Full scale tests for the assessment of the diaphragm capacity of beam-and-block existing floors

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Abstract Floors are structural components of the Lateral Force Resisting System and can be critical in both new designs and seismic retrofitting. In new constructions, they may require specific seismic design to ensure resistance to in-plane seismic forces. In seismic retrofitting, their role becomes particularly relevant when techniques such as exoskeletons are used. Even if they are not designed to resist horizontal loads, an in-plane arch-tie mechanism can be triggered. Regarding existing floors, in the case of beam and hollow block floors (developed mainly in Mediterranean countries), the failure modes may involve different areas of the floor, such as the clay bricks in the core of the arch, the tied arch support or the bottom chord of the tied arch. Among these failure modes, failure at the arch support is a vulnerable mechanism characterized by complex load distribution and deserves further attention and investigation.

The objective of the research is to investigate the in-plane stiffness and capacity of RC beam and clay hollow block floor systems not designed for in-plane seismic forces by performing quasi-static cyclic tests on a full-scale floor. Evaluating and assessing the effectiveness of an arch-tie mechanism and associated capacity models, validating FE models and setting performance targets allows the selection of floors that require intervention. Avoiding such interventions can lead to a sustainable renovation of the building stock without the need to relocate occupants.

Keywords: Beam and hollow block floors, floor diaphragm seismic capacity, Arch-tie mechanism, Full-scale testing, Sustainable renovation, Seismic retrofitting.

Extended abstract

1 Introduction

In Europe, 40% of existing buildings were constructed before the 1960s, lacking environmental and seismic regulations [1]. Their structural service life is now exhausted, requiring deep retrofitting to meet modern safety and sustainability standards [2]. A major challenge in renovating multi-storey residential buildings is avoiding occupant relocation [3]. For this reason, recent research has proposed retrofit measures carried out from outside buildings by introducing the so-called exoskeletons [4] [5], implemented as either shear walls or shell structures enveloping the façade. Although this technique and other structural retrofit solutions are now well-developed, the issue of the in-plane capacity of existing floors serving as floor diaphragms has rarely been addressed. This design need is particularly important considering that floor diaphragms are necessary components of the lateral force-resisting system both in the as-built and retrofitted conditions.

Floor diaphragms play a crucial role in the response to horizontal loads, as their main functions are to ensure the integrity of the structure, transfer inertial loads, provide load paths for lateral forces and prevent the instability of vertical elements that absorb transfer forces resulting from incompatible deformations of the existing structure and the vertical retrofit system or from irregularities in the distribution of infill [6].

When assessing the vulnerability of existing post-World War II buildings, diaphragms are rarely the weakest link in the LFRS, as other vulnerabilities occur before their capacity is reached. However, when planning retrofit measures, their ability to act as diaphragms remains uncertain, especially when additional stiffening elements increase inertia load demand [4]. Indeed, existing floors, even without concrete overlays or collector beams, can resist horizontal seismic loads by triggering a tied-arch resisting mechanism [7]. However, the introduction of discrete stiffer elements can lead to an increase in the span of the resisting arch, varying from the span of a single bay to the distance between the new laterally resisting structural elements (Fig. 1).

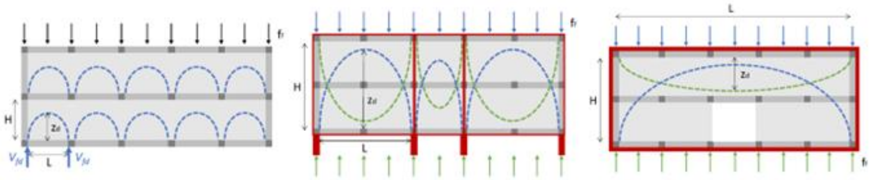

Fig. 1 - Floor load path distribution for the building in as-is situation (a) and retrofitted with shear wall (b) or shell (c) configuration. In (c) the influence of a floor opening is also shown. Taken from Marini, et al. (2022) **[7]**.

While extensive research has been conducted on other floor systems, such as cast-in-place RC floors [6] [8], precast concrete floors [9] [10] [11], and timber diaphragms [12] [13], no experimental investigation has been done on the floor in-plane capacity of beam-and-clay block floors.

A recent study [7] investigated the in-plane load-bearing capacity of beam-and-clay block floors in post-war European RC buildings, which are common in Mediterranean countries. These floors consist of a series of parallel RC beams and rows of hollow clay blocks, sometimes with a 2–5 cm thick RC overlay. Their in-plane load-bearing capacity relies on a tied-arch mechanism, that can fail in three main ways (Fig. 2):

A. *Failure of the arch key section*, in which the bricks are compressed orthogonally to the direction of the hollows;

B. *Failure of the tied-arch supports*, due to combined compression and shear stresses, that may exceed the compression or shear resistance of the bricks or the brick-to-concrete interface;

C. *Failure of the tie*, due to tensile failure of the RC edge beam, loss of adhesion at the brick-to-beam interface, or brick tensile failure.

Their seismic behaviour is often governed by the failure of tied-arch supports (Mechanism B), while the tie failure (Mechanism C) can be mitigated with additional steel ties. Mechanism A is generally not critical unless large openings reduce the arch height-to-span ratio.

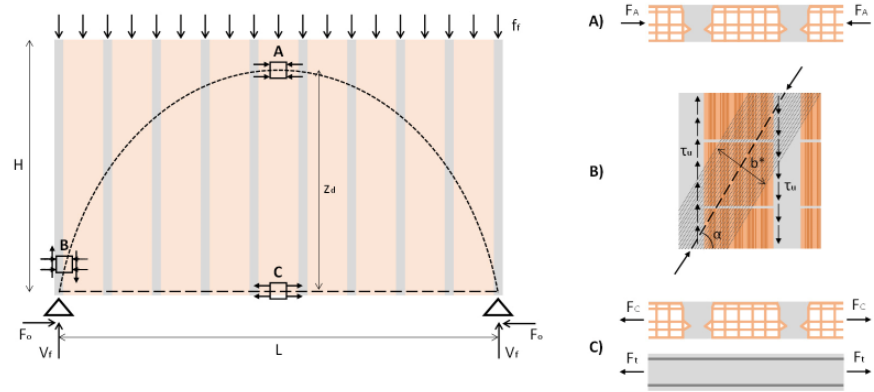

Fig. 2 - Tied-arch mechanism activated within the floor depth and regions of possible failure of the tied-arch resisting system: A) the arch key section, where the brick is compressed

orthogonally to the direction of the hollows (the blocks are considered as an equivalent clay slab with thickness equal to the net thickness of the clay block horizontal webs); B) the tied-arch supports where compression-shear failure may occur; C) the tied-arch bottom chord, with possible overcoming of its tensile strength. Taken from Marini, et al. (2022) **[7]**.

Several experimental tests were carried out to validate the simplified finite element model. Laboratory tests have investigated the shear capacity of single blocks [7] and the load diffusion on a set of 4 blocks under realistic boundary conditions [14]. Additionally, tests were conducted on a 3m long floor segment (12 hollow blocks), both with and without RC overlay, to investigate the mechanism of load diffusion at the tied-arch support, which is the key factor affecting the overall in-plane capacity of the floor system [15]. However, large-scale experimental validation is still required to fully evaluate the capacity models of these floor systems.

2 Foreseen full-scale tests

In order to study the in-plane load-bearing capacity of beam and-clay block floors and to validate the recently proposed analytical and numerical models [7], the ERIES-DICABE project will be carried out in the coming months at the Eucentre facility in Pavia (Italy). This project aims to carry out full-scale tests with beam and clay brick floors. Quasi-static cyclic tests will be carried out to evaluate the local failure mechanisms affecting the capacity of floor diaphragms with realistic geometries and to study their stiffness.
The specimen is full- scale with plan dimensions (12m x 4m). As can be seen in Fig. 3, the specimen is supported by simple vertical reinforced concrete columns sliding over Teflon plates and positioned every 3 metres to create 4 spans of equal extent. An isostatic configuration is provided for the boundary conditions, with a pin on one side of the specimen and a roller on the other. Three 650 kN actuators are foreseen between the specimen and the reaction wall, evenly distributed to create a distributed load.

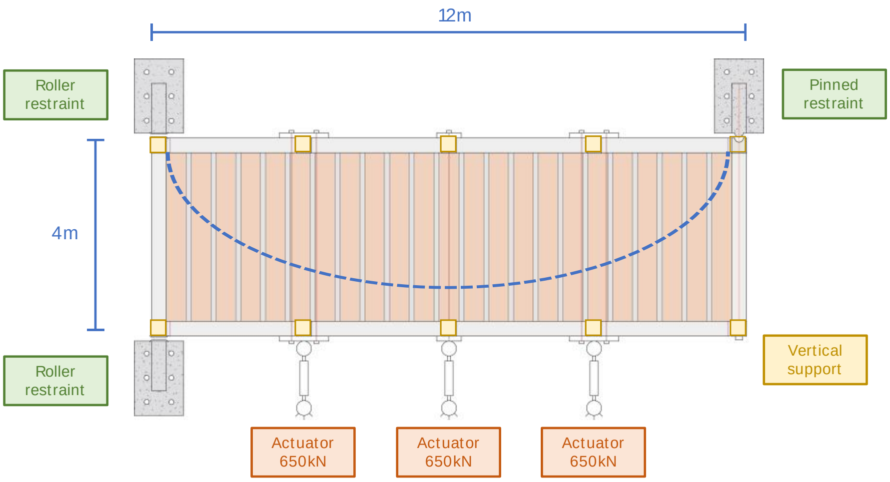

Fig. 3 – ERIES-DICABE test arrangement: 12m x 4m beam and hollow clay block floor system, vertical supports (yellow) every 3 metres, boundary conditions (green) and three 650kN actuators (orange).

The specimen resembles a one-way beam and hollow block floor system without concrete overlay (Fig. 4), particularly critical in existing post-WWII RC buildings.

Fig. 4 - Cross section of the specimen.

As far as the test programme on the floor is concerned, the first step is to apply a uniform load distribution to the sample with all actuators in order to generate an elastic load-displacement curve to evaluate the floor stiffness. The second step is to force the failure mechanism B at the interface between the floor and the curb on the left or right side, whichever occurs first (Fig. 5a). After failure, the RC restraints are moved inward to replace actuators A and C (Fig. 5b) and the cyclic test is continued to investigate the local force transfer mechanisms.

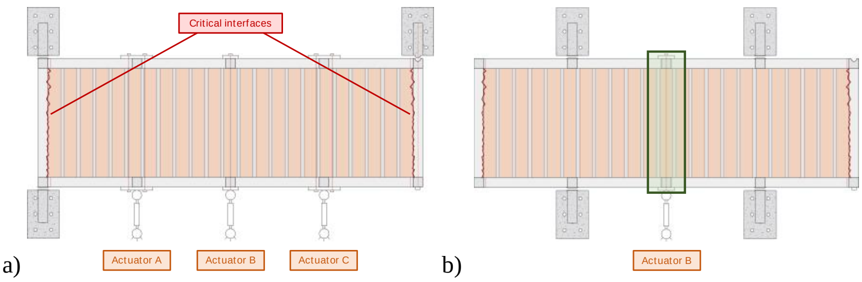

Fig. 5 - (a) Step 1 and 2: evaluation of floor stiffness and of the failure mechanism B at the support interface using all the actuators; (b) Step 3: moving inward of the RC restraints and

further tests on the same sample to evaluate the local transfer mechanism on a beam in the absence of load-distributing elements, using only actuator B.

The experimental tests are expected to confirm the activation of failure mechanism B, which is characterised by shear failure at the arch supports. This result, together with the calibration of the detailed FE modelling, will allow the validation of the proposed analytical framework for the evaluation of the in-plane response of beam and-clay block floors. The latter will serve as a finite element benchmark and it will allow numerical analyses of different floor geometries, boundary conditions and the presence of openings. The study will also define fragility measures for these floor systems. In addition, dynamic identification tests are foreseen. A better understanding of the mechanisms that determine the in-plane resistance of floors can increase the effectiveness of retrofit measures on existing buildings. Finally, the results of this test could serve as the basis for future codes recommendations.

3 Acknowledgements

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