVE COMMITTEE

2018–2019

Voting Members

Officers:

PRESIDENT: Carlos Braceras, Utah*
VICE PRESIDENT: Patrick McKenna, Missouri*
SECRETARY–TREASURER: Scott Bennett, Arkansas*
EXECUTIVE DIRECTOR: Bud Wright, Washington, D.C.

Regional Representatives:

Jennifer Cohan, Delaware
Victoria Sheehan, New Hampshire
Russell McMurtry, Georgia
Joe McGuinness, Indiana
Mark Lowe, Iowa
Roger Millar, Washington
Marc Luiken, Alaska

Nonvoting Members

Immediate Past President: John Schroer, Tennessee

* Elected at AASHTO's 2018 Annual Meeting in Atlanta, Georgia

This page left intentionally blank.

AASHTO COMMITTEE ON BRIDGES AND STRUCTURES, 2018

GREGG FREDRICK, *Chair*

BRUCE V. JOHNSON, *Vice Chair*

JOSEPH L. HARTMANN, Federal Highway Administration, *Secretary*

PATRICIA J. BUSH, *AASHTO Liaison*

ALABAMA, Eric J. Christie, William “Tim” Colquett,
Randall B. Mullins

ALASKA, Leslie Daughtery, Elmer E. Marx, Richard
A. Pratt

ARIZONA, David B. Benton,
David L. Eberhart, Pe-Shen Yang

ARKANSAS, Charles “Rick” Ellis, Mike Hill, Joe
Santini

CALIFORNIA, Thomas A. Ostrom, Gedmund
Setberg, Dolores Valls

COLORADO, Behrooz Far, Stephen Harelson, Jessica
Martinez

CONNECTICUT, Mary E. Baker, Timothy D. Fields

DELAWARE, Jason Arndt, Jason Hastings, Craig A.
Stevens

DISTRICT OF COLUMBIA, Donald L. Cooney,
Konjit C. “Connie” Eskender, Richard Kenney

FLORIDA, Sam Fallaha, William Potter, Jeff
Pouliotte

GEORGIA, Clayton Bennett, Bill DuVall, Steve
Gaston

HAWAII, James Fu, Kevin Murata, John Williams

IDAHO, Matthew Farrar

ILLINOIS, Tim A. Armbrrecht, Carl Puzey, Jayme
Schiff

INDIANA, Andrew Fitzgerald, Jeremy Hunter, Anne
M. Rearick

IOWA, Ahmad Abu-Hawash, James S. Nelson

KANSAS, Mark E. Hoppe, John P. Jones, Curt F.
Niehaus

KENTUCKY, Bart Asher, Andy Barber, Marvin
Wolfe

LOUISIANA, Arthur D’Andrea, Paul Fossier,
Zhengzheng “Jenny” Fu

MAINE, Jeffrey S. Folsom, Wayne Frankhauser,
Michael Wight

MARYLAND, Maurice Agostino, Jesse Creel, Jeffrey
L. Robert

MASSACHUSETTS, Alexander K. Bardow, Thomas
Donald, Joseph Rigney

MICHIGAN, Matthew Chynoweth, Rebecca Curtis,
Richard E. Liptak

MINNESOTA, Arielle Ehrlich, Ed Lutgen,
Kevin Western

MISSISSIPPI, Aaron Cagle, Justin Walker, Scott
Westerfield

MISSOURI, Dennis Heckman, Greg E. Sanders,
Scott Stotlemeyer

MONTANA, Amanda Jackson, Dustin E. Rouse

NEBRASKA, Mark Ahlman, Fouad Jabber, Mark J.
Traynowicz

NEVADA, Troy

NEW HAMPSHIRE, Robert Landry, David L. Scott

NEW JERSEY, Xiaohua “Hannah” Cheng, Eddy
Germain, Dave D. Lambert

NEW MEXICO, Kathy Crowell, Jeff C. Vigil

NEW YORK, Brenda Crudele, Ernest Holmberg,
Richard Marchione

NORTH CAROLINA, Brian Hanks,
Scott Hidden, Girchuru Muchane

NORTH DAKOTA, Jon D. Ketterling, Jason R.
Thorenson

OHIO, Alexander B.C. Dettloff,
Timothy J. Keller, Jeffrey Syar

OKLAHOMA, Steven Jacobi, Walter Peters, Tim
Tegeler

OREGON, Bruce V. Johnson, Albert Nako,
Tanarat Potisuk

PENNSYLVANIA, James M. Long, Thomas P.
Macioce, Lou Ruzzi

PUERTO RICO, (Vacant)

RHODE ISLAND, Georgette Chahine, Keith Gaulin

SOUTH CAROLINA, Terry B. Koon, Jeff Sizemore

SOUTH DAKOTA, Steve Johnson, Dave Madden,
Todd S. Thompson

TENNESSEE, John S. Hastings, Ted A. Kniazewycz

TEXAS, Bernie Carrasco, Jamie F. Farris, Gregg A.
Freeby

U.S. DOT, Joseph L. Hartmann

UTAH, Rebecca Nix, Carmen Swanwick, Cheryl
Hersh Simmons

VERMONT, Kristin M. Higgins, Jim Lacroix

VIRGINIA, Prasad L. Nallapaneni,
Kendal R. Walus, Andrew M. Zickler

WASHINGTON, Tony M. Allen,
Mark A. Gaines, Bijan Khaleghi

WEST VIRGINIA, Ahmed Mongi, William Varney

WISCONSIN, Scot Becker,
William C. Dreher

WYOMING, Jeff R. Booher, Paul G. Cortez,
Gregg C. Frederick, Michael E. Menghini

DELAWARE RIVER AND BAY AUTHORITY,
Shoukry Elnahal

MDTA, Dan Williams

**MULTNOMAH COUNTY TRANSPORTATION
DIVISION**, Jon Henrichsen

N.Y. STATE BRIDGE AUTHORITY, William
Moreau

**U.S. ARMY CORPS OF ENGINEERS—
DEPARTMENT OF THE ARMY**, Phillip W.
Sausser

U.S. COAST GUARD, Kamal Elnahal
U.S. DEPARTMENT OF AGRICULTURE—
FOREST SERVICE, John R. Kattell

TRANSPORTATION RESEARCH BOARD,
Waseem Dekelbab

TABLE OF CONTENTS

Section 1—Introduction.....	1-1
1.1—Scope	1-1
1.2—Definitions	1-2
1.3—Limitations	1-2
1.4—Design Philosophy	1-3
1.5—References.....	1-3
Section 2—Concrete Structures.....	2-1
2.1—Scope	2-1
2.2—Definitions	2-1
2.3—Notation	2-3
2.4—Material Properties.....	2-5
2.4.1—General	2-5
2.4.2—GFRP Reinforcing Bars.....	2-6
2.4.2.1—Tensile Strength and Strain.....	2-6
2.4.2.2—Modulus of Elasticity.....	2-6
2.5—Limit States and Design Methodologies	2-7
2.5.1—General	2-7
2.5.1.1—Limit-State Applicability.....	2-7
2.5.1.2—Design Methodologies.....	2-7
2.5.1.2.1—General	2-7
2.5.1.2.2—B-Regions.....	2-8
2.5.1.2.3—D-Regions.....	2-8
2.5.2—Service Limit State	2-8
2.5.3—Creep Rupture Limit State	2-8
2.5.4—Fatigue Limit State	2-10
2.5.5—Strength Limit State.....	2-11
2.5.5.1—General	2-11
2.5.5.2—Resistance Factors	2-11
2.5.5.3—Stability	2-12
2.5.6—Extreme Event Limit State.....	2-12
2.6—Design for Flexural and Axial Force Effects—B-Regions	2-12
2.6.1—Assumptions for Service, Fatigue, and Creep Rupture Limit States.....	2-12
2.6.2—Assumptions for Strength and Extreme Event Limit States.....	2-13
2.6.2.1—General	2-13
2.6.2.2—Rectangular Stress Distribution	2-13
2.6.3—Flexural Members.....	2-14
2.6.3.1—Stress in GFRP Reinforcement at Nominal Flexural Resistance.....	2-14
2.6.3.2—Flexural Resistance.....	2-14
2.6.3.2.1—Factored Flexural Resistance.....	2-14
2.6.3.2.2—Rectangular Sections	2-14
2.6.3.2.3—Other Cross Sections	2-16
2.6.3.2.4—Strain Compatibility Approach.....	2-16

2.6.3.3—Limits for Reinforcement	2-16
2.6.3.4—Deformations	2-17
2.6.3.4.1—General	2-17
2.6.3.4.2—Deflection and Camber	2-17
2.6.3.4.3—Axial Deformation	2-18
2.6.3.5—Stress Limit for Concrete	2-19
2.6.4—Compression Members	2-19
2.6.4.1—General	2-19
2.6.4.2—Factored Axial Resistance	2-19
2.6.4.3—Biaxial Flexure	2-20
2.6.4.4—Combined Axial and Flexural Load	2-20
2.6.4.5—Stress Limit for Concrete	2-20
2.6.5—Bearing	2-20
2.6.6—Tension Members	2-20
2.6.6.1—Resistance To Tension	2-20
2.6.6.2—Resistance To Combined Tension and Flexure	2-21
2.6.7—Control of Cracking By Distribution of Reinforcement	2-21
2.7—Design for Shear and Torsion—B-Regions	2-23
2.7.1—Design Procedures	2-23
2.7.1.1—Flexural Regions	2-23
2.7.1.2—Regions Near Discontinuities	2-23
2.7.1.3—Interface Regions	2-23
2.7.1.4—Slabs and Footings	2-23
2.7.2—General Requirements	2-24
2.7.2.1—General	2-24
2.7.2.2—Regions Requiring Transverse Reinforcement	2-25
2.7.2.3—Types of Transverse Reinforcement	2-25
2.7.2.4—Minimum Transverse Reinforcement	2-26
2.7.2.5—Maximum Transverse Reinforcement	2-26
2.7.2.6—Maximum Spacing of Transverse Reinforcement	2-27
2.7.2.7—Design and Detailing Requirements	2-27
2.7.2.7.1—General	2-27
2.7.2.7.2—Anchorage of Reinforcement	2-27
2.7.2.7.3—Bending of Reinforcement	2-27
2.7.2.7.4—Closed Stirrups	2-28
2.7.2.7.5—Mechanical Anchorages	2-28
2.7.2.8—Shear Stress on Concrete	2-28
2.7.3—Sectional Design Model	2-29
2.7.3.1—General	2-29
2.7.3.2—Sections Near Supports	2-29
2.7.3.3—Nominal Shear Resistance	2-30
2.7.3.4—Procedure for Determining Shear Resistance of Concrete	2-30
2.7.3.5—Procedure for Determining Shear Resistance Provided By Transverse Reinforcement	2-31
2.7.3.6—Procedures for Determining Shear Resistance Parameters B and Θ	2-32
2.7.3.6.1—Simplified Procedure	2-32
2.7.3.6.2—General Procedure	2-33

2.7.3.7—Longitudinal Reinforcement.....	2-36
2.7.3.8—Sections Subjected To Combined Shear and Torsion.....	2-38
2.7.3.8.1—Transverse Reinforcement.....	2-38
2.7.3.8.2—Torsional Resistance.....	2-38
2.7.3.8.3—Longitudinal Reinforcement.....	2-38
2.7.4—Interface Shear Reinforcement—Shear Friction.....	2-39
2.8—Design of D-Regions.....	2-40
2.9—Reinforcement.....	2-40
2.9.1—Concrete Cover.....	2-40
2.9.2—Hooks and Bends.....	2-40
2.9.3—Spacing of Reinforcement.....	2-40
2.9.3.1—Minimum Spacing of Reinforcing Bars.....	2-40
2.9.3.1.1—Cast-in-Place Concrete.....	2-40
2.9.3.1.2—Precast Concrete.....	2-40
2.9.3.1.3—Multilayers.....	2-41
2.9.3.1.4—Splices.....	2-41
2.9.3.1.5—Bundled Bars.....	2-41
2.9.3.2—Maximum Spacing of Reinforcing Bars.....	2-41
2.9.4—Transverse Reinforcement for Compression Members.....	2-41
2.9.4.1—Columns and Piers.....	2-41
2.9.4.2—Precast Concrete Piles.....	2-41
2.9.4.3—Cast-in-Place Concrete Piles.....	2-42
2.9.4.4—Drilled Shafts.....	2-42
2.9.5—Transverse Reinforcement for Flexural Members.....	2-42
2.9.6—Shrinkage and Temperature Reinforcement.....	2-42
2.9.7—Development and Splices of Reinforcement.....	2-43
2.9.7.1—General.....	2-43
2.9.7.2—Basic Requirements.....	2-43
2.9.7.3—Flexural Reinforcement.....	2-43
2.9.7.3.1—General.....	2-43
2.9.7.3.2—Positive Moment Reinforcement.....	2-43
2.9.7.3.3—Negative Moment Reinforcement.....	2-44
2.9.7.3.4—Moment Resisting Joints.....	2-44
2.9.7.4—Development of Reinforcement.....	2-44
2.9.7.4.1—Deformed Bars in Tension.....	2-44
2.9.7.4.2—Deformed Bars in Compression.....	2-45
2.9.7.4.3—Standard Hooks in Tension.....	2-45
2.9.7.5—Development by Mechanical Anchorages.....	2-45
2.9.7.6—Splices of GFRP Reinforcing Bar.....	2-46
2.10—Provisions for Structure Components and Types.....	2-46
2.10.1—Deck Slabs.....	2-46
2.10.2—Slab Superstructures.....	2-46
2.10.2.1—Cast-in-Place Solid Slab Superstructures.....	2-46
2.10.2.2—Precast Deck Bridges.....	2-47
2.10.3—Beams and Girders.....	2-47
2.10.4—Diaphragms.....	2-47
2.10.5—Footings.....	2-47

2.10.5.1—Shear in Slabs and Footings.....	2-47
2.10.5.1.1—Critical Sections for Shear.....	2-47
2.10.5.1.2—One-Way Action.....	2-47
2.10.5.1.3—Two-Way Action.....	2-47
2.10.6—Concrete Piles.....	2-48
2.11—Anchors.....	2-49
2.12—Durability.....	2-49
2.13—References.....	2-49
Section 3—Decks and Deck Systems.....	3-1
3.1—Scope.....	3-1
3.2—Definitions.....	3-1
3.3—Notation.....	3-2
3.4—General Design Requirements.....	3-2
3.4.1—Interface Action.....	3-2
3.4.2—Deck Drainage.....	3-3
3.4.3—Concrete Appurtenances.....	3-3
3.4.4—Edge Supports.....	3-3
3.4.5—Stay-in-Place Formwork for Overhangs.....	3-3
3.5—Limit States.....	3-3
3.5.1—General.....	3-3
3.5.2—Service Limit State.....	3-4
3.5.3—Creep Rupture Limit State.....	3-4
3.5.4—Fatigue Limit State.....	3-4
3.5.5—Strength Limit State.....	3-4
3.5.6—Extreme Event Limit States.....	3-4
3.6—Analysis.....	3-4
3.6.1—Method of Analysis.....	3-4
3.6.2—Loading.....	3-4
3.7—Concrete Deck Slabs.....	3-5
3.7.1—General.....	3-5
3.7.1.1—Minimum Depth and Cover.....	3-5
3.7.1.2—Composite Action.....	3-5
3.7.1.3—Skewed Decks.....	3-5
3.7.1.4—Edge Support.....	3-5
3.7.1.5—Design of Cantilever Slabs.....	3-6
3.7.2—Empirical Design.....	3-6
3.7.2.1—General.....	3-6
3.7.2.2—Application.....	3-6
3.7.2.3—Effective Length.....	3-7
3.7.2.4—Design Conditions.....	3-7
3.7.2.5—Reinforcement Requirements.....	3-8
3.7.2.6—Deck with Stay-in-Place Formwork.....	3-9
3.7.3—Traditional Design.....	3-9
3.7.3.1—General.....	3-9
3.7.3.2—Distribution Reinforcement.....	3-9
3.7.4—Stay-in-Place formwork.....	3-10