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Experimental response of historic brick masonry under biaxial loading

R. Capozucca

Struct. Engineering, Struct. Section DICEA, Polytechnic University of Marche, Ancona, Italy

HIGHLIGHTS

- Response under earthquake actions of historic unreinforced masonry (HURM).
- HURM is greatly influenced by the proper values of strength under biaxial in-plane loading.
- Results of an experimental research campaign on wallets, triplets, and walls built with solid historic bricks in 1/3rd scale.
- Experimental tests provide data useful to calibrate failure criteria available for assessing HURM.

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ABSTRACT

Unreinforced masonry (URM) structures in seismic areas are usually considered weak in terms of supporting dynamic action. Sufficient regularity of structural organisms plays an important part in fostering adequate behaviour of masonry building although the response of historic-URM (HURM) is greatly influenced by the strength of brick and mortar materials. The analysis of damaged masonry structures following an earthquake puts emphasis on knowing the proper values of strength under biaxial in-plane loading to estimate the response of HURM. On the other hand, damage to masonry buildings subjected to the last earthquakes in Italy (2016–17) which invested mainly its central regions, highlighted the need to further investigate HURM present in many small Italian towns to define the actual behaviour of masonry walls. This paper describes and discusses the results of an extensive experimental research campaign, developed over several years, on wallets, triplets, and walls built with solid historic bricks in 1/3rd scale. Additional experimental tests reported in this paper provide data useful to calibrate failure criteria available for assessing HURM buildings by numerical modelling using FE codes.

1. Introduction

Existing unreinforced masonry (URM) buildings subjected to seismic force often present very low strength, hence their response is rather inadequate. During the last earthquakes, which occurred in the recent decades in Italy (Umbria-Marche 1997–98, L'Aquila 2009, Marche-Lazio-Umbria 2016–17), a large part of historic masonry buildings was greatly damaged, resulting in a high number of victims. Although historic unreinforced masonry (HURM) walls are usually considered brittle to the actions of earthquake, some old brick masonry buildings resisted the effects of seismic movements proving that HURM buildings can resistant earthquakes if adequately conceived. Shear walls, whether solid, or pierced by window and door openings in each storey, represent the basic structural elements of a masonry structure resisting seismic loads. In general, modern masonry buildings are box-type structural systems, composed of vertical and horizontal structural elements; in such structures, forces induced in buildings subjected to earthquakes are transferred from floors to panels. If HURM buildings are well organised with load-bearing and shear walls linked to the floors, this structural organisation, together with adequate strength masonry materials may allow resisting horizontal seismic loads [1]. It is important to underline that floors play a very important role by preventing the separation and out of plane collapse of walls orthogonal to seismic action, thus avoiding the rotation and consequent collapse of walls due to loss of equilibrium. Notwithstanding the presence of rigid floors, HURM buildings reached sudden collapse (Fig. 1(a)); the collapse of a part of a masonry building or, in even worse cases, of entire buildings, was in particular caused by the low strength of the materials used; materials which did not allow reaching shear mechanism. On the other hand, from observations following earthquakes, it appears that many HURM buildings without rigid floor in plane and built using timber beams, resisted the effects of earthquakes because of horizontal tie-beams and the adequate strength of the materials employed (Fig. 1(b)). Safe behaviour of HURM buildings can be

E-mail address: r.capozucca@univpm.it

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List of symbols

exp, theor	index for experimental value; index for theoretical value
σ_x	compressive stress on masonry parallel to bed mortar joints
σ_y	compressive stress on masonry normal to bed mortar joints
σ_v	pre-compression on masonry normal to bed mortar joints
f_t	diagonal tensile strength of masonry
f_x	compressive strength of masonry parallel to bed mortar joints
f_y	compressive strength of masonry normal to bed mortar joints
ε_x	strain on masonry parallel to bed mortar joints
ε_y	strain on masonry normal to bed mortar joints
f_b	compressive strength of brick
E	Young's modulus
G	shear modulus
ν	Poisson's coefficient
ν_{xy}, ν_{yx}	Poisson's coefficients for orthotropic material
E_x, E_y	Young's moduli of masonry-orthotropic material
F	exp. lateral load in shear tests
F_x	compressive force on masonry parallel bed mortar joints
F_y	compressive force on masonry normal to bed mortar joints
F_u	failure lateral load
d	lateral deflection for wall in the principal plane
τ_u	shear strength of masonry
τ_0	initial bond strength
μ	coefficient of friction
f_{tens}	tensile strength of masonry
f_{comp}	compressive strength of masonry
A	area of section of wall
I	moment of inertia
h	height of wall
t_f, l_w	thickness of flanges of wall; length of web

(a) (b)

Fig. 1. (a) Collapse of historical building-Pescara del Tronto, Italy; (b) shear damages of a building in Visso, Italy, 2016.

linked to the appropriate connection of walls, when the latter can maintain a collaboration between plane structures under seismic movements; this behaviour allows the walls to stand up to biaxial in-plane loading due to compression and shear stresses.

The biaxial response of HURM walls to compression and shear stress plays an important role in the behaviour of load-bearing and/or cross walls subjected to in-plane loading under seismic actions. The mechanical parameters that determine the load-bearing capacity and deformability of masonry walls are: compressive and tensile strength of the masonry; elastic moduli and, finally, the ductility factor of a wall as ratio between collapse displacement and displacement at the end of elastic deformation [1]. Extensive research has been carried out in the past on the failure of masonry under biaxial stress state of compression and shear [2–8] and failure criteria of masonry has been a topic of research for many years considering modern masonry [2,7–9]. Brick masonry is a brittle material; often, conventional failure criteria available for concrete or/and soil is adopted with a slight modification [10] although masonry is a material which exhibits distinct directional properties with influence on bed joint orientation in the response [7,11,12]. Code of practice [13,14] usually specifies masonry strength based on testing prisms loaded in compression with