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

ACI 549.6R-20

Guide to Design and Construction of Externally Bonded Fabric-Reinforced Cementitious Matrix (FRCM) and Steel-Reinforced Grout (SRG) Systems for Repair and Strengthening Masonry Structures

Reported by ACI Committee 549

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This guide addresses the use of externally bonded (EB) fabric-reinforced cementitious matrix (FRCM) and steel-reinforced grout (SRG) systems for repair and strengthening of masonry structures. FRCM and SRG are composite materials composed of a reinforcement in the form of open fabric bonded on the masonry surface through an inorganic matrix. In particular, the structural reinforcement for FRCM consists of an open grid fabric of continuous fibers made of carbon, alkali-resistant (AR) glass, polyparaphenylene benzobisoxazole (PBO), aramid, or basalt fibers, while SRG systems use steel cords of twisted wires arranged to form a unidirectional fabric. The matrixes are typically based on combinations of portland cement, silica fume, and fly ash as the binder (cement-based), or on natural hydraulic lime (lime-based), or even on geopolymer (geopolymer-based). FRCM and SRG systems represent an alternative to traditional strengthening techniques such as steel tie

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rods, section enlargement, or even fiber-reinforced polymer (FRP) systems. FRCM and SRG systems can be used for various structural purposes—for example, they are used to: 1) increase the load-bearing capacity of structural members; 2) improve the seismic capacity of buildings; 3) counteract specific incipient or already developed damage; 4) limit opening of cracks; and 5) strengthen local weaknesses. Based on experimental research, analytical work, and field applications, this guide provides the recommendations for the design and structural evaluation of FRCM and SRG systems according to both American and European existing regulations and guidelines.

Keywords: composites; confinement; earthquake-resistant; fabric-reinforced cementitious matrix; lap splices; mortar matrix; steel-reinforced grout; structural analysis; structural design.

CONTENTS

CHAPTER 1—INTRODUCTION

1.1—Introduction

Fabric-reinforced cementitious matrix (FRCM) and steel-reinforced grout (SRG) composites have recently emerged as a viable technology for repairing and strengthening masonry structures, as they offer important advantages in terms of tensile strength, weight, and thickness (Triantafillou and Papanicolaou 2005; Barton et al. 2005; Prota et al. 2006; Papanicolaou et al. 2007a; Borri et al. 2009a; Nanni 2012; De Luca and Tumialan 2014; de Felice et al. 2014). The structural performance of FRCM/SRG, when externally bonded (EB) to masonry, relies on the capacity of the reinforcement to bear the tensile stress, while the compressive stress is carried by the masonry structural element. FRCM/SRG systems prove to be competitive for repair, retrofit, and rehabilitation of existing masonry structures when compared to conventional techniques, such as steel tie rods, section enlargement, and reinforced concrete overlays. When compared to fiber-reinforced polymer (FRP) systems, the substitution of the polymeric matrix with an inorganic one overcomes some of the limitations of FRP in terms of compatibility with the masonry substrate, resistance at high temperature, vapor permeability, application on wet surfaces, and removability (possibility of being removed without significant damage in the original substrate). The advantages of FRCM/SRG composites, especially when lime-based mortars are used as matrixes, make them suitable for the rehabilitation of historic structures and architectural heritage (Valluzzi et al. 2014b).

In FRCM/SRG composites, the matrix has both roles to cover and protect the reinforcement that is embedded inside, and to ensure the stress transfer between the masonry substrate and the reinforcement. The matrix is generally made of fine-grained mortar with a combination of portland cement, silica fume, fly ash, ground-granulated blast furnace slag, and natural pozzolan as the binder (cement-based), or natural hydraulic lime (lime-based), or even of geopolymers (geopolymer-based). Organic components could be also added in the matrix to improve the bond and the workability; however, they may induce a decrease in vapor permeability and fire resistance.

The fabric consists of an open grid of yarns made of carbon, alkali-resistant (AR) glass, basalt, aramid or polyparaphenylene benzobisoxazole (PBO)-continuous fibers. Fabrics are usually arranged in two directions by means of weaving, knitting tufting, or braiding. The spacing of the yarns needs to allow the inorganic matrix to penetrate the fabric. When the reinforcement consists of steel cords of twisted wires arranged to form a unidirectional fabric, the technology is known as SRG (Casadei et al. 2005; Barton et al. 2005; Huang et al. 2005; Borri et al. 2011; De Santis and de Felice 2015a).

Based on the outcomes of the scientific research performed in the past 15 years, the structural members strengthened with FRCM and with SRG composites have analogous behavior. Therefore, the same approach can be used for the design of EB reinforcements with FRCM and SRG systems. On the other hand, some differences exist concerning durability and performance under elevated temperatures; the research on these issues is ongoing.

This guide is the outcome of the work carried out by the ACI 549-L Liaison Committee between ACI Committee 549, "Thin Reinforced Cementitious Products and Ferrocement," and RILEM Committee TC 250-CSM (de Felice et al. 2018a), "Composites for Sustainable Strengthening of Masonry." The joint committee provides guidance for the design of FRCM and SRG systems for repair and strengthening of masonry structures, according to both American and European approaches. The sections dealing with scientific background (Chapter 3); field application examples (Chapter 4); general design considerations (Chapter 6); and reinforcement details and drawing specification (Chapter 11) are common to the two approaches (American and European). To the contrary, a two-column format is used in the other chapters dealing with material characteristics and systems qualification (Chapter 5), and with the design rules for out-of-plane strengthening of walls (Chapter 7), for the in-plane strengthening of walls (Chapter 8), for the confinement of columns (Chapter 9), and for the strengthening of vaults (Chapter 10), and with design examples (Chapter 12). The left column, identified by the ACI logo, is written according to the ASTM standards, the International Code Council-Evaluation Services (ICC-ES) Acceptance Criteria AC434, and ACI 549.4R. The right column, identified by the RILEM logo, is written according to the European Committee for Standardizaton (CEN) EN standards, RILEM TC 232-TDT (Brameshuber 2016), and RILEM TC 250-CSM (de Felice et al. 2018a) recommendations. Despite a number of names and acronyms (including TRM and FRM) used in the scientific literature when referring to externally bonded (EB) mortar-based reinforcements, as clarified in the historical development section of this guide (3.2), only FRCM and SRG are used in this guide.

1.2—Scope

Note that this guide is based on the most recent knowledge and interactions with other technical organizations, such as the working group of the Italian National Research Council (CNR), which was established for the development of guidelines for both the qualification of FRCM/SRG composites and the design of FRCM/SRG-strengthened structures. However, the scientific research on the structural behavior of FRCM/SRG-reinforced masonry structures and on design methods is still under development. Based on current knowledge, conservative values are proposed for the safety coefficients included in the design algorithms provided in this guide. The design algorithms may be subject to future update or revision, and less conservative values, or differentiated values for specific materials or applications, may be assigned to tuning coefficients, strength reduction factors, and partial coefficients based on validation with wider databases of experimental data.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

ACI		RILEM	
A_e =	area of the effectively confined masonry, in.^{2} (mm^2)	A_e =	area of the effectively confined masonry, mm^2 (in.^{2})
A_f =	area of the fabric effective in shear, in.^{2} (mm^2)	A_f =	area of the fabric effective in shear, mm^2 (in.^{2})
A_m =	cross-sectional area of the column, in.^{2} (mm^2)	A_m =	cross-sectional area of the column, mm^2 (in.^{2})
A_s =	area of the steel reinforcement, in^2 (mm^2)	A_s =	area of the steel reinforcement, mm^2 (in.^{2})

b =	width of the crowning beam cross section, in. (mm)	b =	width of the crowning beam cross section, mm (in.)
b_c =	short side dimension of compression member with rectangular cross section, in. (mm)	b_c =	short side dimension of compression member with rectangular cross section, mm (in.)
c =	cohesion of masonry, psi (MPa)	c =	cohesion of masonry, MPa (psi)
c_u =	neutral axis depth from the compressive edge of the cross section, in. (mm)	c_u =	neutral axis depth from the compressive edge of the cross section, mm (in.)
c_u' =	neutral axis depth determined under the preliminary assumption that both the masonry and the FRCM/SRG attain their ultimate strain, in. (mm)	c_u' =	neutral axis depth determined under the preliminary assumption that both the masonry and the FRCM/SRG attain their ultimate strain, mm (in.)
D =	diameter of the confined column, in. (mm)	D =	diameter of the confined column, mm (in.)
E_{2c} =	slope of linear portion of stress-strain model for FRCM-confined masonry, psi (MPa)		
E_f =	stiffness of cracked FRCM/SRG specimen, psi (MPa)	E_f =	design value of the elastic modulus of FRCM/SRG, MPa (psi)
		E_1 =	stiffness of uncracked FRCM/SRG specimen, MPa (psi)
		E_2 =	stiffness of cracked FRCM/SRG specimen, MPa (psi)
E_f^* =	stiffness of uncracked FRCM/SRG specimen, psi (MPa)		
E_m =	Young's modulus of masonry, psi (MPa)	E_m =	Young's modulus of masonry, MPa (psi)
		E_{mat} =	modulus of elasticity of mortar from compression test (Eurocode EN 998-2 and EN 13412), MPa (psi)
E_s =	Young's modulus of steel reinforcement, psi (MPa)	E_s =	Young's modulus of steel reinforcement, MPa (psi)
		E_t =	tensile modulus of elasticity of fabric, MPa (psi)

F_f' =	resultant loads for the FRCM/SRG in tension determined under the preliminary assumption that both the masonry and the FRCM/SRG attain their ultimate strain, lb (N)	F_f' =	resultant loads for the FRCM/SRG in tension determined under the preliminary assumption that both the masonry and the FRCM/SRG attain their ultimate strain, N (lb)
F_m' =	resultant loads for the masonry in compression determined under the preliminary assumption that both the masonry and the FRCM/SRG attain their ultimate strain, lb (N)	F_m' =	resultant loads for the masonry in compression determined under the preliminary assumption that both the masonry and the FRCM/SRG attain their ultimate strain, N (lb)
F_s' =	resultant loads for the internal reinforcement determined under the preliminary assumption that both the masonry and the FRCM/SRG attain their ultimate strain, lb (N)	F_s' =	resultant loads for the internal reinforcement determined under the preliminary assumption that both the masonry and the FRCM/SRG attain their ultimate strain, N (lb)
F_{strip} =	maximum tensile load in the FRCM/SRG strip, lb (N)	F_{strip} =	maximum tensile load in the FRCM/SRG strip, N (lb)
		$f_{c,mat}$ =	characteristic compressive strength of the mortar matrix (Eurocode EN 998-2 and EN 12190), MPa (psi)
f_{ccm} =	maximum compressive strength of confined masonry, psi (MPa)	f_{ccm} =	maximum compressive strength of confined masonry, MPa (psi)
		f_{fbk} =	characteristic value of maximum axial stress in the textile attained in the bond test, MPa (psi)
f_{fe} =	effective tensile stress level in the FRCM/SRG reinforcement, psi (MPa)	f_{fe} =	effective tensile stress level in the FRCM/SRG reinforcement, MPa (psi)
f_{fu} =	ultimate tensile strength of FRCM/SRG, psi (MPa)	f_{fu} =	ultimate tensile strength of FRCM/SRG, MPa (psi)
f_l =	maximum confining pressure due to FRCM jacket, psi (MPa)	f_l =	maximum confining pressure due to FRCM jacket, MPa (psi)
$f_{l,eff}$ =	effective confining pressure due to FRCM/SRG jacket, psi (MPa)	$f_{l,eff}$ =	effective confining pressure due to FRCM/SRG jacket, MPa (psi)
f_{mc} =	compressive strength of mortar from compression test (ASTM C109/C109M), psi (MPa)		

f_{mu} =	compressive strength of masonry, psi (MPa)	f_{mu} =	compressive strength of masonry, MPa (psi)
		f_t =	tensile strength of fabric, MPa (psi)
		$f_{t,max}$ =	maximum stress of fabric in direct tensile test, MPa (psi)
		f_{td} =	design value of the tensile strength of masonry with respect to diagonal tension failure mode, MPa (psi)
		f_{tk} =	characteristic value of the tensile strength of the fabric, MPa (psi)
		f_{vd} =	shear strength of unreinforced masonry (URM) calculated in accordance with Eurocode 6 (EN 1996:1995-02), MPa (psi)
f_{yd} =	design yielding strength of steel reinforcement, psi (MPa)	f_{yd} =	design yielding strength of steel reinforcement, MPa (psi)
H =	height of the masonry wall, in. (mm)	H =	height of the masonry wall, mm (in.)
H_c =	effective height of the column, in. (mm)	H_c =	effective height of the column, mm (in.)
h =	height of the crowning beam cross section, in. (mm)	h =	height of the crowning beam cross section, mm (in.)
h_c =	long side dimension of compression member with rectangular cross section, in. (mm)	h_c =	long side dimension of compression member with rectangular cross section, mm (in.)
I =	moment of inertia of the crowning beam strengthened with FRCM/SRG, in.^{4} (mm^4)	I =	moment of inertia of the crowning beam strengthened with FRCM/SRG, mm^4 (in.^{4})
		i =	grid spacing of the fabric, mm (in.)
		k =	effectiveness factor, depending on the properties of the matrix
		k' =	factor depending on ρ_{mat}, $f_{c,mat}$, and f_{mu}
k_a =	shape factor in the determination of $f_{l,eff}$ (based on the geometry of cross section)	k_a =	shape factor in the determination of $f_{l,eff}$ (based on the geometry of cross section)
k_b =	efficiency factor for FRCM/SRG reinforcement in the determination of ε_{ccm} (based on the geometry of cross section)		

		k_{bc} =	coefficient that accounts for the boundary conditions of the wall
k_n =	fractile coefficient that depends on the number of tested specimens, defined in Annex D of Eurocode 0 (EN 1990:2002-02)		
k_v =	vertical efficiency factor for FRCM/SRG reinforcement in the determination of $f_{l,eff}$ (based on the geometry of cross section)	k_v =	vertical efficiency factor for FRCM/SRG reinforcement in the determination of $f_{l,eff}$ (based on the geometry of cross section)
L =	width of the masonry wall or vault, in. (mm)	L =	width of the masonry wall or vault, mm (in.)
		L_c =	length of the part of the wall in compression, mm (in.)
L_{df} =	development length over which the bond capacity of FRCM/SRG is developed, in. (mm)	L_{df} =	development length over which the bond capacity of FRCM/SRG is developed, mm (in.)
L_{eff} =	effective bond length of the FRCM/SRG system, in. (mm)	L_{eff} =	effective bond length of the FRCM/SRG system, mm (in.)
M_{Ed} =	existing bending moment, in.-lb (N-mm)	M_{Ed} =	existing bending moment, N-mm (in.-lb)
M_n =	nominal flexural strength, in.-lb (N-mm)	M_n =	nominal flexural strength, N-mm (in.-lb)
		M_n^{URM} =	nominal flexural strength of the wall without FRCM/SRG reinforcement, N-mm (in.-lb)
		M_{Rd} =	design flexural strength, N-mm (in.-lb)
		M_{Rd}^{URM} =	design value of the in-plane flexural strength of the unreinforced wall, N-mm (in.-lb)
N_{Ed} =	existing axial load, lb (N)	N_{Ed} =	existing axial load, N (lb)
N_{Edj} =	axial load at the section j of the arch, lb (N)	N_{Edj} =	axial load at the section j of the arch, N (lb)
N_n =	tensile strength of the crowning beam, lb (N)	N_n =	tensile strength of the crowning beam, N (lb)
		N_{Rd} =	design tensile strength of the crowning beam, N (lb)

		$N_{Rd,c}$ =	design axial strength of the column strengthened with FRCM/SRG, N (lb)
n =	number of wall sides strengthened with FRCM/SRG	n =	number of wall sides strengthened with FRCM/SRG
n_f =	number of plies of fabric in the FRCM/SRG reinforcement	n_f =	number of plies of fabric in the FRCM/SRG reinforcement
P_D =	dead load applied on the column, lb (N)		
P_L =	service load applied on the column, lb (N)		
P_i =	weight of the part of the vault placed between two hinges, including the arch self-weight, the backfill load, and that of the superstructure pertaining to the part itself, lb (N)	P_i =	weight of the part of the vault placed between two hinges, including the arch self-weight, the backfill load, and that of the superstructure pertaining to the part itself, N (lb)
R^2 =	correlation factor	R^2 =	correlation factor
r =	radius of gyration of the cross section of the column about the weak axis, in. (mm)		
r_c =	radius of edges of a rectangular cross section confined with FRCM, in. (mm)	r_c =	radius of edges of a rectangular cross section confined with FRCM, mm (in.)
s =	distance between two FRCM/SRG layers, in. (mm)	s =	distance between two FRCM/SRG layers, mm (in.)
s_f =	spacing between strips, in. (mm)	s_f =	spacing between strips, mm (in.)
s_{fH} =	spacing between horizontal FRCM/SRG strips, in. (mm)	s_{fH} =	spacing between horizontal FRCM/SRG strips, mm (in.)
s_{fV} =	spacing between vertical FRCM/SRG strips, in. (mm)	s_{fV} =	spacing between vertical FRCM/SRG strips, mm (in.)
t =	thickness of the masonry wall or vault, in. (mm)	t =	thickness of the masonry wall or vault, mm (in.)
t_f =	design thickness of the fabric in the direction of the load, in. (mm)	t_f =	design thickness of the fabric in the direction of the load, mm (in.)
t_f' =	design thickness of each ply of fabric in the load direction, in. (mm)	t_f' =	design thickness of each ply of fabric in the load, mm (in.)
t_{f*} =	equivalent thickness of the FRCM/SRG strips assumed to be uniformly distributed along the length L of the wall, in. (mm)	t_{f*} =	equivalent thickness of the FRCM/SRG strips assumed to be uniformly distributed along the length L of the wall, mm (in.)

t_{fH} =	equivalent thickness of the FRCM/SRG reinforcement in the horizontal direction, in. (mm)	t_{fH} =	equivalent thickness of the FRCM/SRG reinforcement in the horizontal direction, mm (in.)
t_{fV} =	equivalent thickness of the FRCM/SRG reinforcement in the vertical direction, in. (mm)	t_{fV} =	equivalent thickness of the FRCM/SRG reinforcement in the vertical direction, mm (in.)
t_{mat} =	total thickness of the matrix, in. (mm)	t_{mat} =	total thickness of the matrix, mm (in.)
V_{bjs1} =	bed-joint sliding strength of the URM wall at the initial uncracked stage determined in accordance with ASCE 41, lb (N)		
V_{bjs2} =	bed-joint sliding strength of the URM wall at the final cracked stage determined in accordance with ASCE 41, lb (N)		
V_{dt} =	diagonal tension strength of the URM wall determined in accordance with ASCE 41, lb (N)		
V_{Ed} =	existing shear stress, lb (N)	V_{Ed} =	existing shear stress, N (lb)
V_{Edi} =	external shear demand in the joint i corresponding to the given load multiplier, lb (N)	V_{Edi} =	external shear demand in the joint i corresponding to the given load multiplier, N (lb)
V_f =	contribution of FRCM/SRG to nominal shear strength, lb (N)	V_f =	contribution of FRCM/SRG to design shear strength, N (lb)
V_n^{URM} =	nominal lateral strength of URM wall determined in accordance with ASCE 41, lb (N)		
V_r =	rocking strength of the URM wall determined in accordance with ASCE 41, lb (N)		
		V_{Rd} =	design lateral strength of the wall strengthened with FRCM/SRG, N (lb)
V_{Rdi} =	shear capacity in correspondence of masonry cross sections strengthened with composite material for the given design load multiplier, lb (N);	V_{Rdi} =	shear capacity in correspondence of masonry cross sections strengthened with composite material for the given design load multiplier, N (lb);

$V^R{}_n$ =	nominal lateral strength related to the shear-controlled failure modes of the FRCM/SRG-strengthened wall		
		$V_{Rd}{}^{OP}$ =	design shear strength under out-of-plane loads of the wall strengthened with FRCM/SRG, N (lb)
		V_{Rdt} =	design lateral strength of the URM wall corresponding to diagonal tension, N (lb)
		$V_{Rd}{}^{URM}$ =	design lateral strength of URM wall, N (lb)
		V_{Rjs} =	design lateral strength of the URM wall corresponding to joint sliding evaluated in accordance with Eurocode 6 (EN 1996:1995-02), N (lb)
		$V^R{}_{Rtc}$ =	design lateral strength of the reinforced wall against toe-crushing, N (lb)
		V_{Rtc} =	design lateral strength of the URM wall corresponding to toe crushing, N (lb)
$V^R{}_{tc}$ =	nominal lateral strength of the reinforced wall related to flexure-controlled mechanisms, lb (N)		
V_{tc} =	toe-crushing strength of the URM wall determined in accordance with ASCE 41, lb (N)		
W_{MRj} =	maximum resisting work, in.-lb (N-mm)	W_{MRj} =	maximum resisting work, N-mm (in.-lb)
w_f =	total width of the FRCM/SRG strips bonded to the wall along its width L, in. (mm)	w_f =	total width of the FRCM/SRG strips bonded to the wall along its width L, mm (in.)
w_{f1} =	width of the single strip of FRCM/SRG, in. (mm)	w_{f1} =	width of the single strip of FRCM/SRG, mm (in.)
w_{fH} =	width of the horizontal strips of the FRCM/SRG reinforcement, in. (mm)	w_{fH} =	width of the horizontal strips of the FRCM/SRG reinforcement, mm (in.)
w_{fV} =	width of the vertical strips of the FRCM/SRG reinforcement, in. (mm)	w_{fV} =	width of the vertical strips of the FRCM/SRG reinforcement, mm (in.)

x_{ass} =	position of the center of rotation in the arch collapse mechanism, in. (mm)	x_{ass} =	position of the center of rotation in the arch collapse mechanism, mm (in.)
x_i =	position of the hinge, in. (mm)	x_i =	position of the hinge, mm (in.)
y_s =	distance of the steel reinforcement from the compressed edge of the cross section of the wall, in. (mm)	y_s =	distance of the steel reinforcement from the compressed edge of the cross section of the wall, mm (in.)
z =	distance of the hinge from the end of the FRCM/SRG reinforcement, in. (mm)	z =	distance of the hinge from the end of the FRCM/SRG reinforcement, mm (in.)
		α_1 =	coefficient calibrated by comparison between experimental results and average theoretical data, applied to ε_{fb} in the evaluation of ε_{fd}
		α_2 =	coefficient calibrated by comparison between experimental results and average theoretical data, applied to ε_{tk} in the evaluation of ε_{fd}
α_V =	ratio between V_{Edi} and V_{Rdi}	α_V =	ratio between V_{Edi} and V_{Rdi}
β =	reduction factor applied to the neutral axis depth for the stress block diagram	β =	reduction factor applied to the neutral axis depth for the stress block diagram
		β_s =	slenderness factor
γ =	reduction factor applied to the compressive strength of masonry for the stress block diagram	γ =	reduction factor applied to the compressive strength of masonry for the stress block diagram
		γ_k =	safety factor
		γ_M =	partial safety factor on the design axial strain of the FRCM/SRG composite material
		γ_m =	compressive strength of masonry safety factor calculated in accordance with Eurocode 6 (EN 1996:1995-02)
		γ_s =	surface mass density of the fabric, g/m^2 (lb/in.^{2})
ΔF_{Exp} =	experimental increase in the ultimate load of the vault, lb (N)	ΔF_{Exp} =	experimental increase in the ultimate load of the vault, N (lb)
ΔF_{th} =	theoretical increase in the ultimate load of the vault, lb (N)	ΔF_{th} =	theoretical increase in the ultimate load of the vault, N (lb)

		Δ_f =	standard deviation of the axial stress in the textile provided by the shear bond tests performed in accordance with RILEM TC 250-CSM Recommendation (de Felice et al. 2018a)
		Δ_t =	standard deviation of the tensile strength of the fabric provided by the tensile tests on bare fabrics
ΔM^{Exp} =	experimental increase in flexural strength, in.-lb (N-mm)	ΔM^{Exp} =	experimental increase in flexural strength, N-mm (in.-lb)
ΔM^{th} =	theoretical increase in flexural strength, in.-lb (N-mm)	ΔM^{th} =	theoretical increase in flexural strength, N-mm (in.-lb)
ΔN_{exp} =	experimental axial strength increase, lb (N)	ΔN_{exp} =	experimental axial strength increase, N (lb)
ΔN_{th} =	design value of the theoretical axial strength increase, lb (N)	ΔN_{th} =	design value of the theoretical axial strength increase, N (lb)
ΔV^{exp} =	experimental shear strength contribution of FRCM/SRG, lb (N)	ΔV^{exp} =	experimental shear strength contribution of FRCM/SRG, lb (N)
ΔV^{th} =	theoretical shear strength contribution of FRCM/SRG, lb (N)	ΔV^{th} =	theoretical shear strength contribution of FRCM/SRG, lb (N)
$\Delta\varepsilon$ =	standard deviation of the tensile strain of the FRCM/SRG system		
$\Delta\theta_j$ =	relative rotation between two parts of the arch at the hinge *j*, rad	$\Delta\theta_j$ =	relative rotation between two parts of the arch at the hinge *j*, rad
ε_{ccm} =	axial compressive strain corresponding to the compressive strength of the confined masonry column, in./in. (mm/mm)	ε_{ccm} =	axial compressive strain corresponding to the compressive strength of the confined masonry column, mm/mm (in./in.)
		ε_{fb} =	tensile strain corresponding to the characteristic value of the maximum axial stress in the textile attained in the bond test, mm/mm (in./in.)
ε_{fd} =	design tensile strain of FRCM/SRG, in./in. (mm/mm)	ε_{fd} =	design tensile strain of FRCM/SRG, mm/mm (in./in.)
ε_{fe} =	effective tensile strain level in the FRCM/SRG composite material, in./in. (mm/mm)	ε_{fe} =	effective tensile strain level in the FRCM/SRG composite material, mm/mm (in./in.)

ε_{fu} =	ultimate tensile strain of FRCM/SRG, in./in. (mm/mm)	ε_{fu} =	ultimate tensile strain of FRCM/SRG, mm/mm (in./in.)
$\varepsilon_{f@0.90ffu}$ =	strain corresponding to the 90 percent of the ultimate tensile strength of FRCM/SRG in tensile test, mm/mm (in./in.)		
$\varepsilon_{f@0.60ffu}$ =	strain corresponding to the 60 percent of the ultimate tensile strength of FRCM/SRG in tensile test, mm/mm (in./in.)		
ε_{lim} =	limit strain introduced to prevent excessive damage in the structural member reinforced with FRCM/SRG, in./in. (mm/mm)		
ε_{mu} =	ultimate compressive strain of masonry, in./in. (mm/mm)	ε_u =	ultimate compressive strain of masonry, mm/mm (in./in.)
ε_s =	tensile strain attained by the internal steel reinforcement, in./in. (mm/mm)	ε_s =	tensile strain attained by the internal steel reinforcement, mm/mm (in./in.)
ε_s' =	tensile strain attained by the internal steel reinforcement determined under the preliminary assumption that both the masonry and the FRCM/SRG attain their ultimate strain, in./in. (mm/mm)	ε_s' =	tensile strain attained by the internal steel reinforcement determined under the preliminary assumption that both the masonry and the FRCM/SRG attain their ultimate strain, mm/mm (in./in.)
ε_{syd} =	design yielding strain of steel reinforcement, in./in. (mm/mm)	ε_{syd} =	design yielding strain of steel reinforcement, mm/mm (in./in.)
		ε_t =	ultimate strain of fabric, mm/mm (in./in.)
		ε_{tk} =	ultimate tensile strain corresponding to the characteristic value of the tensile strength of the fabric, mm/mm (in./in.)
		$\varepsilon_{t,max}$ =	strain corresponding to the maximum stress of fabric in direct tensile test, mm/mm (in./in.)
		$\varepsilon_{t@0.1ft,max}$ =	strain corresponding to the 10% of the maximum stress of fabric in direct tensile test, mm/mm (in./in.)