ACCEPTANCE CRITERIA FOR ALTERNATIVE CONSTRUCTION MATERIALS

AND THEIR ROLE IN THE INTERNATIONAL EXISTING BUILDING CODE (IEBC)

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In the United States, the International Building Code (IBC)[1] has been adopted in all 50 states as well as the District of Columbia, Puerto Rico, and the U.S. Virgin Islands as the legal building code. The IBC has also been adopted by the Department of Defense, Department of State, and Department of Commerce. The purpose of the IBC is to establish the minimum requirements to safeguard the public health and safety in new and existing buildings; however, in 2015, the provisions for existing buildings were removed from IBC and a reference to the International Existing Building Code (IEBC)[2] was inserted, mandating its use for existing buildings. Similar to the IBC, Section 104.11 of the IEBC states that supporting data, where necessary to assist in the approval of materials or assemblies not specifically provided for in this code, must consist of valid research reports from approved sources. Two of the alternative materials/technologies not recognized in the IEBC are fiber-reinforced polymer (FRP) and fabric-reinforced cementitious matrix (FRCM) composites for rehabilitation of existing buildings. An "Acceptance Criteria" establishes requirements for testing and evaluation that can lead to the issuance of a product Evaluation ("Research Report" by International Code Council Evaluation Service (ICC-ES). This article will first address the process for code adoption of new materials/technologies. Next, it will summarize and present the key features of some acceptance criteria (AC125,[3] AC434,[4] and AC416[5]) for testing and design of alternative systems related to building repair, as well as underlining their relationship with the consolidated practice of FRP use as outlined in American Concrete Institute (ACI) guidelines.

PREMISE ON CODE ADOPTION

Within the numerous classes of constructed facilities, we focus on buildings even though similar considerations could be drawn for other classes of structures such as environmental and transportation. What distinguishes construction from other industries is the role played by building codes in regulating its activities. Building codes are collections of mandatory provisions that specify minimum acceptable levels of service and safety. They address design, construction, inspection, and occupancy with the purpose of protecting public health, safety, and general welfare.

The practice of developing, approving, and enforcing building codes varies among countries. In some, building codes are developed by government agencies or quasi-governmental standards organizations and then enforced by the central government. Such codes are known as "national building codes." In other countries—such as the United States, where the power of regulating construction and fire safety is vested in local authorities—a system of "model building codes" is used. The model codes become law in a jurisdiction when formally enacted by the appropriate governmental or private authority.

In the United States (and some other parts of the world), the IBC, part of the family of International Codes (I-Codes), is the model code which covers the design, inspection, and construction of new buildings. For current and well-established materials systems and technologies (for example reinforced concrete [RC] design and construction), IBC references additional standard documents (for example, in the case of RC, ACI 318[6]), de-facto making them part of the model code itself. Once IBC is adopted by a state or other legal jurisdiction, it becomes law and, with it, its referenced standards. Based on the previous statements (and except the case when a standard is directly adopted by a jurisdiction), for any standard document to have legal status (for example, ACI documents in mandatory language) and thus be enforceable by a building official, it must be referenced directly by IBC or any of the other I-Codes.

For the case of existing buildings, the model I-Code is the IEBC. It should be noted that IBC used to have a section for existing buildings (Chapter 34). However, in the code cycle starting in 2015, IBC "Chapter 34—Existing Structures" (that covered structural provisions related to evaluation, design, and detailing of existing structures) was dropped and a direct reference to IEBC was inserted, thus recognizing a clear separation between new and existing construction in the I-Codes.

ICC-ES ACCEPTANCE CRITERIA

What happens if there is a new construction material or system that is an alternative to that covered in the I-Codes? Section 104.11 of any I-Code states that:

> *"The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved."*

Subsection to Section 104.11 (Section 104.11.1) addresses the need for research reports. This section states that:

> *"Supporting data, where necessary to assist in the approval of materials or assemblies not specifically provided for in this code, must consist of valid research reports from approved sources"* that are accredited under ISO/IEC 17065.[7]

Section 104.11.2 states that:

> *"Whenever there is insufficient evidence of compliance with the provisions of this code, or evidence that a material or method does not conform to the requirements of this code, or in order to substantiate claims for alternative materials or methods, the code officials have the authority to require tests as evidence of compliance to be made at no expense to the jurisdiction."*

The existence of a set of protocols and provisions is therefore necessary to conduct the tests, the analysis of the results, the design, and the installation of the product on which to base the "Research Report." To this end, ICC-ES develops in partnership with the proposers of new technology-specific documents called "Acceptance Criteria" (AC) for the purpose of issuing "Code Compliance Research (Evaluation) Reports" in accordance with Section 104.11. The AC typically outlines evaluation procedures for product sampling, testing, and quality requirements to be fulfilled to obtain code-compliance verification. Once it is demonstrated that the product is manufactured under an approved quality control program, the research program outlined in the AC is conducted by an independent accredited laboratory certified under ISO/IEC 17025.[8] This international standard is the single-most important standard, establishing the requirements for the competence of testing and calibration laboratories around the world.

The outcomes of the research are then evaluated by ICC-ES and, assuming compliance, a research report is issued. The results of the data generated under an AC evaluation are finally published in a product-specific Evaluation Research Report. Code officials and other interested parties use a code compliance research report to help determine code compliance and enforce building regulations; manufacturers use this same report as evidence that their products comply with code requirements and warrant regulatory approval, design engineers can use to help their design.

AC125 AND AC434

Because neither IBC nor IEBC include provisions for the structural capacity, reliability, durability, and serviceability of concrete and masonry elements strengthened with externally bonded fiber-reinforced polymer (FRP) or fabric-reinforced cementitious matrix (FRCM) composites, to address this shortcoming, ICC-ES established AC125 (for FRP) and AC434 (for FRCM), respectively. AC125 and AC434 are titled "Acceptance Criteria for Concrete, and Reinforced and Unreinforced Masonry Strengthening, Using Externally Bonded Fiber-Reinforced Polymer (FRP)" and "Fabric-Reinforced Cementitious Matrix (FRCM) Composite Systems," respectively. The purpose of AC125 and AC434 is to provide the minimum requirements to qualify the use of FRP and FRCM composite systems while meeting the main objectives of the building codes, including structural strength and serviceability, fire safety, and durability. Figure 1 shows tensile tests of FRP and FRCM coupons of products under evaluation. Both AC125 and AC434 are based on the available knowledge of FRP and FRCM composites regarding performance, design procedures, and limitations at the time they are published.

In 2002, ACI Committee 440, Fiber-Reinforced Polymer Reinforcement, published its first guide for the design and construction using externally bonded FRP composites (ACI 440.2R-02)[9] for strengthening concrete structures. ACI 440.2R was the first comprehensive design guide that provided procedures and limitations as well as service and long-term performance requirements for FRP repair systems. In 2008, ACI Committee 440 published the first revision to the FRP design guide that included significant changes to design requirements to address the influence of bond of externally bonded composites, strengthening of prestressed elements, and acceptable strengthening limits using FRP to guard against structural failure in case the externally bonded reinforcement was damaged due to fire or other causes (ACI 440.2R-08).[10] Currently, there is no reference to the ACI 440.2R guide in IBC or IEBC,

Fig. 1: Tensile tests of (a) FRP; and (b) FRCM coupon, according to AC125 and AC434

in part because the document is written in a nonmandatory format unsuitable for code enforcement. The use of FRP systems as a legitimate strengthening technology; however, is permitted by the recently developed ACI 562-13, "Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings and Commentary,"[11] which again cannot reference ACI 440.2R-08 for the same reason (that is, non-mandatory language). It is envisioned that ACI 562 will eventually be referenced by IEBC as ACI 318 is referenced by IBC.

A guide was published in December 2013 to cover FRCM composite systems used to strengthen existing concrete and masonry structures by ACI Committee 549, Thin Reinforced Cementitious Products and Ferrocement (ACI 549.4R-13).[12] This guide provides background information and field applications of FRCM; FRCM material properties; axial, flexural, and shear capacities of the FRCM-strengthened structures; and structural design procedures. It contains 17 chapters and two appendixes, and draws from AC434 for the provisions of testing and qualification of the constituents as well as the FRCM systems. The guide covers shipping, storage, handling, inspection, evaluation, acceptance, maintenance, and repair of FRCM systems. Emphasis is placed on design requirements and algorithms for the strengthening of both reinforced concrete and masonry members. As for ACI 440.2R, currently, there is no reference to ACI 549.4R in IBC or IEBC, in part because the document is written in nonmandatory language.

To date, AC125 and AC434 are used for code compliance verification of externally bonded FRP and FRCM systems in repair of concrete and masonry buildings. FRP/FRCM systems evaluated under AC125/AC434 are passive-type systems (non-prestressed) applied by wet lay-up procedure; Fig. 2 shows the fabrication of FRP and FRCM panels for testing. A manufacturer can decide to pursue evaluation for certain applications, be it concrete or masonry, columns or beams, as well as decide the purpose for strengthening, such as confinement, flexure, or shear. AC125 and AC434 require full-scale structural testing and analysis of the test results to prove that the specified design methodologies and minimum performance requirements are verified.

Figure 3 shows a flexural test of an RC slab externally strengthened with FRP laminate and conducted for design validation. Both criteria also require environmental and aging tests to prove that the long-term retention of relevant composite properties is 85 to 90% of the original properties, depending on the duration and type of exposure. To this end, the manufacturer would be mandated to create a qualification test plan that includes test matrix, test method, specimen configuration, and theoretical predictions to avoid unintended results and additional tests. For fire-recognition, both AC125 and AC434 also provide fire-resistance-rating test and evaluation provisions.

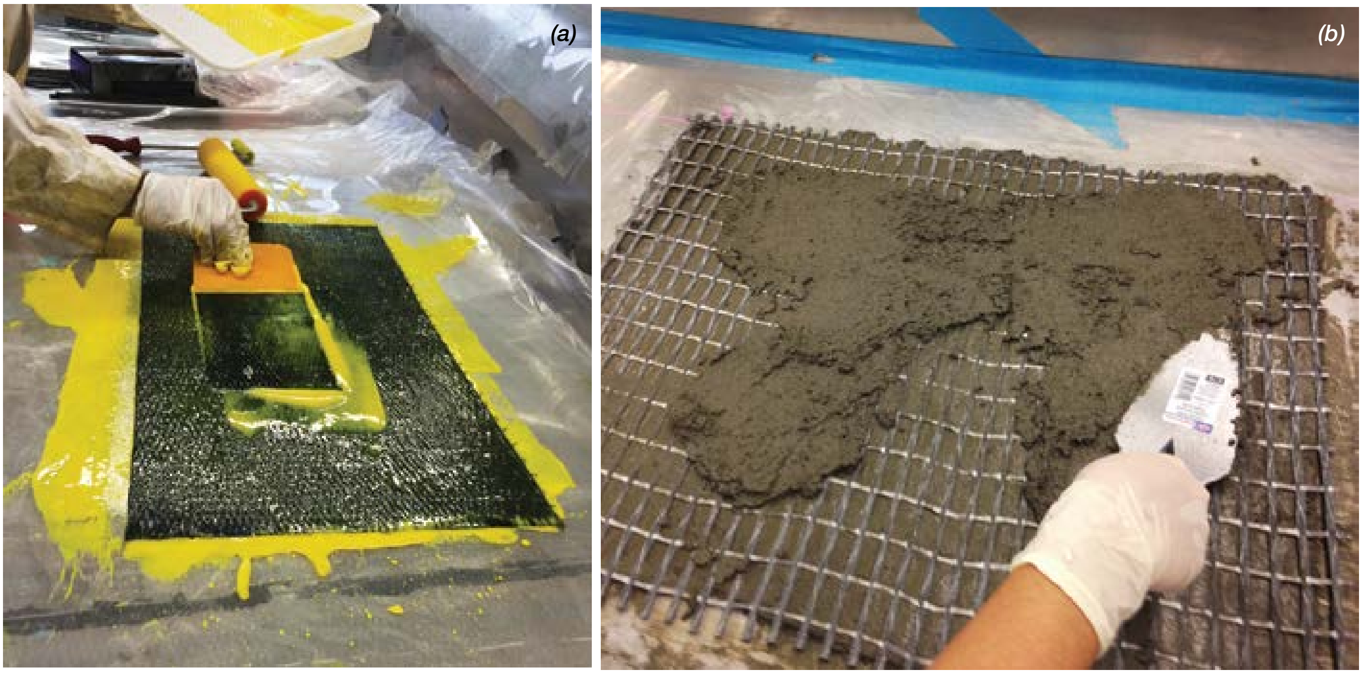

Fig. 2: Fabrication of (a) FRP; and (b) FRCM panel for testing, according to AC125 and AC434

AC416

A newly introduced method, which enables substandard light-frame walls to be used as the lateral force-resisting system in residential buildings, consists of the application of FRP laminates. To have the means to show that this strengthening technique is an acceptable alternative to code-specified methods, the ICC-ES AC for Enhanced Light-Frame Shear Walls Using Glass Fiber-Reinforced Polymer (GFRP) Composite Systems (AC416) was developed. Chapter 3 of the IEBC permits ASCE/SEI 41[13] as a method for seismic rehabilitation of existing structures; however, ASCE/SEI 41 does not address use of FRP composites. An AC to establish requirements for GFRP composite systems applied to existing light-framed shear walls was published by ICC-ES to provide a means to qualify the use of GFRP laminates for all Seismic Design Categories, while also meeting the fundamental objectives of the building codes,

Fig. 3: Flexural test of RC slab strengthened with FRP for design validation, according to AC125

including structural strength and compatibility, fire safety, and durability. Code compliance research report recognition under AC416 certifies that the GFRP-enhanced light-frame shear walls meets quality control requirements, can be designed by a licensed design professional, and can be assessed by the code official. In general, AC416 requires that cyclic shear tests be conducted on the strengthened prototype assemblies, in accordance with ASTM E2126, Section 8.5, Method C (CUREE Basic Loading Protocol),[14] with some modifications and clarifications.

QUALITY CONTROL

All AC have significant quality control provisions. Two aspects are important to be noted in the consideration of quality control measures. The first concerns manufacturing of the component materials. AC requires the quality control systems to be documented, with the documentation conforming to general guidelines as contained in the ICC-ES Acceptance Criteria for Quality Documentation (AC10).[15] These provisions are intended to verify the materials are produced with the expectation that the performance remains as previously demonstrated by testing. As a means of verification, the quality system needs to be reviewed by an accredited inspection agency. The inspection agency must be independent and conform to requirements stipulated in ISO/IEC 17020[16] as determined by a recognized accreditation body. Secondly, the certification body would require the inspection agency to inspect each manufacturing location regularly, no less than two times per year, to provide assurance that the materials are produced in accordance with the approved quality documentation.

CONCLUSIONS

Acceptance and deployment of innovation in construction remains a significant challenge and improved protocols are needed to expedite a process that is presently rather lengthy.

Existing provisions in the I-Code family (Section 104.11 of IBC and IEBC) allow for the design and implementation of materials and technologies not covered by the model building codes. This mechanism is of great relevance to concrete repair, which among all segments of the construction industry is the one that needs creative and innovative solutions based on performance rather than prescriptive requirements.

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REFERENCES

1. ICC, "2015 International Building Code (IBC)," International Code Council, Country Club Hills, IL, 2014, 736 pp.

2. ICC, "2015 International Existing Building Code (IEBC)," International Code Council, Country Club Hills, IL, 2014, 324 pp.

3. AC125, "Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Externally Bonded Fiber-Reinforced Polymer (FRP) Composite Systems," ICC Evaluation Service, Brea, CA, 13 pp.

4. AC434, "Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Externally Bonded Fabric-Reinforced Cementitious Matrix (FRCM) Composite Systems," ICC Evaluation Service, Brea, CA, 17 pp.

5. AC416, "Acceptance Criteria for Enhanced Light-Frame Shear Walls Using Glass Fiber-Reinforced Polymer (GFRP) Composite Systems," ICC Evaluation Service, Brea, CA, 8 pp.

6. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)," American Concrete Institute, Farmington Hills, MI, 2014, 520 pp.

7. ISO/IEC 17065:2012, "Conformity Assessment—Requirements for Bodies Certifying Products, Processes and Services," International Organization for Standardization, Geneva, Switzerland, 27 pp.

8. ISO/IEC 17025:2005, "General Requirements for the Competence of Testing and Calibration Laboratories," International Organization for Standardization, Geneva, Switzerland, 28 pp.

9. ACI Committee 440, "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures (ACI 440.2R-02)," American Concrete Institute, Farmington Hills, MI, 2002, 76 pp.

10. ACI Committee 440, "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures (ACI 440.2R-08)," American Concrete Institute, Farmington Hills, MI, 2008, 76 pp.

11. ACI Committee 562, "Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings (ACI 562-13) and Commentary," American Concrete Institute, Farmington Hills, MI, 2013, 59 pp.

12. ACI Committee 549, "Guide to Design and Construction of Externally Bonded Fabric-Reinforced Cementitious Matrix (FRCM) Systems for Repair and Strengthening of Concrete and Masonry Structures (ACI 549.4R-13)," American Concrete Institute, Farmington Hills, MI, 2013, 69 pp.

13. ASCE/SEI 41-06, "Seismic Rehabilitation of Existing Buildings," American Society of Civil Engineers, Reston, VA, 2007, 428 pp.

14. ASTM E2126-11, "Standard Test Methods for Cyclic (Reversed) Load Test for Shear Resistance of Walls for Buildings," ASTM International, West Conshohocken, PA, 2011, 15 pp.

15. AC10, "Acceptance Criteria for Quality Documentation," ICC Evaluation Service, Brea, CA, June 2014, 8 pp.

16. ISO/IEC 17020:2012, "Conformity Assessment—Requirements for the Operation of Various Types of Bodies Performing Inspection," International Organization for Standardization, Geneva, Switzerland, 18 pp.

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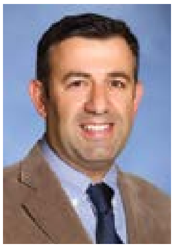

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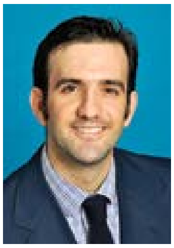

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