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ROMA TRE UNIVERSITY
Department of Engineering
Structures Research Unit

ENEA Casaccia Research Centre
Laboratory of technologies for sustainable
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Shake table tests on a masonry structure

Phase 1: unreinforced specimen

A shake table test will be carried out on a full-scale tuff masonry structure. The specimen is made of a U-shaped masonry structure provided with openings and sustaining a timber roof. Natural accelerograms will be applied in horizontal and vertical directions, with increasing scaling factor up to the severe damage of the specimen. A second shake table session will be performed after retrofitting with Composite Reinforced Mortar.

Tests will be carried out on:

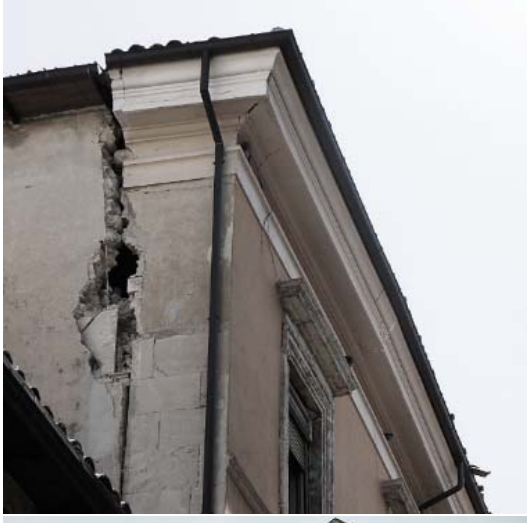
Wednesday 8 November from 9.00am to 5:00pm

The experimental tests will be shared in real time by DySCO Virtual Lab at the following address:
http://connect.portici.enea.it/tavibr

For attending, click on “guest” and write your name, surname and company name.
For information, contact Prof. de Felice at the following address: defelice@uniroma3.it.

Background and motivations of the research project

Unreinforced masonry structures represent a significant proportion of the European building stock and include historic constructions with architectural and cultural value. These buildings date back from some decades to several centuries ago. They have been designed with empirical rules and have undergone changes and modifications over time.
Recent earthquakes have dramatically shown their seismic vulnerability. Under earthquake loads, perimeter walls tend to separate from internal structures and fail by overturning, out-of-plane bending, leaf separation or disaggregation. The failure mode depends upon the morphology of the cross section of the wall, the connections between orthogonal walls, the presence of openings (such as doors or windows), the interaction with other structural members transferring horizontal thrusts (such as roof and vaults).



Despite the importance of minimizing the risks associated with earthquake induced damage on the building stock, and the studies that have been carried out to date to tackle this challenging issue, a deep understanding of the seismic response of existing masonry structures still needs to be gained. Modelling tools, assessment strategies and strengthening solutions should be developed to ensure an adequate protection of the life and health of people, as well as to safeguard the built heritage, in earthquake prone areas.

An experimental investigation on the shake table will be carried out on a full-scale masonry structure, in order to contribute to the existing knowledge on the seismic behaviour of unreinforced masonry buildings. Progressive damage, onset of collapse mechanisms, and modification of dynamic properties will be analysed under increasing intensity of the seismic input.

The research project also aims at investigating the effectiveness of innovative retrofitting solutions with composite materials. For this purpose, a second shake table test session will be performed on the specimen after repair and retrofitting with Composite Reinforced Mortar. Natural accelerograms will be applied and the dynamic response of the specimen will be recorded with the help of innovative 3D motion capture systems. Tests will be carried out at ENEA Casaccia Research Centre (Rome, Italy), equipped with a 4m×4m shake table with six degrees of freedom.

Seismic inputs

Based on previous experience on shaking table tests on full-scale masonry specimens [1,2], a set of four natural records was selected for this study amongst the most severe Italian earthquakes of the last 20 years. Input signals will be applied with increasing scale factor in both horizontal (orthogonal to the front wall) and vertical directions, up to the development of a severe damage state.

Event	Record	PGA (horizontal)	PGA (vertical)
Emilia earthquake, 20/05/2012	Mirandola (MRN)	0.262g	0.303g
Centre Italy earthquake, 24/08/2016	Norcia (NRC)	0.374g	0.215g
Umbria-Marche earthquake, 26/09/1997	Nocera Umbra (NCR)	0.502g	0.406g
L'Aquila earthquake, 06/04/2009	L'Aquila (AQV)	0.657g	0.496g

Masonry structure under investigation

The specimen that will be tested on the shake table is a full-scale masonry structure, made of a 3.30m long façade and two 2.30m long side walls. All the walls are built with tuff blocks and hydraulic lime mortar, and are 25cm thick and 3.60m high. The façade is provided with a window, whereas one of the side walls has a door close to the corner. Timber lintels are placed over the openings. The asymmetric plan layout of the structure will produce torsional effects during earthquake base motion. Finally, a timber roof is placed on top, and it is inclined to transfer a horizontal thrust to the façade. The masonry structure is built on a reinforced concrete foundation, which is necessary to move the specimen in the laboratory hall and fix it to the shake table.

Views of the full-scale tuff masonry structure that will be tested on the shake table during the preparation of the experimental setup

Innovative monitoring with the 3DVision system

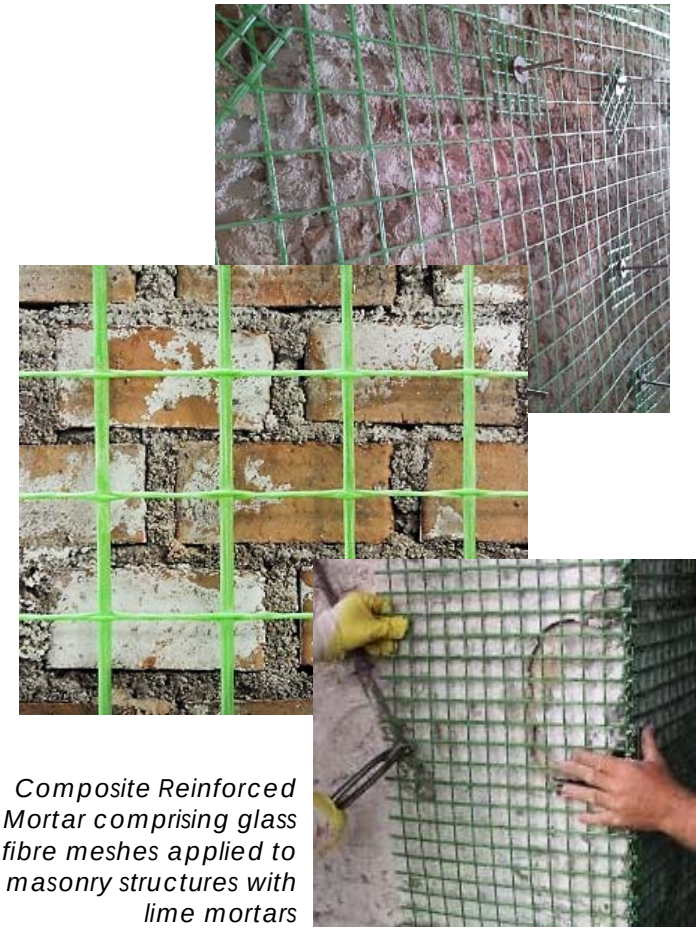
An innovative 3D motion optical system named 3DVision [3] will be used in addition to accelerometers and displacement transducers, to measure displacements during the shake table tests. 3DVision system makes use of wireless passive spherical retro-reflecting markers positioned on several points of the specimen.
The spatial displacements of the markers are recorded by high-resolution near-infrared digital cameras. Data are processed and filtered in the frequency domain. 3DVision will provide the deflections of the walls, will monitor cracking, and will detect the fundamental frequencies and the modal shapes within a MIMO (multi-input/multi-output) Operational Modal Analysis framework.

Piezoelectric accelerometer and retro-reflecting marker for 3DVision Motion Capture System

Future developments

After the shake table test, the specimen will be repaired and retrofitted with a strengthening system comprising high-strength textiles externally bonded with inorganic matrices. Thanks to their high strength-to-weight ratio as well as to the use of mortar matrices, this technology appears particularly suitable for applications to masonry structures in seismic prone areas.

In this study, a bidirectional mesh made of glass fibre bundles coated with epoxy resin, supplied by FIBRENET s.r.l., will be installed to the external surface of the walls with a natural hydraulic lime mortar. A second shake table session will be then carried out to investigate the improvement provided by the reinforcement in terms of maximum intensity of the seismic input attained before damage or collapse occurs, deflection capacity, and dynamic properties. The research project aims at understanding the seismic behaviour of masonry structures reinforced with composites, at showing their potentialities for the protection of the building stock, and at providing experimental evidence for the development of design tools.



Composite Reinforced Mortar comprising glass fibre meshes applied to masonry structures with lime mortars

Scientific coordination

The research project is led by Prof. Gianmarco de Felice of the Department of Engineering of Roma Tre University. The experimental tests are carried out at the ENEA Casaccia Research Centre, under the coordination of Dr. Gerardo De Canio.

Cooperation and financial support

The experimental investigation is carried out within the following partnerships:

- Ministero degli Affari Esteri e della Cooperazione Internazionale (*Italian Ministry for Foreign Affairs*), Direzione generale per la promozione del sistema Paese. ITALY – USA Science and Technology Cooperation Project Nr. PGR00234 "Composites with inorganic matrix for sustainable strengthening of architectural heritage"
- ENEA Casaccia Research Centre, Laboratory of technologies for sustainable Innovation
- Regione Lazio. Progetto COBRA "*Sviluppo e diffusione di metodi, tecnologie e strumenti avanzati per la Conservazione dei Beni culturali, basati sull'applicazione di Radiazioni e di tecnologie Abilitanti*"
- Fibrenet s.r.l. Research Agreement "*Innovative solutions for the strengthening of masonry structures with fibre reinforced composites*"
- Reluis-DPC Executive Project 2018 "*Assessment and Mitigation of Seismic Vulnerability of Existing Masonry Structures*"
- Rilem Technical Committee 250-CSM: Composites for Sustainable Strengthening of Masonry

References to previous shake table tests

[1] AlShawa, O., de Felice, G., Mauro, A., Sorrentino, L. (2012). Out-of-plane seismic behaviour of rocking masonry walls. Earthquake Engineering & Structural Dynamics, 41(5):949-968.

[2] De Santis S., Casadei P., De Canio G., de Felice G., Malena M., Mongelli M., Roselli I. (2016) Seismic performance of masonry walls retrofitted with steel reinforced grout. Earthquake Engineering & Structural Dynamics, 45(2):229-251.

[3] De Canio G., de Felice G., De Santis S., Giocoli A., Mongelli M., Paolacci F., Roselli I. (2016) Passive 3D motion optical data in shaking table tests of a SRG-reinforced masonry wall. Earthquakes and Structures, 10(1):53-71.