



FIRE RESISTANCE OF FRP-STRENGTHENED CONCRETE MEMBERS—TECHNOTE

Keywords: fiber-reinforced polymer; fire; fire protection; fireproofing; repair; strengthening.

Introduction

The use of fiber-reinforced polymer (FRP) materials to strengthen concrete members is an accepted technology. In many applications, performance of FRP-strengthened members during exposure to fire remains a significant concern to design professionals, building officials, and owners. The objective of this TechNote is to provide a brief overview of key concepts, code provisions, and industry guidelines relating to the structural performance of FRP-strengthened members during a fire event.

Research findings regarding the performance of FRP-strengthened members during exposure to fire have been published by Williams et al. (2008). However, design examples and guidance regarding the performance of externally bonded FRP during exposure to fire are not widely available. In addition, differences in the design approaches and load combinations used by the steel and concrete industries, combined with the relatively recent emergence of FRP fire protection systems, have created challenges for practicing engineers tasked with assessing the structural fire resistance of FRP-strengthened members.

Questions

Under what circumstances does an FRP-strengthened member need to be protected from the detrimental effects of fire? If protection is warranted, what fire protection options are available?

Answers

The need for FRP-strengthened members to be protected from fire depends on project-specific factors, including building code requirements, structural parameters, member type, fire risk, fire severity, and method of evaluation. The design professional should evaluate these factors to determine if an unprotected member possesses sufficient strength during (and potentially after) the fire event to resist anticipated demands. Calculations can be performed based on material properties that have been adjusted to account for the detrimental effects of fire while using appropriate load and strength-reduction factors. If the analysis determines that the unprotected member does not possess sufficient strength, then fire protection may be required to enhance performance of the strengthened member. Options include mortars, coatings, boards, or other materials that have been specifically tested for use with the FRP system. As discussed in this TechNote, these insulating materials protect the embedded reinforcing steel and concrete, rather than the FRP system.

Discussion

Building codes establish minimum requirements for structures to resist detrimental effects of a standard fire as defined by test standards such as ASTM E119, UL 263, and ISO 834. In the United States, the code applicable to new construction is typically the International Building Code (IBC). The IBC sets forth required fire-resistance ratings (referred to hereinafter as fire rating) in terms of duration based on occupancy, size, separation, construction materials, and other factors. The required fire rating usually ranges from 1 to 3 hours. Certain low-fire-risk buildings, such as open parking garages sufficiently separated from adjacent occupancies, may not require a fire rating depending on size, construction material, and other factors.

For new construction, the fire rating is typically determined by an architect. Many FRP-strengthening projects do not include an architect on the design team, and even when they do, the architect may have little experience with FRP. In these instances, the building official and architect may require evidence from the structural engineer that the FRP-strengthening complies with fire resistance provisions of the code. If the structural engineer does not possess fundamental knowledge of fire protection concepts or is unfamiliar with interpreting code provisions related to fire, then assistance from an experienced fire protection design professional should be obtained.

Section 703.3 of the 2018 IBC requires, in part, that the element or assembly requiring a fire rating be evaluated based on the standard fire exposure and acceptance criteria specified in ASTM E119. Acceptable evaluation methods listed in the 2018 IBC Section 703.3 include:

- a) Fire-resistance designs documented in approved sources
- b) Prescriptive designs listed in the 2018 IBC Section 721
- c) Calculations in accordance with the 2018 IBC Section 722

The first method consists of specifying members and assemblies that have been historically used in new construction, such as for structural steel framing and metal floor deck assemblies. The method consists of selecting a specific combination of materials, some of which may be proprietary, that have been tested, under load, in furnaces in accordance with ASTM E119 or UL 263. Members and assemblies that have been tested are considered by the IBC to represent a qualified design for fire rating purposes and are described using drawings supplemented by detailed narrative. A source of qualified designs is the Underwriters Laboratory (UL) online certification search engine, UL Product iQ™, which replaced the UL Fire-Resistance Directory. Because a qualified design is based on testing an assembly constructed with specific materials, dimensions, concrete cover, and other features, it is most applicable to projects having identical characteristics to the tested assembly. However, even if a project-specific member does not have identical characteristics, the underlying thermal data collected during furnace testing of an assembly may be useful for purposes of calculating the fire resistance of FRP-strengthened members using the third method (2018 IBC Section 722).

The second method consists of ensuring that sufficient concrete cover is present over reinforcing steel. Detailed, prescriptive tables in the 2018 IBC Section 721 give required cover based on member type (for example, slab, beam, or column) and other factors. None of the member types listed in the tables include externally bonded FRP. Therefore, the second method has no information directly applicable to FRP-strengthened members.

The third method consists of calculating the fire resistance of concrete members in accordance with ACI 216.1, incorporated by reference in the 2018 IBC Section 722. This method is the evaluation approach that can be used for FRP-strengthened members.

FRP systems

Externally bonded FRP systems do not have the benefit of concrete cover to provide thermal protection from fire. Furthermore, as compared with reinforcing steel, FRP systems typically exhibit greater and more rapid deterioration of mechanical and bond properties. The glass transition temperature of FRP systems (T_g) depends on the type of resin and other factors but is normally in the range of 140 to 180°F (60 to 82°C) (ACI 440.2R).

For both contact-critical and bond-critical applications, properties of the polymer are essential in achieving proper structural performance of the strengthened member. At a temperature close to the T_g , properties of the polymer are reduced, and the polymer begins to creep, exhibits a lower modulus, and loses its ability to transfer stresses from the concrete to and among the fibers (ACI 440.2R). When the temperature of the FRP system exceeds the T_g , considerable deterioration of the FRP material properties and bond to the substrate should be expected (ACI 440.2R).

Calculations to evaluate structural fire resistance

ACI 562 provides design and construction requirements relating to repair of concrete buildings. Section 7.9.2 of ACI 562-16 permits external FRP systems to be installed without additional fire protection as long as it has been shown by calculation that the unrepaired structure possesses a minimum level of strength during the fire event. The level of required strength is defined in ACI 562-16 Eq. (5.5.3) as

$$\phi_{ex} R \geq (0.9 \text{ or } 1.2)D + (0.5)L + (0.2)S \quad (1)$$

where R is the nominal resistance of the structure, computed using the probable material properties during the fire event; $\phi_{ex} = 1$; and D , L , and S , are the effects of dead, live, and snow load requirements, respectively. This load combination results in a lower demand than is associated with analysis at normal temperature. The lower demand reflects the fact that occurrence of a severe fire is a low-probability event and, therefore, the presence of full design loads during the fire event is remote. Note that Section 5.5.2.1 of ACI 562-16 requires use of a 1.0 factor on live load for applications involving libraries, warehouses, and other occupancies where the nominal live load has a high likelihood of being sustained.

ACI 440.2R provides recommendations for the design and construction of externally bonded FRP systems for repair and strengthening of concrete structures. Section 9.2.1 of ACI 440.2R-17 includes limits on strengthening that can be used to ensure a strengthened structure will not collapse in a fire event. The level of required strength can be based on either of two load combinations that are given by Eq. (9.2.1a) and (9.2.1b) of ACI 440.2R-17.

Equation (9.2.1a) is based on provisions in **ACI 216.1**. Equation (9.2.1b) is ACI 562-13 Eq. (5.5.3), which contains a term for extraordinary loading events (A_k). The A_k term does not appear in **ACI 562-16**; instead, internal forces and thermal deformations during the fire event are required to be considered.

The load combination in ACI 562-16 Eq. (5.5.3) is recommended in place of those presented in Section 9.2.1 of **ACI 440.2R-17** related to fire exposure.

Equation (9.2) of ACI 440.2R-17 should not be used to assess strength during exposure to fire. The intent of Eq. (9.2) is to guard against collapse at normal temperature in the event of damage to the FRP system due to vandalism, inadvertent removal during subsequent renovation, or other non-fire-related causes.

The member strength during the fire event should be based on material properties that reflect reduction due to effects of elevated temperature. A simplified calculation showing basic concepts of evaluating the strength of a reinforced concrete beam, using reduced material properties, is provided at the end of this TechNote. Consistent with principles described in **ASTM E119** and ACI 216.1, the strength reduction factor ϕ used in the calculation should be taken as 1.0. Calculations based on principles described in ACI 216.1 and other rational methods represent the type of engineering analysis permitted by the **2018 IBC** Section 722. ACI 216.1 does not explicitly address FRP-strengthened members. However, data contained in ACI 216.1 relating to reduced concrete and steel strength can be incorporated into the calculations. The contribution of the FRP system should be neglected in the calculations unless the continued effectiveness of the FRP materials and bond to substrate can be proven through testing.

For certain types of concrete members, the use of calculations in accordance with IBC 2018 Section 722 may represent a viable method of demonstrating code compliance of nonprotected FRP systems during exposure to fire. In such instances, fire protection is not required to ensure adequate safety against collapse from fire. However, a coating to mitigate flame spread and smoke generation is often required by the building code, even if thermal protection for structural purposes is not required.

Evaluation by calculations in accordance with IBC 2018 Section 722 is an accepted and code-compliant approach; it is not an alternate method requiring specific review and approval by the building official. Unfortunately, many building officials have limited experience with calculations to evaluate fire resistance, and even fewer have experience with calculations involving FRP systems. Additionally, the building official may be reluctant to accept FRP as a structural material because it is not explicitly listed in the IBC. Therefore, despite specific provisions in the IBC permitting use of calculations, the design professional should consult with the building official at an early stage in the design process to avoid possible delays during plan review and permitting.

Fire protection systems

If evaluation by calculations pursuant to the 2018 IBC Section 722 is not feasible on a project due to schedule, budget, or other constraints, and an FRP-strengthened structure is required to have a fire rating, then use of an ASTM E119 qualified fire protection system may be a suitable means of demonstrating code compliance. Protection systems that have attained compliance with ASTM E119 criteria are assigned a designation (that is, design number) by the agency conducting the evaluation. Figure 1 shows examples of fire protection systems applied over FRP-strengthened members.



Fig. 1—Examples of fire protection systems: (a) protective coating on shear repair; and (b) protective mortar on flexural FRP-strengthened members (images courtesy of M. Lee).