John J. Myers, Douglas Gremel, Alvin Ericson, and Chad Van Kampen

New ACI 440.11 code adopted for design of concrete reinforced with glass-fiber-reinforced polymer bars

- A new code has been published on the design of concrete reinforced with glass-fiber-reinforced-polymer bars.

- This article provides background on this new code and discusses potential uses for precast concrete components and structures.

The American Concrete Institute (ACI), through the work of ACI Committee 440, Fiber-Reinforced Polymer Reinforcement, has published ACI 440.11-22, *Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary*.[1] This new code was developed by an American National Standards Institute–approved consensus process and addresses structural systems, members, and connections, including cast-in-place, precast, nonprestressed, and composite concrete construction.

This is the first comprehensive building code covering the use of nonmetallic, GFRP reinforcing bars in structural concrete applications. GFRP reinforcement has been in use for decades as an alternative to steel reinforcement because of its noncorrosive, nonmagnetic, and lightweight properties.

Scope and organization of ACI 440.11

The new ACI 440.11-22 code includes 27 chapters with provisions for designing GFRP-reinforced concrete beams, one-way and two-way slabs, columns, walls, connections, and foundations. Other model codes and standards can directly reference ACI 440.11-22 to allow for widespread, responsible use of this important technology.

ACI 440.11-22 mirrors ACI's *Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary* (ACI 318R-19)[2] with the same layout and chapters but also uses existing provisions where possible. An equals sign is used to indicate where provisions in ACI 440.11-22 are identical to provisions in ACI 318-19 (see section 7.7.1.1 in **Fig. 1**). Where a section in ACI 318-19 does not apply, sections are noted as "Intentionally left blank" in ACI 440.11-22 (see section 7.7.1.4 in Fig. 1). The consistency was intentional to help design professionals and practitioners familiar with ACI 318-19 to become familiar with and use ACI 440.11-22 more efficiently.

There are a few topics in ACI 318-19 that are not addressed or not applicable to ACI 440.11-22. Not addressed in ACI 440.11-22 are chapter 12, "Diaphragms;" chapter 14, "Plain Concrete;" chapter 17, "Anchoring to Concrete;" chapter 18, "Earthquake-Resistant Structures;" and chapter 23, "Strut-and-Tie Models." Diaphragms are expected to be included in the next edition. ACI 440.11-22 also does not cover lightweight concrete, prestressed concrete, deep beams, and shotcrete. ACI 440.11-22 does not permit GFRP-reinforced concrete members to be designed as part of a seismic-force-resisting system in seismic design categories B and C nor does it permit any GFRP reinforced concrete member in structures assigned to seismic design categories D, E, and F.

Research is ongoing with respect to anchoring fiber-reinforced-polymer (FRP) bars into existing concrete using epoxy or adhesive systems along with expanding the current anchoring database with short anchoring lengths using FRP bars. Although the linear elastic nature of FRP products proves to be less ductile than steel reinforcement, more work is needed to specifically develop and detail more ductile connections should it be used for seismic application. To date, some work has been done to examine hybrid bars that provide a combination of higher strength and stiffness with improved strain capacity at failure. In addition, although FRP has been used in prestressed applications, it is less mature than traditional prestressed steel applications and design processes; however, advances are being made in the area of anchor and grip FRP bars, which had been one of the major challenges for use of high-strength/high-stiffness FRP products.

Design differences from ACI 318

Some of the key design differences for FRP bars include using guaranteed bar properties provided by the manufacturer. These properties often vary not only by bar manufacturer but also by bar size. The properties do not align similarly to specific steel grades that are familiar to many designers for reinforced concrete or prestressed concrete. In addition, the FRP design approach uses an environmental reduction factor that considers the long-term service life of the material. In the case of steel reinforcement, no considerations are included for long-term environmental degradation due to corrosion and loss of cross section, for example. ACI 440.11-22 allows for both over-reinforced designs (concrete crushing) as well as under-reinforced designs (bar rupture). The failure mode is affiliated with a specific strength reduction factor similar to steel reinforcement design; however, unlike ACI 318-19, for FRP design an over-reinforced design permits a higher strength reduction factor.

Although some FRP products, such as carbon-fiber-reinforced polymer, have similar stiffness to steel, other FRP products, such as GFRP, have much lower stiffness. This means that many designs may be governed by serviceability limits rather than strength. On an equal reinforcement area basis, FRP design will often produce larger deflections and wider cracks. Larger crack widths may be accepted since FRP is noncorrosive; however, there is a perception of failure with larger visible crack width. Commentary section R24.3.2 in ACI 440.11-22 discusses the crack control provision differences between ACI 440.11-22 and ACI 318-19. Notably, the maximum bar spacing limits in ACI 318-19 correspond to a maximum crack width of approximately 0.018 in. (0.457 mm) whereas the maximum bar spacing limits in ACI 440.11-22 are based on a crack width of 0.028 in. (0.711 mm). This larger crack spacing is to prevent deterioration due to freezing and thawing rather than reinforcement corrosion for steel.

For designing the bond and development length for GFRP bars, ACI 440.11-22 specifies the length based on the required stress in the bar to develop the full nominal section capacity and not f_{fu}. This is different from ACI 318-19, which specifies lengths to develop f_y of the steel reinforcement. There are dif-

7.7—GFRP reinforcement detailing

7.7.1 *General*

=**7.7.1.1** Concrete cover for reinforcement shall be in accordance with 20.5.1.

7.7.1.2 Development lengths of reinforcement shall be in accordance with 25.4.

7.7.1.3 Splices of reinforcement shall be in accordance with 25.5.

7.7.1.4 Intentionally left blank.

7.7.2 *GFRP reinforcement spacing*

=**7.7.2.1** Minimum spacing s shall be in accordance with 25.2.

7.7.2.2 Spacing of longitudinal reinforcement closest to the tension face shall not exceed s given in 24.3.

7.7.2.3 Maximum spacing s of reinforcement shall be the lesser of $3h$ and 18 in.

7.7.2.4 Maximum spacing s of reinforcement required by 7.5.2.3 shall not exceed the lesser of $3h$ and 12 in.

Figure 1. Example use of existing ACI 318-19 provision in ACI 440.11-22. Note: An equals sign is used before provisions in ACI 440.11-22 that are identical to provisions in ACI 318-19.

ferences in shear design as well since GFRP has lower dowel resistance, lower modulus of elasticity, lower tensile strength around a bend compared with the straight part of a bar, higher tensile strength, and no yield point. The larger crack widths relate to less aggregate interlock, and the smaller compression zone depth results in less concrete resistance in the compression zone. Therefore, the contribution from the concrete V_c varies for FRP compared with steel. ACI 440.11-22 ignores the contribution of GFRP bars in compression. For beams in flexure, the designer replaces the FRP area with an equivalent area of concrete. For columns, a limit tensile strain of 1% is set to ensure that failure in the GFRP bar will not occur.

Key differences from conventional steel reinforcement

Some key differences between using GFRP and conventional steel reinforcement in concrete that may be considered limitations include no yielding before failure, low transverse strength, susceptibility to fire and smoke production, a high coefficient of thermal expansion perpendicular to the fiber direction, and the inability to field bend bars; however, these limitations are offset by some key advantages, including a high longitudinal strength–to–weight ratio, corrosion resistance, electromagnetic neutrality, high fatigue resistance, low thermal and electrical conductivity, a light weight, and ease of cutting on-site.

Some desirable applications for using GFRP reinforced concrete include the following:[3]

- any concrete member susceptible to corrosion by chloride ions or chemicals
- any concrete member requiring nonferrous reinforcement because of electromagnetic considerations
- as an alternative to epoxy, galvanized, or stainless steel reinforcing bars
- where machinery will consume the reinforced member (such as in mining and tunneling)
- applications that require thermal nonconductivity

Material requirements in ASTM D7957-22 for GFRP bars

ACI 440.11-22 makes substantial references to ASTM D7957, *Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement*.[4] Analogous to ASTM A615 for steel,[5] D7957 provides physical and mechanical property limits used by the designer and referenced in ACI 440.11-22. In addition to providing consensus design values, D7957 describes a variety of ASTM test methods used to qualify a given GFRP bar. The standard is somewhat prescriptive in nature in that it limits constituent materials to those that have been extensively tested and proved to provide excellent long-term performance. A voluminous amount of research, testing, and validation has gone into evaluating all aspects of FRP bar performance and in following a prescriptive method with testing of certain parameters, the ASTM committee has distilled this body of work so the designer will have the best assurance of good long-term performance.

The D7957 material standard goes beyond providing design material limits by standardizing a series of qualifying characterization tests and a series of quality assurance tests to be performed on a given production lot as shown in **Fig. 2**. It also recommends sampling frequency for qualification and quality control as shown in **Fig. 3**.

GFRP bars from varying bar producers have different form factors and means of enhancing the surface of the bar to effect bond with the concrete. Thus, the concept of a nominal bar area that is the same as that of A615 is used to calculate all properties. Because there is a wide variation in bond enhancements on GFRP bars (sand coatings, helical wrap surfaces, helical

D7957/D7957M – 17

TABLE 1 Property Limits and Test Methods for Qualification[A]

Property	Limit	Test Method
Mean Glass Transition Temperature	Midpoint temperature ≥100 °C [212 °F]	ASTM E1356
Mean Degree of Cure	≥95 %	ASTM E2160
Mean Measured Cross-Sectional Area	Table 3	ASTM D7205/D7205M, subsection 11.2.5.1
Guaranteed[B] Ultimate Tensile Force	Table 3	ASTM D7205/D7205M
Mean Tensile Modulus of Elasticity	≥44,800 MPa [6 500 000 psi]	ASTM D7205/D7205M
Mean Ultimate Tensile Strain	≥1.1 %	ASTM D7205/D7205M
Guaranteed[B] Transverse Shear Strength	≥131 MPa [19 000 psi]	ASTM D7617/D7617M
Guaranteed[B] Bond Strength	≥7.6 MPa [1100 psi]	ASTM D7913/D7913M
Mean Moisture Absorption to Saturation	≤1.0 % to saturation at 50 °C [122 °F]	ASTM D570, subsection 7.4
Mean Alkaline Resistance	≥80 % of initial mean ultimate tensile force following 90 days at 60 °C [140 °F]	ASTM D7705/D7705M, Procedure A
Guaranteed[B] Ultimate Tensile Force of Bent Portion of Bar	≥60 % of the values in Table 3	ASTM D7914/D7914M

[A]For the determination of the mean and guaranteed properties, at least 24 samples shall be obtained in groups of eight or more from three or more different production lots. The mean and guaranteed properties shall satisfy the limits.
[B]Guaranteed property is defined in 3.2.5.

Figure 2. ASTM D7957 table of property limits and test methods for qualification. Source: Reprinted, with permission, from ASTM D7957/D7957M-22 *Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement*, copyright ASTM International. A copy of the complete standard may be obtained from www.astm.org.

TABLE 2 Property Limits and Test Methods for Quality Control and Certification[A,B]

Property	Limit	Test Method
Fiber Mass Content	≥70 %	ASTM D2584 or ASTM D3171
Glass Transition Temperature	Midpoint temperature ≥100 °C [212 °F]	ASTM E1356
Degree of Cure	≥95 %	ASTM E2160
Measured Cross-Sectional Area	Table 3	ASTM D7205/D7205M, subsection 11.2.5.1
Ultimate Tensile Force	Table 3	ASTM D7205/D7205M
Tensile Modulus of Elasticity	≥44 800 MPa [6 500 000 psi]	ASTM D7205/D7205M
Ultimate Tensile Strain	≥1.1 %	ASTM D7205/D7205M
Moisture Absorption in 24 h[T]	≤0.25 % in 24 h at 50 °C [122 °F]	ASTM D570, subsection 7.4

[A]For the determination of each of the property limits, five random samples shall be obtained from each production lot. Each individual sample shall satisfy the property limits.
[B]For bent bars, the tests are performed on the straight portion of the bars.

Figure 3. ASTM D7957 table of property limits and test methods for quality control and certification. Source: Reprinted, with permission, from ASTM D7957/D7957M-22 *Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement*, copyright ASTM International. A copy of the complete standard may be obtained from www.astm.org.

wrapped and sand coated surfaces, ribbed lugs, and machined lugs), D7957 provides a tolerance for deviation from nominal. Using the Archimedes method, the measured cross-sectional area of a given bar is determined and the measured area of the bar must fall within the tolerances shown in **Fig. 4**.

Characterization tests tend to be more elaborate in nature and take longer to perform. For example, ASTM D7705 testing requires the bar to be subjected to an elevated-temperature alkaline-solution bath for up to 90 days and residual tensile strength is measured to screen constituent materials for suitable long-term durability.

In addition to tests performed on straight lengths of GFRP bar, D7957 describes testing and limits on fabricated bent shapes. The use of D7957 has standardized the GFRP bar industry and allowed designers to implement bars without having to commit to a specific proprietary supplier. If designers follow the values and limits in D7957 along with the design provisions of ACI 440.11-22, they will be following consensus standards that have been met by multiple suppliers and can be validated and traceable to production lot certifications ensuring a long lasting and safe implementation.

2024 IBC adoption and reference

To this end, the 2024 *International Building Code*[6] adopted a proposed change submitted by ACI as follows.

> *1901.2.1 Structural Concrete with GFRP reinforcement. Cast-in-place structural concrete internally reinforced with glass fiber reinforced polymer (GFRP) reinforcement conforming to ASTM D7957 and designed in accordance with ACI CODE 440.11 shall be permitted where fire resistance ratings are not required and only for structures assigned to seismic design category A.*

The justification for the proposed change was described as follows:

> *The addition of this new standard allows the design and construction of cast-in-place reinforced concrete using non-metallic reinforcement bars. Currently the design and construct requirements contained in the standard are limited to use in Seismic Design Category A. ACI Committee 440 developed this standard to provide for public health and safety by establishing minimum requirements for strength, stability, serviceability, durability, and integrity of GFRP reinforced concrete structures.*
>
> *The standard not only provides a means of establishing minimum requirements for the design and construction of GFRP reinforced concrete, but for acceptance of design and construction of GFRP reinforced concrete structures by the building officials or their designated representatives.*

Bar Designation No.	Nominal Dimensions		Measured Cross-Sectional Area Limits mm^2 [in.^{2}]		Minimum Guaranteed Ultimate Tensile Force kN [kip]
	Diameter mm [in.]	Cross-Sectional Area mm^2 [in.^{2}]	Minimum	Maximum	
M6 [2]	6.3 [0.250]	32 [0.049]	30 [0.046]	55 [0.085]	27 [6.1]
M10 [3]	9.5 [0.375]	71 [0.11]	67 [0.104]	104 [0.161]	59 [13.2]
M13 [4]	12.7 [0.500]	129 [0.20]	119 [0.185]	169 [0.263]	96 [21.6]
M16 [5]	15.9 [0.625]	199 [0.31]	186 [0.288]	251 [0.388]	130 [29.1]
M19 [6]	19.1 [0.750]	284 [0.44]	268 [0.415]	347 [0.539]	182 [40.9]
M22 [7]	22.2 [0.875]	387 [0.60]	365 [0.565]	460 [0.713]	241 [54.1]
M25 [8]	25.4 [1.000]	510 [0.79]	476 [0.738]	589 [0.913]	297 [66.8]
M29 [9]	28.7 [1.128]	645 [1.00]	603 [0.934]	733 [1.137]	365 [82.0]
M32 [10]	32.3 [1.270]	819 [1.27]	744 [1.154]	894 [1.385]	437 [98.2]

Figure 4. ASTM D7957 table of geometric properties. Source: Reprinted, with permission, from ASTM D7957/D7957M-22 *Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement*, copyright ASTM International. A copy of the complete standard may be obtained from www.astm.org.

The standard applies to GFRP reinforced concrete structures designed and constructed under the requirements of the general building code.

GFRP reinforced concrete is especially beneficial for satisfying a demand for improved resistance to corrosion in highly corrosive environments, such as reinforced concrete exposed to salt water, salt air, or deicing salts.

This standard establishes minimum requirements for GFRP reinforced concrete in a similar fashion as ACI 318 Building Code Requirements for Structural Concrete *establishes minimum requirements for structural concrete reinforced with steel reinforcement. A separate standard is needed, as GFRP reinforcement behaves differently than steel reinforcement.*

Currently GFRP is accepted for use to reinforce highway bridge decks. Acceptance is primarily in areas where deicing salts are used on the roads and cause severe corrosion to conventional steel reinforcement. This proposed change provides minimum requirements for other applications where GFRP reinforced concrete is being considered, such as marine and coastal structures, parking garages, water tanks, and structures supporting MRI machines. Design reasons to use GFRP bars in structures are resistance to corrosion in the presence of chloride ions, lack of interference with electromagnetic fields, and low thermal conductivity.

Currently the standard prohibits the use concrete internally reinforced with GFRP for applications where fire resistance ratings are required. Chapter 6 of the International Building code cites applications for floors, roofs, walls, partitions, and primary and secondary structural frames where fire resistance ratings are not required.

Precast concrete design applications

ACI 440.11-22 may be applied to the design of precast concrete members in similar fashion to ACI 318-19. ACI 440.11-22 allows the use of nonmetallic corrosion-resistant reinforcement in the design of precast concrete beams, slabs, columns, and walls. GFRP reinforcement has been used in major applications, such as in civil structures including bridge decks and marine applications including piers and seawalls. Precast concrete products used in these areas will also benefit from the corrosion resistance of nonmetallic reinforcement. *AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete*[7] is applicable to precast concrete bridge deck panels.

The key aspect to remember about designing with GFRP compared with steel is that although strength usually governs with steel, it is most often deflection and crack control that govern GFRP design because GFRP bars have a lower modulus of elasticity. Additional recommendations for the design of specific precast concrete components include the following:

- For flexural design, do not simply use a same-size or one-to-one bar substitution in structural members. Compression often controls design in flexural members reinforced with GFRP reinforcement and is the favored response.

- For column design, ignore the presence of GFRP bars in compression because they do not contribute anything and just use the overall area of concrete and its compressive strength.

- For seismic design, use GFRP only to resist dead and live loads.

- GFRP bars should not be used in lateral-load-resisting systems.

In detailing, note that 90-degree bends are the only practical solution when fabricating stirrups because all bends are made at the factory during initial production, never in the field. GFRP uses thermoset resins that cannot be reheated and only no. 2 through no. 8 bars are allowed for bending.

Minimum GFRP bar development lengths are 12 in. (305 mm) or 20 bar diameters. Mechanical splices must meet 1.25 of the guaranteed minimum ultimate tensile strength of the bar. Unlike steel, GFRP bars vary in strength by size, with the smallest being stronger per unit area.

Durability of GFRP reinforced concrete

Long-term durability performance of GFRP reinforced concrete in field applications is questioned because of the material's linear elastic behavior and the use of separate environmental reduction factors in the design process, even after knowing the materials are noncorrosive. Recent long-term field studies[8,9] evaluating GFRP reinforced concrete structures constructed 15 to 20 years ago continue to demonstrate excellent long-term performance. Additional studies on in-place performance have indicated no significant change in the properties of GFRP.[10]

Additional resources

Additional information is available on the ACI web site at Concrete.org.

References

1. ACI (American Concrete Institute) Committee 440. 2022. *Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary*. ACI 440.11-22. Farmington Hills, MI: ACI.

2. ACI Committee 318. 2019. *Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19)*. Farmington Hills, MI: ACI.

3. NEx Workshop on Designing Concrete Structures Reinforced with GFRP Bars Using the New ACI Code 440.11-22 presented in Dallas, Texas, Oct. 26, 2022.

4. ASTM International Subcommittee D30.10. 2022. *Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement*. ASTM D7957. West Conshohocken, PA: ASTM International.

5. ASTM International Subcommittee A01.05. 2022. *Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement*. ASTM A615. West Conshohocken, PA: ASTM International.

6. International Code Council. *2024 International Building Code*. Country Club Hills, IL: International Code Council, forthcoming.

7. AASHTO (American Association of Highway and Transportation Officials). 2018. *AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete*. 2nd ed. Washington, DC: AASHTO.

8. Al-Khafaji, A. F., R. T. Haluza, V. Benzecry, J. J. Myers, C. E. Bakis, and A. Nanni. 2021. "Durability Assessment of 15- to 20-Year-Old GFRP Bars Extracted from Bridges in the US—Part II: GFRP Bar Assessment." *Journal of Composites for Construction* 25 (2). https://doi.org/10.1061/(ASCE)CC.1943-5614.0001112.

9. Benzecry, V., A. F. Al-Khafaji, R. T. Haluza, C. E. Bakis, J. J. Myers, and A. Nanni. 2021. "Durability Assessment of 15- to 20-Year-Old GFRP Bars Extracted from Bridges in the US—Part I: Selected Bridges, Bar Extraction, and Concrete Assessment." *Journal of Composites for Construction* 25 (2). https://doi.org/10.1061/(ASCE)CC.1943-5614.0001110.

10. Benmokrane, B., C. Nazair, M. A. Loranger, and A. Manalo. 2018. "Field durability study of vinyl-ester-based GFRP rebars in concrete bridge barriers." *Journal of Bridge Engineering* 23 (12). https://doi.org/10.1061/(ASCE)BE.1943-5592.0001315.

Notation

f_{fu} = design ultimate tensile strength of fiber-reinforced polymer

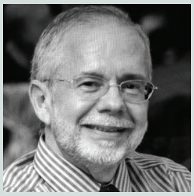
f_y = specified yield strength of reinforcement

V_c = nominal shear strength provided by concrete

About the authors

John J. Myers, PhD, PE, FACI, FASCE, FIAAM, FTMS, FVEST, is a professor in the Civil, Architectural and Environmental Engineering Department and director of the Missouri Center for Transportation Innovation at the Missouri University of Science and Technology in Rolla.

Douglas Gremel is the director of engineering at Owens Corning Infrastructure Solutions LLC in Seward, Neb. He has a BS in engineering science, electrical engineering, and business administration from Colorado State University in Fort Collins.



Alvin Ericson, FACI, FPCI, is an independent technical marketing consultant specializing in fiber-reinforced-polymer composite and precast concrete construction systems. He has a BS in architecture from the Massachusetts Institute of Technology in Cambridge and an MBA from Northeastern University in Boston, Mass.

Chad Van Kampen, MASCE, PE, LEED AP BD+C, LPCI, is a licensed professional engineer in multiple states and manager of preconstruction with Fabcon Precast in Grandville, Mich. He has a BS in civil engineering from Calvin College in Grand Rapids, Mich., and extensive senior-level management experience with large complex projects centered on the precast concrete construction industry. An active member of PCI and AltusGroup, Van Kampen serves as chair of the PCI FRP Composites Committee and Total Precast Systems Committee and vice chair of the PCI Hollow Core Committee.

Abstract

The American Concrete Institute has published ACI 440.11-22, *Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary*. This new code was developed by an American National Standards Institute–approved consensus process and addresses structural systems, members, and connections, including cast-in-place, precast, nonprestressed, and composite concrete construction. ACI 440.11-22 is the first comprehensive building code covering the use of nonmetallic, GFRP reinforcing bars in structural concrete applications. This article provides background on this new code and discusses potential uses for precast concrete components and structures.

Keywords

Composite construction, GFRP, glass-fiber-reinforced polymer, reinforcing bar.

Publishing details

This paper appears in *PCI Journal* (ISSN 0887-9672) V. 68, No. 2, March–April 2023, and can be found at https://doi.org/10.15554/pcij68.2-05. *PCI Journal* is published bimonthly by the Precast/Prestressed Concrete Institute, 8770 W. Bryn Mawr Ave., Suite 1150, Chicago, IL 60631.

Reader comments

Please address any reader comments to *PCI Journal* editor-in-chief Tom Klemens at tklemens@pci.org or Precast/Prestressed Concrete Institute, c/o *PCI Journal*, 8770 W. Bryn Mawr Ave., Suite 1150, Chicago, IL 60631.