American Concrete Institute®
Advancing concrete knowledge

Strengthening of Masonry Structures

ACI Spring 2011 Convention
April 3 - 7, Tampa, FL

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ACI Web Sessions

The audio for this web session will begin momentarily and will play in its entirety along with the slides.

However, if you wish to skip to the next speaker, use the scroll bar at left to locate the speaker's first slide (indicated by the icon in the bottom right corner of slides 10 and 46). Click on the thumbnail for the slide to begin the audio for that portion of the presentation.

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ACI Web Sessions

ACI is bringing you this Web Session in keeping with its motto of "Advancing Concrete Knowledge." The ideas expressed, however, are those of the speakers and do not necessarily reflect the views of ACI or its committees.

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ACI Web Sessions

ACI Web Sessions are recorded at ACI conventions and other concrete industry events. At regular intervals, a new set of presentations can be viewed on ACI's website free of charge.

After one week, the presentations will be temporarily archived on the ACI website or made part of ACI's Online CEU Program, depending on their content.

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ACI Online CEU Program

ACI offers an easy-to-use Online CEU Program for anyone who needs to earn Continuing Education credits.

Once registered, you can download and study reference material. After passing a 10-question exam on the material, you will receive a certificate of completion that you can present to local licensing agencies.

Visit **www.concrete.org/education/edu_online_CEU.htm** for more information.

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ACI Conventions

ACI conventions provide a forum for networking, learning the latest in concrete technology and practices, renewing old friendships, and making new ones. At each of ACI's two annual conventions, technical and educational committees meet to develop the standards, reports, and other documents necessary to keep abreast of the ever-changing world of concrete technology.

With over 1,300 delegates attending each convention, there is ample opportunity to meet and talk individually with some of the most prominent persons in the field of concrete technology. For more information about ACI conventions, visit www.aciconvention.org.

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Fall 2011 Seminars

These seminars, cosponsored by ACI and the Portland Cement Association (PCA), will cover all the major changes in the new edition of the **318-11 Building Code**.

DATE	LOCATION	DATE	LOCATION
September 13	Chicago, IL	November 3	Charlotte, NC
September 27	Philadelphia, PA	November 8	Boston, MA
September 29	Houston, TX	November 10	Detroit, MI
October 4	Seattle, WA	November 15	Des Moines, IA
October 6	Los Angeles, CA	November 17	Portland, OR
October 11	New York, NY	November 29	Denver, CO
October 13	Minneapolis, MN	December 1	Phoenix, AZ
October 20	Cincinnati, OH	December 6	Atlanta, GA
October 25	New Brunswick, NJ	December 8	Washington, DC
October 27	St. Louis, MO	December 13	Dallas, TX
November 1	Orlando, FL	December 15	San Francisco, CA

For more information, visit ACI seminars.

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ACI Web Sessions

This ACI Web Session includes two speakers presenting at the ACI spring convention held in Tampa, FL April 3 – 7, 2011.

Additional presentations will be made available in future ACI Web Sessions.

Please enjoy the presentations.

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Advancing concrete knowledge

Strengthening of Masonry Structures

ACI Spring 2011 Convention
April 3 - 7, Tampa, FL

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Mahmut Ekenel, ACI member, is a Staff Engineer at the ICC-Evaluation Service, Los Angeles, CA. He received his B.S. from Turkey, M.S. from Southern Illinois University and Ph.D. from Missouri University of Science & Technology. His research interests include fiber-reinforced polymer strengthening, fiber-reinforced concrete and anchorage to concrete. He is a member of ACI Committees 440 - Reinforced Polymer Reinforcement and 544 - Fiber-Reinforced Concrete.

ACI WEB SESSIONS

RECENT REVISIONS TO ACCEPTANCE CRITERIA FOR CONCRETE AND MASONRY STRENGTHENING USING EXTERNALLY BONDED FRP SYSTEMS (AC125)

Presenter:

Mahmut Ekenel, Ph.D., P.E., ICC-Evaluation Service

Co-authors:

Silvia Rocca, Ph.D., Structural Group

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Brian Gerber, P.E., S.E., ICC-Evaluation Service

Tarek Alkhrdaji, Ph.D., P.E., Structural Group

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Model Building Code (IBC)

- In the U.S.A, where the power to regulate construction is vested in local authorities, a system of model building codes is used. The *International Building Code®* (IBC) is a model building code.
- The purpose of the model code (IBC) is to establish the minimum requirements to safeguard the public health and safety through structural strength.

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Model Building Code (IBC)

The *International Building Code* (IBC) is the predominant model building code in the U.S.

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Model Building Code (IBC)

The *International Building Code* (IBC) has been adopted in all 50 states, DC, Puerto Rico and the U.S. Virgin Islands.

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Structural Design Under the IBC

The 2009 IBC addresses use of structural concrete in Chapter 19. The primary reference document in Chapter 19 is ACI 318-08.

The 2009 IBC addresses use of masonry in Chapter 21. The primary reference document in Chapter 21 is TMS 402/ACI 530/ASCE 5.

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Alternative Materials Under the IBC

104.11 Alternative materials, design and methods of construction and equipment; 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*. An alternative material, design or method of construction shall be *approved* where the *building official* finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, *fire resistance*, durability and safety.

104.11.1 Research reports: Supporting data, where necessary to assist in the approval of materials or assemblies not specifically provided for in this code, shall consist of valid research reports from *approved* sources.

- IBC Section 104.11 allows alternative materials
- IBC Section 104.11.1 allows research reports as a source of information on alternative materials

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Alternative Materials Under the IBC

- Neither ACI 318 nor TMS 402/ACI 530/ASCE 5, as referenced by the IBC, addresses externally bonded FRP applications.
- Since FRP composites are not within the IBC, FRP composites are considered alternative materials.
- To address this shortcoming, an acceptance criteria (AC125) was established for concrete and masonry strengthening using externally bonded fiber-reinforced polymer composite systems in 1997.

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Acceptance Criteria, AC125

AC125 was published to provide the requirements to qualify use of FRP composites for compliance with the model building code (IBC).

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Alternative Materials Under the IBC

The outcome of an acceptance criteria is an evaluation (research) report which shows building code compliance of the alternative material.

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Acceptance Criteria, AC125

AC125 addresses model building code (IBC) objectives:

- Strength
- Durability
- Fire Safety
- Environmental sensitivities

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Acceptance Criteria, AC125

Some AC125 sections:

- Section 4.3: Product sampling
- Sections 5.1-5.7: Structural tests
- Section 5.8: Physical and mechanical properties tests
- Sections 5.9-5.17: Durability tests
- Section 6.0: Quality control
- Section 7.3: Design criteria

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Acceptance Criteria, AC125

In addition to providing design guidelines, AC125 requires full-scale structural testing and analysis of the test results to prove that the specified design methodologies and minimum performance requirements are verified.

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Acceptance Criteria, AC125

AC125 also requires environmental and aging tests to prove that the long term retention of relevant FRP properties is 85 to 90 percent, depending on the type of exposure.

No additional environmental reduction design factors are required if the long term retention exceeds these limits.

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ACI 440

In 2002, **ACI Committee 440** published its first guide for the design and construction FRP composites externally bonded to concrete (**ACI 440**).

ACI 440 provided the first comprehensive design guide that provided procedures and limitations as well as service and long term performance requirements.

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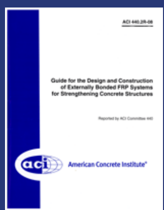
ACI 440



- Currently, there is no reference to **ACI 440** guide in the International Building Code (IBC).
- This is partly because the document is presented in a non-mandatory format unsuitable for code enforcement.

ACI WEB SESSIONS

AC125 vs. ACI 440

- First AC125 that was published in 1997 provided needed guidance to manufacturers and engineers on performance requirements and limitations of externally bonded FRP composite strengthening systems.
- However, the state of the art of FRP design and performance has changed significantly over the past 13 years.

ACI WEB SESSIONS

AC125 vs. ACI 440

- In 2008, ACI 440 published revisions to the ACI 440.2R that included significant changes to design requirements for FRP systems externally bonded to concrete structures.
- In 2010, ACI 440 also published ACI 440.7R-10 design guides for FRP systems externally bonded to unreinforced masonry structures.

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AC125 vs. ACI 440

- Aligning AC125 acceptance criteria with ACI 440 is of great importance to the industry to ensure that the design requirements are reflected in the material evaluation and testing.

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AC125 vs. ACI 440

The main changes to AC125 made in 2010 can be summarized as follows:

- The inclusion of additional strength reduction factors
- Adding creep rupture and fatigue stress limits
- Adding FRP design strain limit to prevent possible FRP debonding failure
- Adding mild steel stress limit at service condition
- Updating procedure for shear strength enhancement of RC beams.
- Adding detailed procedures for axial load capacity enhancement of RC columns
- Adding FRP design strain limit to prevent potential debonding of FRP flexural reinforcement in masonry walls

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AC125 vs. ACI 440

Additional Strength Reduction Factors (Ψ_f) for FRP Contribution:

- The reliability analysis indicated that introducing additional strength reduction factor (Ψf) will produce reliability indices comparable with the current industry standard for repair and strengthening applications. These factors have been included in ACI 440.2R-08.
- These factors have also been adopted by AC125 in the latest revision (2010):

ψ_f = FRP strength reduction factor
= 0.85 for flexure (calibrated based on design material properties)
= 0.85 for shear (based on reliability analysis) for three-sided FRP U-wrap or two-sided strengthening schemes
= 0.95 for shear fully wrapped sections

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AC125 vs. ACI 440

Creep Rupture and Fatigue Stress Limit of FRP Reinforcement:

- Previous AC125 required physical properties such as creep to be determined by ASTM D 2990 and reported for design.
- ACI 440.2R:

TABLE 1—CREEP RUPTURE STRESS LIMITS IN FRP REINFORCEMENT

PARAMETER	Fiber Type		
Stress Type	GFRP	AFRP	CFRP
Creep Rupture	$0.20f_{fu}$	$0.30f_{fu}$	$0.55f_{fu}$

- Revised AC125 requires creep stresses for design to be the lesser of the analysis of tests of ASTM D 2990 or the maximum values given above in Table 1.

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AC125 vs. ACI 440

Flexural Strength Enhancement for Reinforced Concrete (RC) Members

- In the previous AC125, the design strain of FRP was limited to 75 percent of the ultimate design strain, independent of the type, thickness, or stiffness of the FRP reinforcement:

$$f_{ft} = E_f \varepsilon_f \le 0.75 f_{fu}$$

- The previous AC125 also did not consider the effects of material stiffness and the use of multiple plies on the effective (achievable) design stress of FRP and the possible FRP debonding failure mode.

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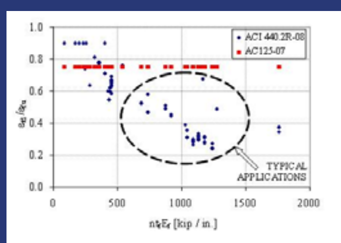
AC125 vs. ACI 440



Effect of Axial Stiffness (Multiple Plies) on FRP Strain at Failure

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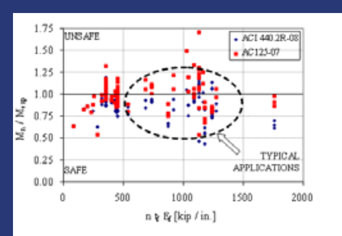
AC125 vs. ACI 440



Ratio of Predicted Flexural Nominal Capacities to Experimental Results

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AC125 vs. ACI 440

Flexural Strength Enhancement for Reinforced Concrete (RC) Members:

AC125 was modified to predict FRP design strain using effective strain in the FRP (ϵ_{fd}) as:

$$\varepsilon_{fd} = 0.083\sqrt{\frac{f_c'}{nE_f t_f}} \le 0.9\varepsilon_{fu}$$

$$\varepsilon_{fd} = 0.41\sqrt{\frac{f_c'}{nE_f t_f}} \le 0.9\varepsilon_{fu}$$

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AC125 vs. ACI 440

Mild Steel Stress Limit at Service Condition

- ACI 440.2R required that yielding of steel at service must be avoided as it may lead to severe serviceability problems:
  - can reduce the stiffness of the member at service
  - can result in excessive and permanent deformations
- Therefore, ACI 440.2R limits the steel stress under service conditions to 80 percent of the steel yield strength.
- AC125 criteria was modified to include a limit of the stress in the steel reinforcement at service of $0.80f_y$.

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AC125 vs. ACI 440

Shear Strength Enhancement

In AC125, the shear strength provided by the FRP reinforcement is computed independently of the effect of critical parameters such as: strength of the concrete substrate, number of FRP plies, and FRP stiffness. Additionally, these equations consider the full depth of the section, which is not practical for beams with existing slabs.

$$V_f = 2.25 n t_f f_f D \sin^2 \theta$$

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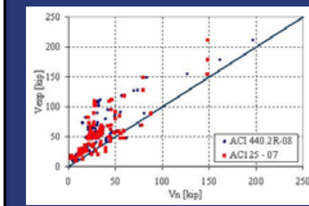
AC125 vs. ACI 440



Predicted shear nominal capacities to experimental results

Shear Strength Enhancement

To address these inconsistencies, AC125 adopted the approach of 440.2R to calculate the FRP contribution to the shear strength in rectangular sections, even though the two approaches produce comparable nominal capacities.

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AC125 vs. ACI 440

Shear Strength Enhancement

The FRP contribution to the shear strength in rectangular sections is now determined as follows:

$$V_f = \frac{A_{fv} f_{fe} (\sin\alpha + \cos\alpha) d_{fv}}{s_f}$$

$\varepsilon_{fe} = 0.004 \leq 0.75 \varepsilon_{fu}$ for completely wrapped members

$\varepsilon_{fe} = \kappa_v \varepsilon_{fu} \leq 0.004$ for 2-sides or 3-sides (U-wrapped) members

$$\kappa_v = \frac{k_1 k_2 L_e}{468 \varepsilon_{fu}} \leq 0.75$$

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AC125 vs. ACI 440

Axial Load Capacity Enhancement

- Axial load capacity enhancement provisions in the previous AC125 were given without distinction between RC and masonry columns, or circular and rectangular
- The previous AC125 criteria did not provide any limit for the hoop or transverse strain in the FRP at failure
- The previous AC125 approach implied a linear variation of the increment in concrete compressive strength (f'_{cc}/f'_c) to the FRP volumetric ratio (ρ_f).

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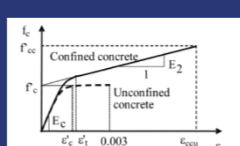
AC125 vs. ACI 440

The revised AC125 for axial strength enhancement is now only applicable to RC columns. The adopted stress-strain behavior for FRP-confined concrete was taken from ACI 440.2R, and was based on the model by Lam and Teng (2003) which provides reasonable predictions for real size columns.



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AC125 vs. ACI 440

Flexural Strength Enhancement for Un-reinforced Masonry Walls:

- The provisions for flexural strengthening in the previous AC125 were given with no distinction between RC beams and masonry walls, except for the minimum specified bond strength for masonry of $2.5(f'_m)^{0.5}$.
- To be consistent with ACI 440.7 and to prevent potential debonding of the FRP reinforcement, the effective strain in the FRP is limited to 45% of the FRP ultimate strain.
- The force provided by the FRP reinforcement:

$$p_{fm} = n t_f f_{fe} \leq 1500\ lb/in$$

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Summary

- As of now, FRP design and construction requirements are only specified in guidelines, and are not part of any building code. AC125 is the only document used to verify compliance of the application of externally bonded FRP systems with building codes
- Therefore, keeping AC125 provisions up-to-date is of great importance to the repair industry so as to eliminate confusion and ensure consistency in evaluation and design requirements.

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Summary

- These revisions that were implemented to AC125 in 2010, justified by the evaluation of test data conducted by different Task Groups within ACI Committee 440, enable AC125 and ACI 440 to be more closely aligned, providing uniform design and evaluation requirements of externally bonded FRP composites throughout the U.S.A.

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THANK YOU

ICC EVALUATION SERVICE
Ensuring that building products meet code requirements.

STRUCTURAL GROUP

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Marco di Ludovico is Assistant Professor of Structural Engineering at the University of Naples Federico II, Italy. He received his Ph.D. in Seismic Risk at the University of Naples Federico II, Italy. His research interests include nonlinear behavior of reinforced concrete structures, seismic strengthening of reinforced concrete structures using advanced materials, strengthening of bridge members using composites and analysis of reinforced concrete members subjected to axial load and biaxial bending.

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INTRODUCTION

Tuff buildings (even of historical and artistic relevance) are a significant part of the existing buildings in the Mediterranean area.

A large number of existing masonry structures shows damages due to a wide range of events (i.e. environmental deterioration, inadequate construction techniques and materials, design for gravity loads only).

In plane mechanisms

DAMAGES
In plane Shear Diagonal Cracks on the masonry walls

L'Aquila Earthquake April 6, 2009

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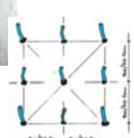
In plane mechanisms



DAMAGES
In plane Shear Diagonal Cracks on the masonry walls

INTERVENTIONS
To increase the mechanical characteristics of masonry panels:
1. Iniections

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INTRODUCTION

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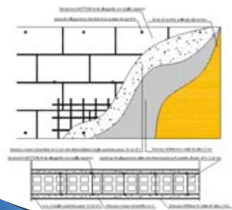
In plane mechanisms



DAMAGES
In plane Shear Diagonal Cracks on the masonry walls

INTERVENTIONS
To increase the mechanical characteristics of masonry panels:
1. Iniections

2. Steel or FRP Reinforced plaster

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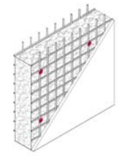
INTRODUCTION

Several available strengthening techniques to reduce the seismic vulnerability of masonry buildings may be too invasive especially when the historical value of architectural heritage has to be preserved. In such cases properties like reversibility,compatibility and sustainability could become critical for the selection of the most appropriate strengthening technique

Use of FRP system but…

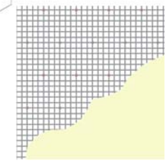


No epoxy resins for bonding fibers

FRP grid bonded with mortar:
a) Cement based mortar
b) pre-mixed high ductility hydraulic lime and pozzolan based mortar

Basalt FRP grid and Glass FRP grid

Is it effective??



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EXPERIMENTAL PROGRAM: Specimens' geometry

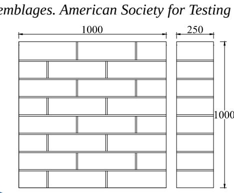
Diagonal Compression Tests on 9 Masonry Panels

Tuff Bricks Dimensions: 390x250x115 mm

Mortar Thickness: 10-15 mm

Panels Dimensions: 1000x1000x250 mm

ASTM E 519-81. 1981. *"Standard test Method for Diagonal Tension (Shear) in Masonry Assemblages. American Society for Testing Materials"*



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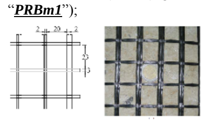
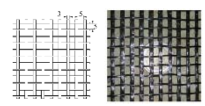
EXPERIMENTAL PROGRAM: Test Matrix

The 9 masonry panels have been tested in three different configurations:

a) 2 unreinforced panels used as control specimens (series **"P"**);
b) 3 panels reinforced on both sides by means of one ply of balanced primed alkali-resistant fiberglass (**GFRP**) grid, bonded with a lime and pozzolan based mortar (series "***PRGm1***");
c) 3 panels reinforced on both sides by means of one ply of **GFRP** grid bonded with a cement based mortar (series ***"PRGm2*** ").
d) 1 panel reinforced on both sides by means of one ply of unbalanced primed alkali-resistant basalt (**BFRP**) grid, bonded with a lime and pozzolan based mortar (series "***PRBm1***");



GFRP grid – PRGm1/PRGm2
(mesh 25 mm x 25 mm, unit weight of 225 g/m^2)



BFRP grid – PRBm1
(mesh 6 mm x 6 mm, unit weight of 250 g/m^2)

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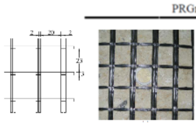
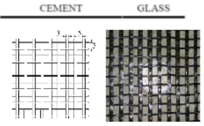
EXPERIMENTAL PROGRAM: Test Matrix

The 9 masonry panels have been tested in three different configurations:

SERIES	SPEC. LABEL	MORTAR TYPE	FRP GRID TYPE
P	P1	-	-
	P2	-	-
PRGm1	PRGm1_1	LIME AND POZZOLAN	GLASS
	PRGm1_2	LIME AND POZZOLAN	GLASS
	PRGm1_3	LIME AND POZZOLAN	GLASS
PRBm1	PRBm1_1	LIME AND POZZOLAN	BASALT
PRGm2	PRGm2_1	CEMENT	GLASS
	PRGm2_2	CEMENT	GLASS
	PRGm2_3	CEMENT	GLASS



GFRP grid – PRGm1/PRGm2



BFRP grid – PRBm1

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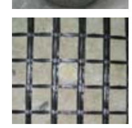
EXPERIMENTAL PROGRAM: Strengthening Procedure

Substrate pre-wetting until saturation to avoid the mortar drying out due to the water adsorption of tuff (resulting in poor bond)
Installation of a first layer of mortar (average thickness 5 mm)

Installation of a first layer of FRP grid on both panels'sides



Installation of a second layer of mortar (average thickness 5 mm)

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EXPERIMENTAL PROGRAM: Materials Properties

TUFF UNITS :

Flexural Strength 3.45 MPa

Compressive Strength 4.00 MPa

Bending Tests (6 Tests) 360 × 60 × 90 mm

Compression tests (8 tests) 60 × 60 × 60 mm

SPECIMENS' MORTAR :

Bending Tests 40 × 40 × 160 mm

Compression tests 60 × 60 × 80 mm circa

Binder 310 kg/m²

Sand 1245 kg/m³

Water 195 kg/m³

Flexural Strength 1.30 MPa

Compressive strength 3.72 MPa

UNI EN 772-1: (2002). "Metodi di prova per elementi in muratura – Resistenza a compressione".
UNI EN 998-2 (2004). "Specifiche per malte per opere murarie – Malte da muratura".

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EXPERIMENTAL PROGRAM: Materials Properties

Two types of mortar were used to bond the FRP Reinforcement:

LIME POZZOLAN MORTAR (M1) :

Mixture of hydraulic lime and sand (ratio 1:3) added with short glass fibers (about 10% of total weigth) mixed with latex and water (ratio 1:2)

Flexural Strength 8.05 MPa

Compressive Strength 16.15 MPa

specifically formulated to be very similar in terms of mechanical properties and porosity to mortars used in the existing masonry historical buildings

CEMENT MORTAR (M2) :

Cement based one obtained as a mixture of fine-grained 20 selected aggregates, special admixtures and synthetic polymers in water dispersion

Flexural Strength 9.88 MPa

Compressive Strength 28.25 MPa

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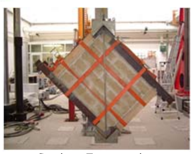
EXPERIMENTAL PROGRAM: Test Setup



Specimen Transportation

4 LVDTs along diagonals 1 LVDT orthogonal

Test - Setup

Load Cell
Spherical hinge

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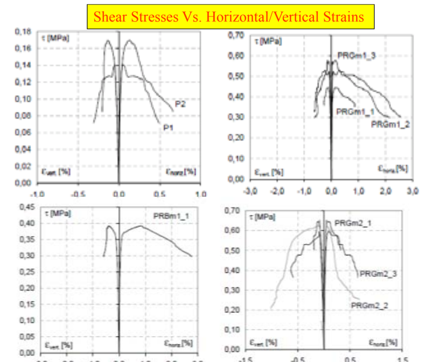
EXPERIMENTAL PROGRAM: Test Results

Shear Stresses Vs. Horizontal/Vertical Strains



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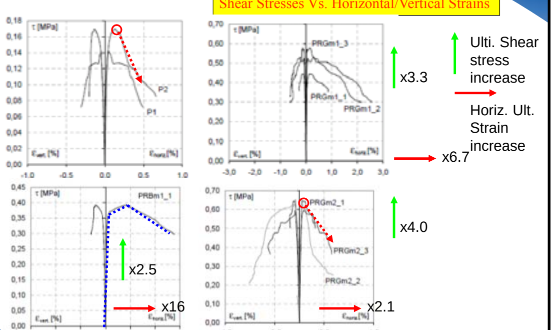
EXPERIMENTAL PROGRAM: Test Results

Shear Stresses Vs. Horizontal/Vertical Strains



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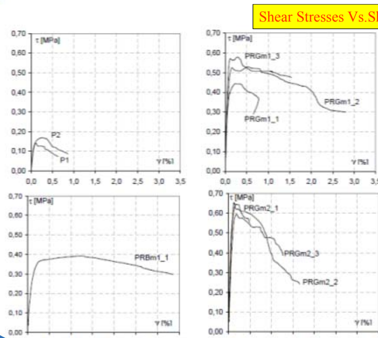
EXPERIMENTAL PROGRAM: Test Results

Shear Stresses Vs.Shear Strains



$\gamma = \varepsilon_v + \varepsilon_h$

Modulus of rigidity, G: the secant modulus between the origin and the stress equal to 30% of the peak stress

Local panel ductility, μ: ratio between the shear strain (γu) at which the shear stress drops at 80% of τ_{max}, and the shear strain corresponding to τ_{max}, γ_{max}

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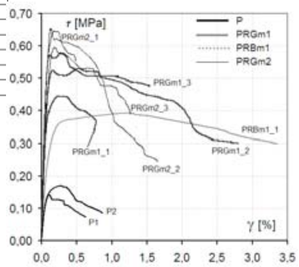
EXPERIMENTAL PROGRAM: Test Results

Spec.	τ_{max}	τ_u	ν	γ_{max}	γ_u	G	μ
	[MPa]	[MPa]		[%]	[%]	[MPa]	
P1	0.14	0,11	0,42	0,10	0,53	258	5,5
P2	0.17	0,14	0,36	0,27	0,46	296	1,7
PRGm1_1	0,44	0,36	0,53	0,23	1,12	654	4,8
PRGm1_2	0,53	0,42	0,47	0,53	1,91	799	3,6
PRGm1_3	0,58	0,46	0,20	0,28	1,64	1010	5,8
PRBm1_1	0.39	0,31	0,44	1,23	2,98	369	2,4
PRGm2_1	0.65	0,52	0,64	0,18	0,50	1204	2,8
PRGm2_2	0.66	0,52	0,42	0,12	0,81	918	6,5
PRGm2_3	0.60	0,48	0,53	0,19	1,00	663	5,3

1MPa = 145.04 psi



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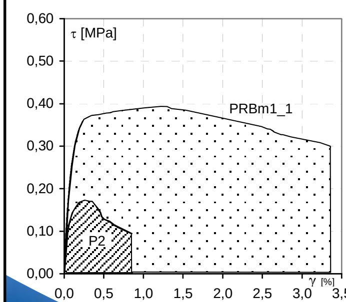
EXPERIMENTAL PROGRAM: Test Results

Energy Dissipation Capacity



Maximum energy dissipation it attained in the case of panels reinforced by using a lime and pozzolan based mortar combined with basalt grid

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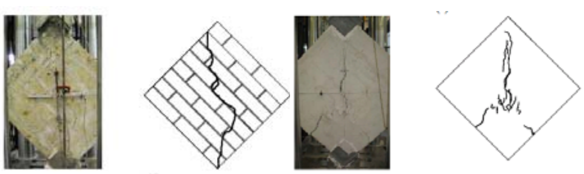
EXPERIMENTAL PROGRAM: Failure Modes

Series P

PRGm1



Strengthened specimens of each series were affected by a different crack pattern and failure mode if compared to that of control panels. On **control specimens** the failure was due to a main **wide pseudo-vertical crack developing along the mortar joints**. On strengthened specimens were characterized, independently from the type of grid adopted as reinforcement, by a more uniform crack pattern: several cracks less wide

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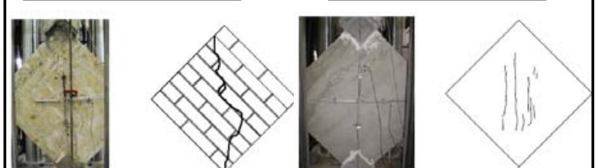
EXPERIMENTAL PROGRAM: Failure Modes

Series P

PRGm2



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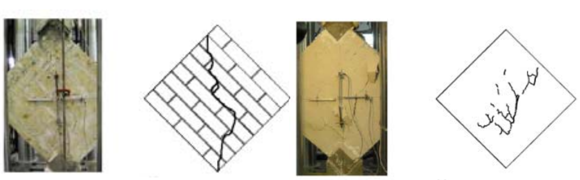
EXPERIMENTAL PROGRAM: Failure Modes

Series P

PRBm1



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CONCLUSION

The result of experimental tests showed that:

1. Significant shear strength increase were achieved by using both GFRP and BFRP grids ranging between about 150%-320%.

2. GFRP grids allowed higher shear stress increase to be achieved, especially if bonded with a cement based mortar .

3. A better post-peak response was attained on specimens strengthened by using BFRP grid bonded with lime and pozzolan mortar .

4. The innovative mortar with mechanical properties and porosity very close to mortars used in the existing masonry historical buildings has resulted effective to bond FRP grids and increase both shear strength and ductility of tuff masonry panels.

5. Strengthened specimens showed a uniform crack pattern characterized by cracks with a small width if compared to those observed on the unreinforced panels. This phenomenon indicates a larger energy dissipation capacity.

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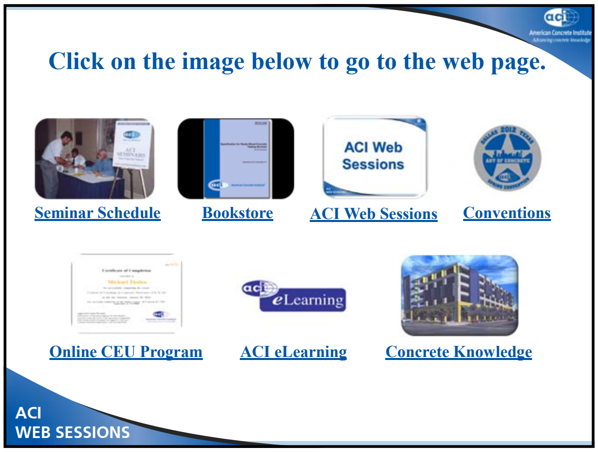
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