Building Code Compliance of Alternative Applications Case Study

Twisted steel micro reinforcement in concrete

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This article describes one industry effort to develop alternative methods for designing concrete in compliance with current building codes in the United States. While it focuses on how ICC-ES AC470,[1] International Code Council Evaluation Service Acceptance Criteria, leverages the plain concrete design pathway for structural concrete and the development of new test methods to demonstrate code compliance for twisted steel micro reinforcement (TSMR), these methods could potentially be used for other forms of alternative reinforcement.

Building Codes

Model building codes establish minimum requirements for new building construction and may be adopted by building officials in various jurisdictions, with or without modifications. The International Building Code (IBC) has been adopted in all 50 states, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands. Furthermore, several other countries/jurisdictions, including Saudi Arabia, Jamaica, and Abu Dhabi, use IBC as a reference for developing their national building codes. Another model building code, the International Residential Code (IRC), has been adopted by most U.S. states as a legal building code. It is noteworthy to mention that both the IBC and IRC contain references to standards promulgated by other organizations, including ACI and the Steel Deck Institute (SDI). To the extent that they are referenced, these standards are part of IBC and IRC. Further, many of these standards allow the use of alternative reinforcement as described herein.

ACI CODE-318

The 2021 IBC[2] refers to ACI 318-19, "Building Code Requirements for Structural Concrete."[3] The upcoming 2024 edition of the IBC will refer to ACI CODE-318-19(22).[4] ACI 318-19, Section 9.6.3.1, allows the use of steel fibers for shear reinforcement for very limited applications. Table 9.6.3.1 of ACI 318-19 refers to use of steel fiber-reinforced concrete in cases where minimum area of shear reinforcement $A_{v,min}$ is not required. For steel fibers, ACI 318-19, Section 26.4.1.6.1, requires compliance with ASTM A820/A820M-16, "Standard Specification for Steel Fibers for Fiber-Reinforced Concrete."

ACI 332

The 2021 IRC[5] refers to ACI 332-20, "Code Requirements for Residential Concrete,"[6] which allows the use of fibers in concrete for hot weather construction and slabs. In accordance with ACI 332-20, Section 7.7.3, fibers must comply with requirements of ASTM C1116/C1116M-10(2015), "Standard Specification for Fiber-Reinforced Concrete."

SDI C

The 2021 IBC refers to ANSI/SDI C - 2017, "Standard for Composite Steel Floor Deck-Slabs."[7] Section 2.4-B-15-a-2 of this standard allows the use of steel fibers as temperature and shrinkage reinforcement, but at a rate not less than 25 lb/yd^3 (14.8 kg/m^3). The standard also requires compliance with ASTM A820/A820M for steel fibers.

Alternative Materials

The 2021 IBC, Section 104.11, allows for the integration of new construction products, systems, and technologies not explicitly described in the code itself, permitting manufacturers to demonstrate that these products are compliant with the intent of the code. Section 104.11.1 states that "Supporting data, where necessary to assist in the approval of materials or assemblies not specifically provided for in the code, can consist of valid research reports from approved sources."[2] This is typically accomplished in two stages: first creating acceptance criteria documents and then issuing research reports.

Acceptance criteria documents outline specific product sampling, testing, and quality requirements that must be fulfilled to verify that a product is code compliant. Research reports verify building code compliance and are issued according to specific acceptance criteria. The research results are summarized in an evaluation report and made available to code officials, licensed design professionals, and the public.

Compliance Verification

Given there are limited mentions of steel fibers and no mentions of TSMR in IBC and IRC, an acceptance criteria document, ICC-ES AC470, was developed to provide requirements for demonstrating building code compliance of TSMR. ICC-ES is a product certification body accredited by the ANSI National Accreditation Board (ANAB) under ISO/IEC17065:12 requirements.[8] AC470 describes evaluating the use of TSMR in concrete to comply with building code objectives, such as structural strength, fire resistance, material properties, and durability.

TSMR Design Types in AC470

AC470 defines five design types for TSMR (see Table 1). The design professional must select the appropriate design type considering the characteristics of the project. In addition to the standards referenced in IBC and IRC, AC470 refers to practices produced by ACI Committees 330, Concrete Parking Lots and Site Paving, and 360, Design of Slabs on Ground. ACI 360R-10, "Guide to Design of Slabs-on-Ground,"[10] allows the use of plain concrete in Chapter 7 and steel fibers in Section 11.3 to reinforce concrete slabs-on-ground for increased strain strength, impact resistance, flexural toughness, crack-width control, and tensile strength. The guide refers to ACI 544.4R, 544.1R, and 544.3R[11-13] reports and ASTM A820/A820M for identification of fibers that can be used under this document. ACI PRC-330-21, "Commercial Concrete Parking Lots and Site Paving Design and Construction—Guide,"[14] uses plain concrete design methods for pavement design. The report refers to ASTM C1116/C1116M-10a(15) for steel fibers. Pavementdesigner.org, developed through a collaboration of the American Concrete Pavement Association (ACPA), Portland Cement Association (PCA), and National Ready Mixed Concrete Association (NRMCA), implements ACI PRC-330-21.

Minimum Requirements Testing

This is testing to assure that TSMR does not negatively impact the performance of the concrete and that mixtures with TSMR have adequate freezing-and-thawing resistance and post-crack tensile capacity. The testing is done under a different ICC-ES acceptance criteria (AC208, "Steel Fibers in Concrete"[15]).

Modulus of rupture (Types S, G, and P)

The designs under AC470 are typically governed by concrete cracking and crushing limit states. Accordingly, testing is done in a variety of concrete mixtures to characterize the relationship between flexural tensile strength (modulus of rupture f_r) and compressive strength f'_c. The results are used to compute maximum design strengths.

Composite concrete steel decks (Type C)

Serviceability is the governing design factor in slab-on-metal-deck construction (another term for composite concrete-steel deck). The method seeks only to provide replacement for the minimum required steel for temperature and shrinkage. Specially designed specimens which meet SDI C requirements for traditional shrinkage and temperature reinforcement, as well as specimens using alternative reinforcement, are exposed to an environment that induces tensile strain/stress that exceeds the capacity of plain concrete. If the average measured crack width of the specimens reinforced with alternative reinforcement, in this case TSMR, is less than the average measured crack width of control specimens reinforced with conventional shrinkage and temperature reinforcement (for example, welded wire reinforcement [WWR]) after

Table 1:
Design types for TSMR in AC470

Type N, non-structural	Discontinuous steel reinforcement used as an alternative to the shrinkage and temperature reinforcement specified in Section 24.4 of ACI 318-19 for plain concrete footings, and for plain concrete slabs (as defined by ACI 360) supported directly on the ground
Type S, structural elastic design supported structures	Applications that fall within the scope of ACI 318-19, Chapter 14; IBC, Section 1906; ACI 332-14, Section 8.2.1;[9] IRC, Sections R404.1.3 and R608.1; or Tables 8.2.1.3a and 8.2.1.3b of ACI 332-14.[9] Discontinuous steel reinforcements are also used as an alternative to horizontal temperature and shrinkage reinforcement in structural plain concrete walls covered in IBC, Section 1906; IRC, Sections R404.1.3 and R608.1; and ACI 332-14, Sections 8.2.1 and 8.2.7[9]
Type G, slabs-on-ground	Applications that fall within the scope of ACI 360, Chapter 7 (plain concrete slabs) or Section 11.3 (fiber-reinforced concrete slabs)
Type P, parking lots	Applications that fall within the scope of ACI 330, Chapter 3—Pavement Design
Type C, composite concrete slabs over steel deck	Applications that are alternative to SDI C, Section 2.4-B-15-a (as referenced by IBC, Section 2210.1.1) for concrete over composite steel decks when discontinuous steel reinforcement is used as temperature and shrinkage reinforcement

environmental cycling, the reinforcement and its dosage are considered acceptable.

Test Methods in AC470

Modulus of rupture

Flexural testing is conducted according to ASTM C78/C78M, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)," as shown in Fig. 1. The standard (Section 6.2) allows for testing of any size specimen "provided the smaller cross-sectional dimension of the beam is at least three times the nominal maximum size of the coarse aggregate." The maximum coefficient of variation (COV) of test results must be equal to or less than 15% (Commentary Section R8.1.2 in ACI CODE-355.2-22[16]).

Compressive strength

Compressive strength testing is done in accordance with ASTM C39/C39M, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." Average compressive strength is measured with the TSMR added to the concrete. Maximum COV of test results must be equal to or less than 15% (Commentary Section R8.1.2 in ACI CODE-355.2-22).

Fire resistance

The criteria allow for optional evaluation of fire rating in accordance with 2021 IBC, Section 703.

Shrinkage cracking

A modification to the standard ASTM C1579, "Standard Test Method for Evaluating Plastic Shrinkage Cracking of Restrained Fiber Reinforced Concrete (Using a Steel Form Insert)," was developed to evaluate tensile strain due to shrinkage in composite slab-on-metal-deck assemblies. A standard piece of composite decking is secured to an aluminum base plate (Fig. 2). Two specimens, one constructed with conventional WWR and one with TSMR, are fabricated and tested simultaneously by exposure to conditioned heat and airflow.

Test Data Analysis and Design Limits

AC470 requires additional analysis for application of Types S, G, and P.

Modulus of rupture (Type S)

Type S criteria (see Table 1) are based on ACI 318-19, Chapter 14, application limits and design equations with three modifications. First, the value allowed for f_r is modified based on testing required by AC470. Second, a size effect factor is included to account for the depth of the section. Third, a capacity reduction is determined to assure compliance with ASCE/SEI 7-16, Table 1.3-1.[17,18] It should be noted that ACI 318-19, Chapter 14, specifies a very conservative f_r of concrete for flexure as $5\sqrt{f_c'}$ in Eq. (14.5.2.1a).

Modulus of rupture and compressive strength

The relationship between f_r and f_c' ($R_{c,ave}$) is determined by dividing f_r from ASTM C78/C78M tests by the square root of f_c'. The maximum limit for flexural strength L_f is equal to $R_{c,ave}$

$$L_f = R_{c,ave} = \frac{f_r}{\sqrt{f_c'}} \tag{1}$$

Modulus of rupture COV and resistance factor

The calculations given in Eq. (2) and later are necessary to consider the variability in f_r as well as other variability inherent to the system, and to account for the higher reliability index required for brittle materials in ASCE/SEI 7-16, Table 1.3-1,

Fig. 1: ASTM C78/C78M flexural test setup

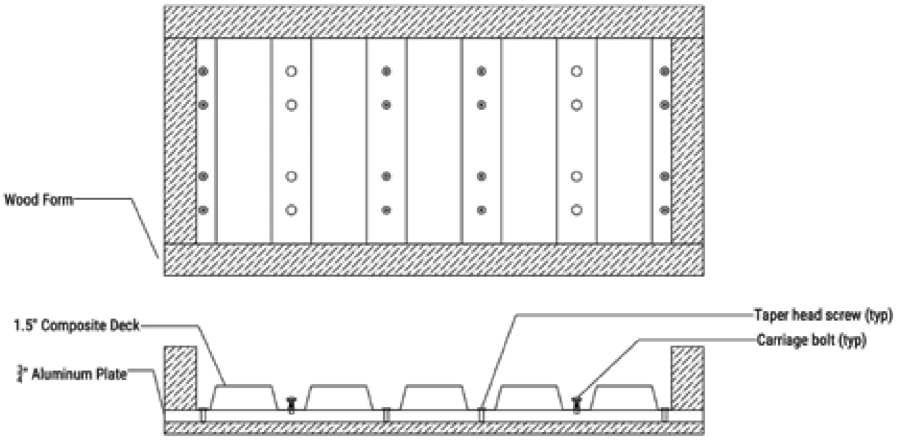

Fig. 2: Shrinkage specimen for ASTM C1579 testing

assuming a reliability index of 4.0.[19] The governing resistance factor (ϕ) is adopted as the lesser of the standard 0.6 for plain concrete and the value calculated using this approach. Typical values range from 0.55 to 0.60.

The overall COV V_r is the root sum squared of the sources of variability

$$V_r = \sqrt{V_b^2 + 2V_h^2 + V_p^2 + V_{ip}^2 + COV^2} \tag{2}$$

where V_b is the COV of member width; V_h is the coefficient of variation of member depth; V_p is the professional factor which accounts for accuracy of design equations; and V_{ip} is the in-place mixture variation factor.

Scale effect adjustment factor

Size effect is a well-known and accepted property of materials. ACI 318-19, Eq. (14.5.2.1a), with $5\sqrt{f_c'}$, does not include consideration for the size effect. However, AC470 implements a size effect factor developed by Legeron[20] and adopted in the *fib* Model Code 1990[21]

$$\lambda_s = \frac{2.5\left(\frac{h_b}{h_0}\right)^{0.7}}{1+1.5\left(\frac{h_b}{h_0}\right)^{0.7}} \tag{3}$$

where h_0 is the depth of the member being designed; and h_b is the depth of the ASTM C78/C78M test beam.

Flexural design limits

AC470 specifies flexural strengths based on modified versions of ACI 318-19, Chapter 14, Eq. (14.5.2.1a) and Eq. (a) in Table 14.5.4.1, taking into account f_r, ϕ, and the size effect factor in Eq. (3):

- For pure flexure

$$M_u \leq \lambda_s \phi L_f \sqrt{f_c'} S_m \tag{4}$$

- For combined flexure and axial compression

$$\frac{M_u}{S_m} - \frac{P_u}{A_g} \leq \lambda_s \phi L_f \sqrt{f_c'} \tag{5}$$

where M_u is the moment strength; P_u is the axial strength; S_m is the section modulus; A_g is the gross cross-sectional area; and λ_s is the size effect factor.

Modulus of rupture (Types G and P)

Per AC470, designs for slabs-on-ground and pavement are based on average f_r in accordance with ACI 360 and ACI 330

$$f_r = L_f \sqrt{f_c'} \tag{6}$$

Summary

The IBC is the predominant building code in the United States. Section 104.11 of the code allows for alternative materials, designs, and methods provided that such alternatives have been evaluated to meet code requirements. AC470 provides the evaluation criteria and data for quantifying the use of TSMR in concrete in compliance with the building codes. An evaluation report has been issued in accordance with AC470 and is intended to demonstrate building code compliance verification for TSMR as alternative reinforcement used in concrete for several specific applications.

References

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Note: Additional information on the ASTM standards discussed in this article can be found at **www.astm.org**.

Selected for reader interest by the editors.

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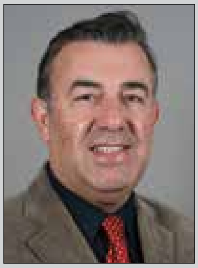

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