IN-LB	Inch-Pound Units
SI	International System of Units

Guide to Design and Construction of Externally Bonded Fabric-Reinforced Cementitious Matrix and Steel-Reinforced Grout Systems for Repair and Strengthening of Concrete Structures

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Fabric-reinforced cementitious matrix (FRCM) and steel-reinforced grout (SRG) systems for rehabilitation and strengthening concrete structures is an alternative to traditional techniques such as fiber-reinforced polymers (FRPs), steel plate bonding, section enlargement, and external post-tensioning. An FRCM/SRG is a composite material consisting of one or more layers of inorganic matrix reinforced with dry fibers in the form of open mesh or fabric. The inorganic matrixes are typically cement-based, lime-based, or geopolymer. When adhered to concrete structural members, they form an FRCM/SRG system that acts as supplemental, externally bonded reinforcement. This guide addresses the history and use of FRCM and SRG systems rehabilitation and strengthening, their unique material properties, and recommendations on their design, construction, and inspection. Guidelines are based on experimental research, analytical work, and field applications.

Keywords: cyclic loading; deflection; earthquake-resistant; fabric-reinforced cementitious matrix fatigue systems; fiber-reinforced polymer systems; lap splices; meshes; substrate repair; rehabilitation; surface preparation.

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

Fabric-reinforced cementitious matrix (FRCM) and steel-reinforced grout (SRG) composites have recently emerged as a viable technology for rehabilitation and strengthening concrete structures. The strengthening and rehabilitation of existing concrete structures has traditionally been accomplished using new and conventional materials and construction techniques, including externally bonded fiber-reinforced polymer (FRP) systems, steel plates, reinforced concrete (RC) overlays, and post-tensioning.

The primary reasons for considering FRCM/SRG as a suitable strengthening material system are from the inorganic matrix that shows properties of:

a) Inherent heat resistance

b) Compatibility with the substrate (that is, allows vapor permeability and application on a wet surface)

c) Long-term durability

FRCM and SRG are systems where all constituents are developed and tested as a unique combination and should not be created by randomly selecting and mixing products available in the marketplace.

AC434 establishes guidelines for the manufacturers for necessary tests and calculations required to receive a product research report from ICC-ES. Once received, the evaluated system can be accepted by code officials under Section 104.11.1 of the International Building Code (IBC 2018). Section 104.11.1 allows research reports to be used as a source of information to show building code compliance of alternative materials.

1.2—Scope

This guide covers fabric-reinforced cementitious matrix (FRCM) and steel-reinforced grout (SRG) composite systems used to strengthen or rehabilitate existing concrete structures, providing background information and field applications; composite material properties; axial, flexural, and shear capacities of the FRCM/SRG-strengthened structures; and structural design procedures.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

A_c = net cross-sectional area of compression member, in.^{2} (mm^2)

A_e = area of effectively confined concrete, in.^{2} (mm^2)

A_f = area of mesh reinforcement by unit width, in.^{2}/in. (mm^2/mm)
A_g = gross cross-sectional area of compression member, in.^{2} (mm^2)
A_s = area of longitudinal steel reinforcement, in.^{2} (mm^2)
b = short side dimension of compression member with rectangular cross section, in. (mm)
b_w = web width, in. (mm)
D = diameter of compression member, in. (mm)
d = distance from extreme compression fiber to centroid of tension reinforcement, in. (mm)
d_f = effective depth of the FRCM/SRG shear reinforcement, in. (mm)
E_2 = slope of linear portion of stress-strain model for FRCM/SRG-confined concrete, psi (MPa)
E_c = modulus of elasticity of concrete, psi (MPa)
E_f = tensile modulus of cracked FRCM/SRG specimen, psi (MPa)
E_f^* = tensile modulus of elasticity of uncracked FRCM/SRG specimen, psi (MPa)
f_c = compressive stress in concrete, psi (MPa)
f_c' = specified compressive strength of concrete, psi (MPa)
f_{cc}' = maximum compressive strength of confined concrete, psi (MPa)
f_{fe} = effective tensile stress level in FRCM/SRG attained at failure, psi (MPa)
f_{fs} = tensile stress in FRCM/SRG reinforcement under service load, psi (MPa)
f_{ft} = transition stress corresponding to transition point, psi (MPa)
f_{fu} = ultimate tensile strength of FRCM/SRG, psi (MPa)
f_{fv} = design tensile strength of FRCM/SRG shear reinforcement, psi (MPa)
f_l = maximum confining pressure due to FRCM/SRG jacket, psi (MPa)
f_{ss} = tensile stress in the steel reinforcement under service load, psi (MPa)
f_y = steel tensile yield strength, psi (MPa)
h = long side dimension of compression member with rectangular cross section, in. (mm)
i = grid spacing of fabric, in. (mm)
ℓ_{df} = critical length to develop bond capacity of FRCM/SRG, in. (mm)
M_{cr} = cracking moment of unstrengthened member, in.-lb (N-mm)
M_f = contribution of FRCM/SRG to nominal flexural strength, in.-lb (N-mm)
M_n = nominal flexural strength, in.-lb (N-mm)
M_s = contribution of steel reinforcement to nominal flexural strength, in.-lb (N-mm)
n = number of layers of mesh reinforcement
P_n = nominal axial strength, lb (N)
r = radius of edges of a rectangular cross section confined with FRCM/SRG, in. (mm)
V_c = contribution of concrete to nominal shear strength, lb (N)
V_f = contribution of FRCM/SRG to nominal shear strength, lb (N)
V_n = nominal shear strength, lb (N)
V_s = contribution of steel reinforcement to nominal shear strength, lb (N)
t = equivalent thickness of fabric, in. (mm)
ε_c = compressive strain level in concrete, in./in. (mm/mm)
ε_c' = compressive strain of unconfined concrete corresponding to f_c', in./in. (mm/mm); may be taken as 0.002
ε_{ccu} = ultimate compressive strain of confined concrete corresponding to $0.85f_{cc}'$ in a lightly confined member (member confined to restore its concrete design compressive strength), or ultimate compressive strain of confined concrete corresponding to failure in a heavily confined member
ε_{fd} = design tensile strain of FRCM/SRG, in./in. (mm/mm)
ε_{fe} = effective tensile strain level in FRCM/SRG composite material attained at failure, in./in. (mm/mm)
ε_{ft} = transition strain corresponding to the transition point, in./in. (mm/mm)
ε_{fu} = ultimate tensile strain of FRCM/SRG, in./in. (mm/mm)
ε_{fv} = design tensile strain of FRCM/SRG shear reinforcement, in./in. (mm/mm)
ε_{sy} = steel tensile yield strain, in./in. (mm/mm)
ε_t = net tensile strain in extreme tension steel reinforcement at nominal strength, in./in. (mm/mm)
ε_t' = transition strain in the stress-strain curve of FRCM/SRG-confined concrete, in./in. (mm/mm)
ϕ_m = strength reduction factor for flexure
ϕ_v = strength reduction factor for shear
κ_a = efficiency factor for FRCM/SRG reinforcement in the determination of f_{cc}' (based on the geometry of cross section)
κ_b = efficiency factor for FRCM/SRG reinforcement in the determination of ε_{ccu} (based on the geometry of cross section)
ρ_g = ratio of the area of longitudinal steel reinforcement to the cross-sectional area of a compression member (A_s/bh)

2.2—Definitions

Please refer to the latest version of ACI Concrete Terminology for a comprehensive list of definitions. Definitions provided herein complement that resource.

coating—an organic compound applied to fabric after weaving to protect fibers, increasing the long-term durability and stability of the fabric, and allowing for ease of handling and installation.

cure—providing adequate moisture, temperature, and time to allow the concrete/mortar to achieve the desired properties for its intended use.

engineered cementitious composite—easily molded mortar-based composite reinforced with specially selected short random fibers, usually polymer fibers.

fabric—manufactured planar textile structure made of fibers, yarns, or both, that is assembled by various means such as weaving, knitting, tufting, felting, braiding, or bonding of webs to give the structure sufficient strength and other properties required for its intended use.

fabric-reinforced cementitious matrix composite—composite material consisting of a sequence of one or more layers of inorganic matrix reinforced with dry fibers in the form of open single or multiple fabric that, when adhered to concrete structural members, forms an FRCM system.

fabric-reinforced cementitious matrix composite configuration—combination of all applicable parameters that affect the performance of FRCM, such as layers, thicknesses, components, and bonding agents.

greige fabric—unfinished fabric just off the loom or knitting machine.

inorganic matrix—inorganic hydraulic and nonhydraulic binder (mortar) that holds in place the structural reinforcement meshes in FRCM and SRG composite materials. If the mortar is polymer-modified, the maximum content of organic compounds (dry polymers) in the matrix is limited to 5 percent by weight of cement.

mesh—fabric (two-dimensional structure) or textile (two- or three-dimensional structure) with open structure; in an open structure, the yarns or strands do not come together, leaving interstices in the fabric or textile.

passive composite system—composite system that is not pre- or post-tensioned.

sizing—organic compound applied to fibers during the fiber manufacturing process to provide enhanced fiber characteristics such as abrasion resistance.

strand—ordered assemblage of filaments of predetermined quantity based on the number of filaments per strand that have a high ratio of length to diameter, are normally used as a unit, and are bundled together to resist splitting or filamentation.

steel-reinforced grout composite—composite material consisting of a sequence of one or more layers of inorganic matrix reinforced with high-strength steel wires in the form of open single or multiple textiles that, when adhered to concrete structural members, forms an SRG system.

steel-reinforced grout composite configuration—combination of all applicable parameters that affect the performance of SRG, such as layers, thicknesses, components, and bonding agents.

structural reinforcement mesh—open mesh of strands made of or steel wires or dry fibers, such as alkali-resistant glass, aramid, basalt, carbon, and polyparaphenylene benzobisoxazole, consisting of primary-direction and secondary-direction strands connected perpendicularly; polymeric coatings are typically applied to dry fibers to increase long-term durability of the mesh and ease of handling and installation; the typical strand spacing of primary-direction and secondary-direction strands is less than 0.75 in. (19 mm).

CHAPTER 3—BACKGROUND

3.1—FRCM and SRG systems features

Fabric-reinforced cementitious matrix (FRCM) and steel-reinforced grout (SRG) are systems based on inorganic (cementitious, lime-based, or geopolymeric) matrixes. Unlike polymeric binders, inorganic matrixes cannot fully impregnate individual fibers. Therefore, the fiber sheets typically used in fiber-reinforced polymer (FRP) that are installed by manual layup are replaced in FRCM and SRG with a structural reinforcing mesh (fabric). The strands of the FRCM fabric are typically made of fibers that are individually coated but are not bonded together by a polymeric resin. If a polymer is used to either cover or bond the strands, such polymer does not fully penetrate and impregnate the fibers as it would in FRP. For these reasons, the term dry fiber is used to characterize an FRCM fabric. The strands of the SRG are usually made of high-strength, galvanized steel wires that are twisted together to form the cords.

FRP systems for reinforcement of concrete, in both new construction and repair, are addressed in ACI 440R and ACI 440.2R. One example of an FRP material system for concrete reinforcement, in the form of a closely spaced grid, is an epoxy-impregnated carbon fiber grid successfully used in precast and prestressed concrete products (Grimes 2009).

FRCM and SRG systems have several advantageous features (RILEM Technical Committee 201 2006; Peled 2007c; Fallis 2009; Nanni 2012):

a) Compatibility with chemical, physical, and mechanical properties of the concrete substrate
b) Ease of installation as traditional plastering or trowel trades can be used
c) Porous matrix structure that allows air and moisture transport both into and out of the substrate
d) Good performance at elevated temperatures in addition to partial fire resistance
e) Ease of reversibility (that is, the ability to undo the repair without harming the original structure)

3.2—Background

Fabric-reinforced cementitious matrix (FRCM) and steel-reinforced grout (SRG) composite systems evolved from the conventional ferrocement where the metallic reinforcement is replaced by fabrics of dry fibers in case of FRCM (Fig. 3.2a) or high-strength metal strands in the case of SRG (Naaman 2012). Recent advances in textile engineering have added significant knowledge to this area where reinforcement options have been extended to two-dimensional fabrics and three-dimensional textiles made from carbon, alkali-resistant (AR) glass, polyparaphenylene benzobisoxazole (PBO), aramid, basalt, steel, vegetal (Mercedes et al.

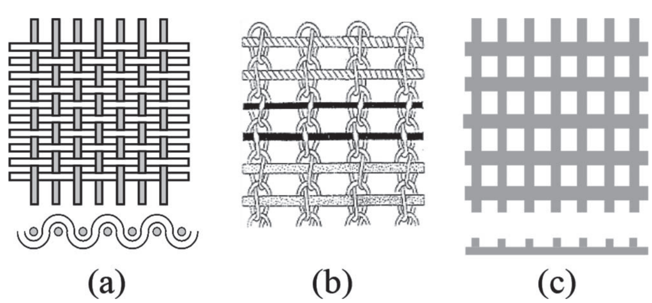

Fig. 3.2a—Different fabric assembly: (a) woven; (b) knitted; and (c) bonded.