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Shake table tests for the seismic assessment of hollow brick internal partitions

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ABSTRACT

The collapse of hollow brick internal partitions is one of the most widely reported nonstructural damage after an earthquake, especially in the European area. Full-scale experimental tests on standard hollow brick partitions are described in the paper. In particular, bidirectional shaking table tests are performed in order to investigate the seismic performance of hollow brick partitions, subjecting the partition simultaneously to interstorey relative displacements in their own plane and accelerations in the out of plane direction. A steel test frame is properly defined in order to simulate the seismic effects at a generic building storey. A set of five couples of accelerograms are selected matching the target response spectrum provided by the U.S. code for nonstructural components in order to investigate a wide range of seismic input. Three damage states are considered in this study and correlated to an engineering demand parameter, i.e. the interstorey drift ratio, through the use of a damage scheme. The tested specimen exhibits significant damage for 0.3% interstorey drift and extensive damage for drift close to 1%. The correlation between the dynamic characteristics of the test setup, in terms of damping ratio and natural frequency, and the recorded damage is shown.

1. Introduction

Nonstructural components (NSCs) are those systems and components attached to the floors, roof and walls of a building or industrial facility that are not part of the main load-bearing structural system, but may also be subjected to large seismic actions [1]. The investigation of the seismic behaviour of NSC performance is nowadays recognised to be a key topic in the framework of the earthquake risk mitigation. The paper deals with internal partition systems, i.e. a typical architectural NSC.

Performance-based seismic engineering clearly includes the seismic performance of NSC in the assessment of the behaviour of the whole building system: the behaviour of both structural and nonstructural elements define the building seismic performance [2]. NSCs usually exhibit damage even for low-intensity earthquakes causing the evacuation of the whole building. Their seismic performance is critical especially for hospitals or strategic buildings, that should remain operative after an earthquake.

Taghavi and Miranda [3] point out that NSCs give the largest contribution to the total cost of a building; for this reason the NSCs contribution should not be neglected in the evaluation of the economic loss due to an earthquake. Their economic impact is much more severe if losses of inventory and downtime cost are considered: the cost related to nonstructural components failure may easily exceed the replacement cost of the building [4]. Moreover, the failure of nonstructural components may also represent a threat to life safety. A partition or infill overturning may easily cause injuries or casualties.

Few studies were conducted in the past on nonstructural components performance evaluation, particularly referring to suspended ceiling systems [5–7] and plasterboard partitions [8–11]. Very limited studies were conducted in the past on the seismic behaviour of hollow brick internal partitions, even though they are very common in the European area both in residential and industrial buildings [12,13]. Furthermore, recent earthquakes demonstrated that brick partitions usually exhibit extensive damage jeopardizing the functionality of the whole building (Fig. 1). The high vulnerability of the hollow brick partitions may result in significant damages that are not acceptable in hospital buildings; San Salvatore hospital in L'Aquila (Fig. 1b), struck by L'Aquila earthquake in 2009, clearly showed this issue.

In this paper the seismic performance of hollow brick partitions is investigated. Such partitions are built in order to be representative of the "classical" existing partitions, widespread in the European area. The seismic performance evaluation is pursued

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(a) (b)

Fig. 1. Damage recorded in hollow brick partitions after 2009 L'Aquila earthquake in (a) a residential building and (b) in San Salvatore hospital.

via shake table tests with increasing intensity. The shake table tests allow subjecting the partition simultaneously to interstorey relative displacements in their own plane and accelerations in the out of plane direction.

The recorded damage states are correlated to an engineering demand parameter through the use of a damage scheme; some considerations on the hysteretic curve, the natural frequency, the damping ratio and the partition base shear are made through a complete analysis of the recorded quantities.

2. Experimental facilities and test set up, specimens and input

The shake table tests aim to investigate the seismic behaviour of hollow brick partitions. As shown in Fig. 2, the test setup consists of: (a) a shake table simulator; (b) an existing 3D steel test frame, used in a test campaign on plasterboard partitions [5,9], able to transfer the seismic input to the partitions; and (c) the specimen, i.e. hollow brick partitions.

The seismic qualification of hollow brick partitions is carried out by the earthquake simulator system available at the laboratory of the Department of Structures for Engineering and Architecture at the University of Naples Federico II. The system consists of two 3 m × 3 m square shake tables. Each table is characterized by two degrees of freedom in the two horizontal directions. The maximum payload of each shake table is 200 kN with a frequency range of 0–50 Hz, peak acceleration, associated to the maximum payload, equal to 1.0 g, peak velocity equal 1 m/s and total displacement equal to 500 mm (±250 mm). Only one shake table is used in this experimental campaign.

The function of the existing test frame is to dynamically excite the specimen, subjecting the partitions to a wide range of interstorey drifts and accelerations. Indeed, internal partitions are architectural nonstructural components that are displacement-sensitive in their own plane and acceleration-sensitive in their out of plane direction. A steel test frame is therefore designed in order to simulate the seismic behaviour of a generic storey of a structure located in a high seismicity area [8]. In particular, it is characterized by:

- A realistic value of mass, i.e. specific mass ratio equal to 1.0 t/m^2.
- A realistic stiffness: the interstorey displacement d_r is assumed to be equal to 0.005 times the interstorey height, for a "frequent" (i.e. 50 years return period) earthquake typical of high seismicity areas. Indeed, the test frame is designed in order to exhibit a 0.5% interstorey drift for an earthquake characterized by S_{DS} equal to 0.60 g. Such an intensity level is representative of an earthquake with 0.24 g peak ground acceleration, i.e. an intensity level of earthquake with 50 years return period in a high seismicity zone according to the indications included in [15].

The columns of the test frame are 150 × 150 × 15 mm box sections, according to the parametric study included in [8]; each column is 2.9 m high. Steel horizontal beams, consisting of 120 × 120 × 15 mm cross section profiles, are connected to the columns through pin connections. At the top of the structure a reinforced concrete slab is placed; its plan dimensions are 2.15 m × 2.65 m and its thickness is 250 mm. The total mass of the test frame (excluding partitions) is 5.215 t. The test frame is designed according to the Eurocodes 3 and 8 [16–18] by modal response spectrum analysis. It is considered one load combination, the seismic one, with the two orthogonal horizontal components acting simultaneously. The behaviour factor is assumed to be equal to 1, since the test frame is designed to remain in the elastic range even if subjected to the most intense input acceleration time history. Further details on the definition of the test frame are indicated in [14].

The specimen consists of three partitions and as many steel frames surrounding them placed on an "I" shape RC slab (Fig. 3): the steel frames and the slab connect the specimen with the existing test frame and the shake table. The partitions are constituted by hollow bricks jointed and plastered with mortar; the vertical joints among the bricks are staggered.

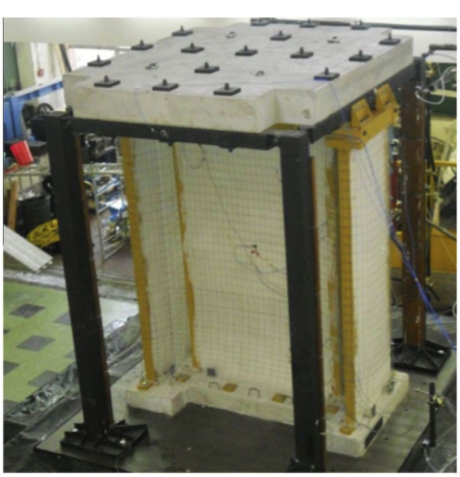

Fig. 2. Global view of the test setup.

2.1. Test setup and specimen: definition of proper boundary conditions

The design and the geometry of the setup are defined to simulate the realistic conditions to which a standard hollow brick partition is typically subjected.

The specimen is doubly symmetric and presents a 150 cm wide partition and two smaller 80 cm wide partitions in the orthogonal