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ROMA TRE UNIVERSITY
Department of Engineering
Structures Research Unit

ENEA Casaccia Research Centre Laboratory of technologies for sustainable Innovation
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Shake table test on a masonry structure retrofitted with composite reinforced mortar

A shake table test will be carried out on a full-scale tuff masonry structure retrofitted with an innovative composite reinforced mortar system. The specimen is a U-shaped masonry structure provided with openings and sustaining a timber roof. After a former shake table test session without reinforcement, it has undergone repair and strengthening works in which a glass fabric applied with a natural hydraulic lime mortar to the outer surface of the damaged walls. Natural accelerograms will be applied in horizontal and vertical directions, with increasing scaling factor to collapse. Results will show the dynamic behaviour of masonry structures strengthened with composite reinforced mortars and the enhancement of the seismic performance provided by the retrofitting work.

Tests will be carried out on:

Monday 18 December 2017 from 3.00pm to 5:00pm
Tuesday 19 December 2017 from 10.00am to 2:00pm

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 and on the most appropriate retrofitting technologies, still needs to be gained, in order to ensure an adequate protection of the life and health of people and to safeguard the built heritage in earthquake prone areas.
Externally bonded composite materials appear particularly promising for seismic retrofitting of existing masonry constructions. Thanks to their high strength-to-weight ratio they can provide a significant enhancement of the seismic capacity (by contrasting the onset of collapse mechanisms) with minimum mass increase. When applied to the external surface of the walls, they can also be integrated in the plaster layer during the ordinary maintenance works of the façades, as a compatible, sustainable and cost-efficient solution for the seismic protection of the built heritage.

Following a former shake table test on a full-scale unreinforced masonry specimen, a second investigation will be carried out after repair and retrofitting works. The research project aims at investigating the effectiveness of innovative retrofitting solutions with composite reinforced mortar composited, comprising a glass fibre reinforced polymer mesh applied with natural hydraulic lime mortar. Progressive damage, onset of collapse mechanisms, and modification of dynamic properties will be analysed under increasing intensity of the seismic input and compared to those exhibited by the same specimen before reinforcement took place.

Natural accelerograms will be applied and the dynamic response of the specimen will be recorded with the help of a 3D motion capture system. 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 in shake table tests [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 are the same ones used in the tests on the unreinforced specimen and will be applied with increasing scale factor, in both horizontal (orthogonal to the façade) and vertical directions, to collapse.

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 and damage pattern after the former shake table tests

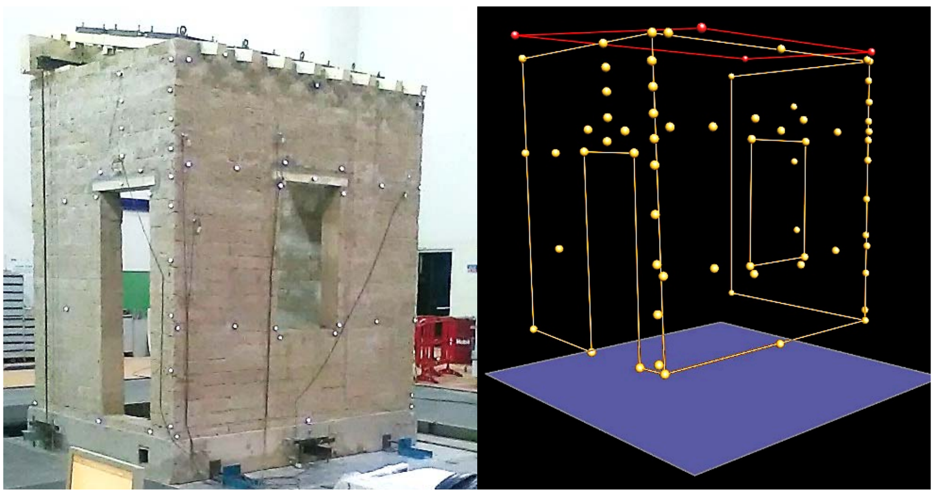
The specimen that will be tested on the shake table is made of a 3.30m long façade and two 2.30m long side walls. The walls are built with tuff blocks and hydraulic lime mortar, and are 25cm thick and 3.60m high. The façade is provided with a window, whereas one of the side walls has a door close to the corner. Timber lintels are placed over the openings. The asymmetric plan layout of the structure produces 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.

In the former shake table session on the unreinforced specimen, during the test with Umbria-Marche record (NCR) with PGA=0.42g, a diagonal crack developed in the lateral wall, over the door, causing the partial detachment of the façade. Smaller cracks also appeared on top of the front wall, near the timber beams of the roof, whereas no damage developed on the other lateral wall.

The crack pattern observed in the tests highlights the important role played by wall connections, openings and horizontal thrusts.

Views of the unreinforced full-scale tuff masonry structure after the first session of tests on the shake table.

Innovative monitoring with the 3DVision system



Position of the markers on the specimen and 3DVision motion capture system for the measurement of spacial displacement in shake table tests.

A 3D motion optical system [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.

Seismic retrofitting with Comoposite Reinforced Mortar

After the shake table test, the specimen was repaired by repointing the cracks with lime-based grout, and retrofitted with a composite reinforced mortar system, comprising a bidirectional glass fibre reinforced polymer (GFRP) mesh, supplied by FIBRENET s.r.l.. The mesh was applied with natural hydraulic lime mortar to the outer surface of the façade and of the lateral wall with the door. GFRP non-crossing connectors (3/m^2) were also installed to improve the substrate-to-reinforcement load transfer capacity. No reinforcement was applied to the other (undamaged) side wall. This technology is non-invasive and appears particularly suitable for applications to masonry structures in seismic prone areas. It has the thickness of the plaster layer, so it can be integrated in post-earthquake retrofitting or in ordinary preventative maintenance works on the façades. The mortar matrix is projected onto the masonry surface, making installation fast and cost-efficient. Finally, since application is carried out only to the outer side of the walls, occupants are not required to evacuate the building.

The shake table session on the retrofitted specimen will 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 in earthquake prone areas, and at providing experimental evidence for the development of design tools.

Installation of the composite reinforced mortar:
1) Repair of cracks
2) Preparation of the substrate
3) Installation of the GFRP mesh
4) Installation of the GFRP connectors (3/m^2)
5) Projection onto the outer masonry surface of the mortar matrix
6) Finishing

Scientific coordination

The research project is led by Prof. Gianmarco de Felice of the Department of Engineering of Roma Tre University. Shake table tests are performed 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
- Fibrenet s.r.l. Research Agreement "*Innovative solutions for the strengthening of masonry structures with fibre reinforced composites*"
- 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*"
- 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.