AASHTO

GUIDE SPECIFICATIONS FOR

DESIGN OF BONDED FRP SYSTEMS FOR REPAIR AND STRENGTHENING OF CONCRETE BRIDGE ELEMENTS

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Section 1:

INTRODUCTION

1.1—SCOPE

These Guide Specifications are intended for the repair and strengthening of reinforced and prestressed highway bridge structures using externally bonded fiber reinforced polymer (FRP) composite systems. These Guide Specifications supplement the *AASHTO LRFD Bridge Design Specifications*, Ninth Edition, 2020 (AASHTO LRFD). Except where specifically provided below, all provisions of AASHTO LRFD shall apply.

These Guide Specifications state only the minimum requirements necessary to provide for public safety and are not intended to supplant proper training or the exercise of judgment by the Engineer of Record. The Owner or the Engineer of Record may require the structural design or the quality of materials and construction to exceed the minimum requirements.

These specifications employ the Load and Resistance Factor Design (LRFD) methodology, in which the load and resistance factors have been developed from structural reliability theory based on current probabilistic/statistical models of loads and structural performance.

Seismic design shall be in accordance with either the provisions in the appropriate sections of AASHTO LRFD or the provisions in the *AASHTO Guide Specifications for LRFD Seismic Bridge Design*.

Except where specifically provided below, all provisions of the AASHTO *LRFD Bridge Construction Specifications* shall apply.

C1.1

This Article discusses the scope of these Guide Specifications, their applicability, and their limitations. This Article is analogous to the opening articles, Articles X.1, of each of the Sections of AASHTO LRFD.

The commentary is not intended to provide a complete historical background concerning the development of these or previous specifications, nor is it intended to provide a detailed summary of the studies and research data reviewed in formulating the provisions of the specifications. However, references to North American and international guidelines (ACI 440.2R, CSA S806-12, 2017; fib technical report bulletin 90, 2019; CNR-DT 200 R1, 2013; Technical Report No. 55, 2012; JSCE, 2001; and AFGC, 2003) as well as relevant research data dealing with externally bonded FRP reinforcement for reinforced and prestressed concrete structures are provided for those who wish to study the background material in depth.

NCHRP Report 609 presents recommended construction specifications concerning the use of externally bonded FRP reinforcement for strengthening concrete structures.

The commentary directs attention to other documents that provide suggestions for carrying out the requirements and intent of these Guide Specifications. However, the commentary and references herein are not part of these Guide Specifications.

1.2—FRP SYSTEMS

In general, procedures for the installation of FRP systems are developed by the manufacturer and can vary between the available systems. Two optional types of externally bonded FRP systems are available. The first type consists of dry fiber-fabric sheets saturated with an epoxy resin. The second type of system consists of precured laminates (manufacturer fabricated), in the form of plates, shells, and rods.

The dry fiber-fabric sheets are commonly applied using a wet-layup process, where the fiber-fabric sheets are saturated using an impregnating resin on site. Prepreg systems, where the fiber-fabric sheets are saturated off-site but cured

C1.2

The wet-layup system is the more versatile of these systems because the fabric/cloth is flexible and can conform to most shapes in the field. Installation procedures may also vary depending on the type and condition of the structure to be strengthened. The application of FRP systems will not stop the ongoing corrosion of existing steel reinforcement. The cause of corrosion to internal steel reinforcement should be addressed and corrosion-related deterioration should be repaired prior to application of any FRP system.

NSM FRP systems are advantageous as they are less prone to delamination and environmental degradation, and allow for effective inspection

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in place by heating or by other methods are also available. Pre-cured laminate plates and rod panels are bonded to the concrete surface with an adhesive resin. In near-surface mounted (NSM) FRP systems, small diameter pre-cured rods and plates/strips are installed and bonded into grooves on the concrete surface using adhesive resin. Pre-cured shells are applied around columns to provide confinement. Pre-cured systems comprising sheets and grids with multi-directional fiber reinforcement are also available.

1.3—SUBSTRATE REPAIR AND SURFACE PREPARATION

All repairs to the concrete substrate shall be carried out according to applicable specifications prior to FRP application. Externally bonded FRP strengthening shall not be applied on concrete suspected of containing corroded reinforcement. Corroded reinforcement shall be cleaned, and the surrounding contaminated concrete shall be removed (ICRI 310.1R-08 and ACI 440.2R). Concrete removal shall extend along the reinforcing steel until there is no further delamination, cracking, or corrosion and the reinforcing steel is well bonded to the surrounding concrete (ICRI 310.1R-08). Any other defective concrete within the FRP application area shall be removed according to ICRI 310.1R-08. Replacement of concrete shall be carried out with material conforming to ICRI 320.2R-18. The repair material shall have a compressive strength equal to or greater than the original concrete, but not less than 4.5 ksi and 5.5 ksi at 7 and 28 days, respectively. Cracks wider than 0.01 in. and with spacing less than 1.5 in. or cracks wider than $^{1}/_{32}$ in. shall be filled using epoxy injection (NCHRP Report 609).

The concrete surface shall be prepared to a minimum concrete surface profile (CSP) 3 as defined by the ICRI-surface-profile chips (ICRI 310.2R-13, NCHRP Report 609). Localized out-of-plane variations (suggested to be taken as any 6 in. by 6 in. section) throughout the concrete surface where the FRP system is applied, including form lines, shall not exceed $^{1}/_{32}$ in., or the tolerances recommended by the FRP system manufacturer, whichever is smaller. Holes and voids shall be filled with a compatible epoxy paste (thickened epoxy/putty). It is recommended that surface preparation be accomplished using abrasive or water-blasting techniques. All laitance, dust, dirt, oil, curing compound, existing coatings, and any other matter of concrete surfaces compared to the wet-layup system. NSM FRP systems have a greater anchoring or bond capacity compared to the surface bonded FRP systems, and may be more suitable for cases in which the concrete surface requires significant surface preparation.

C1.3

The bond behavior of the FRP system is highly dependent on a sound concrete substrate and on the workmanship of the installation; either one or both can significantly influence the integrity of the FRP strengthening system. Proper preparation and profiling of the concrete substrate is necessary to achieve optimum bond strength. Improper surface preparation can lead to premature debonding or delamination.

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that could interfere with the bond between the FRP system and concrete substrate shall be removed.

When fibers are wrapped around corners, the corners shall be rounded to a minimum $^1/_2$-in. radius to prevent stress concentrations in the FRP system and voids between the FRP system and the concrete. Rough edges shall be smoothed by grinding or with putty prior to FRP application. The substrate repair, including any crack injections, and surface preparation shall be inspected by a licensed engineer or qualified inspector knowledgeable in FRP systems prior to FRP installation.

1.4—INSTALLATION OF FRP

Unless approved by the Engineer of Record, externally bonded FRP shall not be applied if rain, snow, or dew point condensation is expected. Primers, putty, saturating resin, or adhesives shall not be applied on cold, frozen, damp, or wet surfaces. Ambient and concrete surface temperature shall be between 50–90 degrees F unless specified by the manufacturer. Enclosures and external heat sources may be utilized to meet the required environmental conditions.

Mixing of all resin, primer, and putty shall be carried out at the manufacturer-specified temperature range, mix proportions, and mix durations. Any resin that exceeds its pot life or shows sign of increased viscosity shall not be used.

C1.4

When concrete and atmospheric temperatures exceed 90 degrees F, difficulties may be experienced in application of the epoxy compound owing to acceleration of the reaction and hardening rates. If ambient temperatures above 90 degrees F are anticipated, work should be scheduled when the temperature is lower, such as in the early morning hours. If it is necessary to apply epoxy compounds at temperatures exceeding 90 degrees F, the work should be supervised by a person experienced in applying epoxy at high temperatures. Epoxy systems formulated for elevated temperature are available.

At low temperatures, difficulties may occur due to deceleration of the reaction rates. Manufacturer-recommended substrate temperatures or a minimum temperature of 50 degrees F and rising is recommended during installation. With manufacturer approval, specialized devices, such as warming blankets, may be used. The presence of frost or ice crystals may also be detrimental to the bond between the FRP and the concrete.

NCHRP Report 609 and ICRI 330.2-16 provide specifications for the installation of externally bonded FRP reinforcement for strengthening concrete structures.

1.4.1—Wet Lay-Up FRP Systems

A primer coating shall be applied if required for the FRP system. The saturating resin shall ensure full impregnation of the fabric sheet. Manufacturer recommendations shall be followed for impregnating the fabric. The saturated fabric is placed on the concrete substrate and rolled in the direction of the fibers to remove entrapped air. An

C1.4.1

The primer may be applied by a clean roller or brush. When applied uniformly, the bond between concrete substrate and FRP system is improved. If a primer is not required, a first coat of saturating resin should be applied as an undercoat to all locations of the concrete surface where the FRP is to be applied. The rate of coverage for the primer and saturating

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additional saturating resin coating shall be applied over the top of the fabric to ensure full saturation of the fibers. The fabric sheets shall be aligned with the fibers in the direction indicated on the design drawings or other contract documents. For multi-ply applications, the steps shall be repeated for each additional fabric sheet. The installed fibers shall be free of kinks, wrinkles, and waviness.

resin is listed in the system specifications or data sheet. Special equipment, such as saturators, may be used on large projects to evenly impregnate the fabric and to speed up the process.

A "dry" lay-up, where a first coat of saturating resin is applied on to the substrate and the fabric is installed without pre-impregnation (unsaturated) can be carried out when applying a single "thin" fiber sheet. Here, it is important to apply sufficient coating of saturating resin over the installed fabric to fully impregnate the fibers. The Engineer of Record should approve the use of dry lay-up prior to installation.

In multi-ply applications, each new ply should be supported by the previously-applied system and be applied prior to the gelation of the previous layer. If the previous layer has cured, new plies of fabric sheets may only be applied after surface preparation per manufacturer instructions. Too many plies applied in a single day could result in slippage or separation due to self-weight of the saturated fabric sheets (NCHRP Report 609). Fiber misalignment can affect strength of the FRP system. Anchors such as U-wraps and FRP spike anchors will provide anchorage against premature delamination of the FRP system.

1.4.2—Pre-Cured FRP Systems

For pre-cured FRP laminate plates, depending on manufacturer specifications, the adhesive resin shall be applied to the required thickness on the concrete substrate, the FRP laminate, or both. The laminate shall be pressed on to the concrete using a hard rubber roller or similar tool until any entrapped air is released and excess adhesive resin is forced out on both sides. The manufacturer-specified bond thickness shall be maintained during the installation of pre-cured FRP laminates.

For FRP rod panels, the adhesive resin is applied on to the concrete surface to the manufacturer-specified thickness. The rod panels are pressed into the adhesive resin until the FRP rods are covered by the resin. Excess resin is spread uniformly over the rod panels.

C1.4.2

The adhesive resin may be applied using a spatula or any other suitable method. Splicing of pre-cured FRP laminate plates using a splice plate is not recommended. FRP rod panels facilitate modular construction suitable for locations with limited access and can be spliced using a finger joint.

1.4.3—NSM FRP Systems

In NSM FRP, pre-cured FRP rods/bars or plates/strips are installed into pre-cut or ground grooves in the concrete. The grooves shall be cleaned prior to FRP installation to remove all laitance that would

C1.4.3

NSM FRP systems allow for strengthening in negative moment regions without exposure to mechanical or abrasion damage. Compared to other externally bonded FRP systems, NSM FRP

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prevent sufficient bonding with the FRP. The groove shall be half-filled with adhesive resin for NSM FRP, and the FRP rod or strip is pressed into the groove to force the resin to flow around it and completely fill the space between the FRP and sides of the groove. The groove shall then be fully filled with additional adhesive resin and the surface is leveled.

1.5—INSPECTION, EVALUATION, AND ACCEPTANCE

FRP strengthening is performed on structurally deficient or damaged reinforced or prestressed concrete bridge elements. Before a strengthening procedure is implemented, the extent of deficiency and suitability of FRP strengthening shall be evaluated. Systems considered for FRP strengthening shall be inspected by a licensed engineer or qualified inspector knowledgeable in FRP systems and installation procedures. The following shall be recorded at the time of installation:

- date and time of installation;
- ambient temperature, relative humidity, and general weather observations and surface temperature of concrete;
- surface dryness, surface preparation methods, and resulting profile using the ICRI-surface-profile chips;
- qualitative description of surface cleanliness;
- type of auxiliary heat source, if applicable;
- widths of cracks not injected with epoxy;
- fiber-fabric sheets or pre-cured laminate batch number(s) and approximate locations in the structure;
- batch numbers, mixture ratios, mixing times, and qualitative descriptions of the appearance of all mixed resins, including primers, putties, saturants, adhesives, and coatings mixed for the day;
- observations of progress of cure of resins;
- conformance with installation procedures;
- location and size of any delaminations or air voids;
- general progress of work;

systems also have better durability under long-term environmental exposure.

C1.5

Evaluation of moisture content or outgassing of the concrete should be done by determining if moisture will collect at bond lines between old concrete and epoxy adhesive before epoxy has cured. This may be accomplished by taping an 18 in. × 18 in. polyethylene sheet to the concrete surface. If moisture collects on the underside of the polyethylene sheet before epoxy would cure, then allow concrete to dry sufficiently to prevent the possibility of a moisture barrier between old concrete and new epoxy (ASTM D4263).

During installation, sample cups of mixed resin should be prepared according to a predetermined sampling plan and retained for testing to determine level of curing in accordance with ASTM D2583. The relative cure of the resin can also be evaluated on the project site by physical observation of resin tackiness and hardness of work surfaces or hardness of retained resin samples.

For bond-critical applications, tension adhesion testing of cored samples should be conducted using the methods in ACI 503R or ASTM D7522/D7522M. The sampling frequency should be specified. Tension adhesion strengths should exceed 200 psi and exhibit failure of the concrete substrate (ACI 440.2R).

The necessary evaluation criteria for repair of existing concrete structures and post-repair evaluation criteria are well established in the following documents:

- ACI 201.1R: *Guide for Conducting a Visual Inspection of Concrete in Service*
- ACI 224.1R: *Causes. Evaluation, and Repair of Cracks in Concrete*
- ACI 364.1R: *Guide for Assessment of Concrete Structures Prior to Rehabilitation*

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- level of curing of resin in accordance with ASTM D2582; and
- adhesion strength.

- ACI 440.2R: *Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures*
- ACI 503R: *Use of Epoxy Compounds with Concrete*
- ACI 546.3: *Guide to Materials Selection for Concrete Repair*
- ICRI 310.1R: *Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion*
- ICRI 320.2R: *Guide for Selecting and Specifying Materials for Repairs of Concrete Surfaces*
- NCHRP Report 609: *Recommended Construction Specifications Process Control Manual for Repair and Retrofit of Concrete Structures Using Bonded FRP Composites*

Relevant specifications and guidelines provided by FRP manufacturers should also be carefully reviewed prior to the design of any strengthening system.

1.6—REPAIR OF DEFECTS

The repair of defects highlighted herein is applicable only to wet-layup FRP systems. Repair of other FRP systems shall be submitted for approval by a licensed engineer. Small defects no larger than $^1/_4$ in. diameter do not need corrective action unless they occur next to edges or when there are more than five such defects in an area of 10 ft^2. Small voids between $^1/_4$ in.–$1^1/_4$ in. in diameter shall be repaired in accordance with ICRI 330.2 by epoxy injection, provided the defect does not extend the entire thickness of the laminate in multi-ply applications.

Defects larger than $1^1/_4$ in. in diameter are considered large defects. An area of at least 1 in. beyond the defect shall be carefully removed and covered using an FRP patch of similar material. The substrate shall be prepared in accordance with Article 1.3 and the FRP material applied in accordance with Article 1.4.1, except the patch shall extend the lap length for the FRP material or a minimum of 6 in. on all sides of the removed area. These repairs are only applicable to defects in a single ply application. Unless repair is approved by the Engineer of Record, full replacement of FRP system shall be carried out if large defects are found in multi-ply FRP systems.

C1.6

Based on NCHRP Report 609, defects in FRP systems may include:

- voids between the concrete and the FRP system,
- delamination or voids within layers of the FRP system,
- broken or damaged edges of the FRP system,
- wrinkling or buckling of fibers and fiber tows,
- fracture of fibers, breakage in fabric,
- cracks, blisters, and peeling of the protective coating,
- resin-starved areas with non-uniform impregnation,
- under-cured or incompletely cured resin, and
- incorrect fiber orientation.

Large defects, such as debonding between layers of multi-ply FRP systems, may require full replacement. Depending on the size of the defect and whether the area is critical to structural integrity, it may be advisable to remove and re-apply the entire FRP system (NCHRP Report 609).

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