Construction and Building Materials 122 (2016) 231–241

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

An experimental study on the influence of composite materials used to reinforce masonry ring beams

Romina Sisti [a], Marco Corradi [b,a,*], Antonio Borri [a]

[a] Department of Engineering, University of Perugia, Via Duranti, 93, 06125 Perugia, Italy
[b] Mechanical and Construction Engineering Department, Northumbria University, Wynne-Jones Building, NE1 8ST Newcastle upon Tyne, United Kingdom

HIGHLIGHTS

- We carried out bending tests on 10 full-scale composite-reinforced masonry ring-beams.
- Ring beams were reinforced with different composite materials embedded into an inorganic matrix.
- GFRP grids, glassfibre nets and PBO cords have been used to reinforce the masonry beams.
- Reinforced ring beams presented enhanced behavior and increased mechanical properties.

ARTICLE INFO

Article history:
Received 14 March 2016
Received in revised form 21 June 2016
Accepted 23 June 2016

Keywords:
Masonry
Mechanical testing
Composite materials
Earthquake engineering

ABSTRACT

For historic masonry constructions the out-of-plane wall behavior is critical to seismic performance. Because the main cause of out-of-plane collapses is the wall-to-wall level of connection, the application of a reinforced concrete (RC) ring beam at the eaves level of historic masonry buildings is an effective method to prevent an out-of-plane mechanism of a wall panel. However this effective reinforcing method presents some drawbacks. In order to address this, this paper describes the problems associated with this "traditional" reinforcing method and introduces a new retrofitting technique for historic masonry buildings by realizing a new type of ring beam made of recycled old stones or bricks reinforced at the bed joints with glass-fiber sheets, GFRP (Glass Fiber Reinforced Polymer) grids or/and PBO (polybenzoxazole: poly-p-phenylene benzobisoxazole) cords. An experimental investigation has been carried out on 10 full-scale rubble-stone or brickwork masonry ring beams. The testing included the use of composite materials inserted into the mortar joints during the fabrication phase of the beams and pinned end conditions (four-point bending configuration). Beams were reinforced with different composite layouts.

1. Introduction

The estimation of the strength of a masonry construction is based on the analysis of the modes of failure and several theories have been developed which are able to predict the type, direction and magnitude of loading which will produce the failure in that mode.

Masonry constructions tend to lack connections between walls and between walls and floors. Most traditional typologies of historic construction have roof and floors which span only one way and in case of a seismic event the transfer of the horizontal loads from these horizontal structural elements into the walls is often critical.

In order to achieve unitary behavior of the structure against earthquakes, these constructions must be upgraded so that they avoid local collapse and have integrating structural elements. Because of the wall-to-roof connection is often considered as the principal critical element, several solutions have been proposed in the past. For example, improvement has been achieved by tie rods or ring beams. In old buildings, it is often possible to find wooden/metal ties and connectors inside masonry [1–2]. In the 70 s and 80 s of last century, wood beam floors have been replaced with RC ring beams (Fig. 1) [3–5] or with heavy two-ways RC roofs and floors. Stiff diaphragm-like floors are desirable structurally but require the dismantling of old two-ways spanning wooden floors.

During 1998–2011 a series of experiments were carried out at several laboratories in Italy, France, Greece, Portugal and Slovenia

* Corresponding author at: Mechanical and Construction Engineering Department, Northumbria University, Wynne-Jones Building, NE1 8ST Newcastle upon Tyne, United Kingdom.
E-mail address: marco.corradi@northumbria.ac.uk (M. Corradi).

http://dx.doi.org/10.1016/j.conbuildmat.2016.06.120
0950-0618/

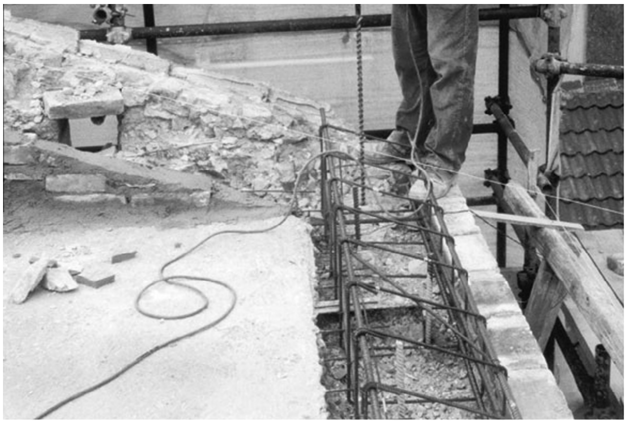

Fig. 1. Example of a RC ring-beam.

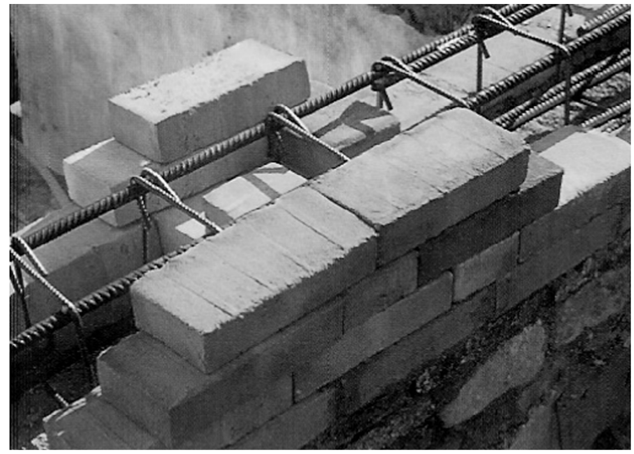

Fig. 3. Example of a brickwork steel-reinforced ring-beam.

to asses a range of different reinforcing methods for historic masonry. A growing awareness amongst researchers and engineers of the importance of the mechanical properties of FRP (*Fiber Reinforced Polymer*) have produced interesting structural solutions for the rehabilitation of existing masonry constructions.

Recent earthquakes have shown the limitations of new and more conventional techniques. For example the installation of RC ring beams has proved to be ineffective or to increase the seismic vulnerability of the construction when inadequately designed, not well connected to the existing masonry, when used on a poor masonry or in combination with heavy RC floors. It has been recognized by now that the greater stiffness of the RC ring beam compared to the stiffness of the masonry, produces a different response in these two materials during earthquakes and causes the load to be unevenly spread. In order to prevent out-of-plane collapse mechanisms, the action of vertical static loads may contribute to stabilize wall panels, but the application of stiff RC ring beam may cause the re-distribution of vertical compressive stresses and some portions of masonry could results unloaded and, during earthquakes, be prone to become unstable (Fig. 2) [6–8].

Nowadays, it's usual to apply steel-profiles or masonry ring beams (Figs. 3 and 4). However, when a building is faced with stone, ring beams are made thinner than the wall so that they are screened and remain invisible on the façade. This kind of reinforcement is impossible when the thickness of the wall is small and it introduces an element which is extraneous to the existing structure.

Recently researchers have focused their interest on the use of composite materials coupled with non-polymeric matrixes [9–14], like lime-based mortars [15–18] with the aim at increasing the durability [19,20]. The aim is to avoid the use of epoxy or other polymeric resins, due to their critical long-term behavior. In this area, the new reinforced masonry ring beam proposed in this paper is based on the aspiration to use existing materials (stones or bricks), with a composite reinforcement embedded into the mortar bed joints. This retrofitting method requires the demolition of a small portion of the walls. These are then reconstructed, using recovered stones and hydraulic mortar reinforced with composite

Fig. 4. Example of a steel-profile ring-beam.

Fig. 2. Examples of an out-of-plane collapse due to poor connection between the RC ring beam and the underlying masonry.