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SEISMIC PERFORMANCE OF HOLLOW BRICK INTERNAL PARTITIONS

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Abstract. *Bidirectional shaking table tests are performed on standard hollow brick partitions, subjecting the partitions simultaneously to interstory relative displacements in their own plane and accelerations in the out of plane direction. Five couples of accelerograms are selected matching the target response spectrum provided by the U.S. code for nonstructural components, i.e. AC156, in order to investigate a wide range of seismic demand. Three damage states are considered and correlated to an engineering demand parameter, i.e. the interstory drift ratio. The tested specimen exhibits significant damage for 0.3% interstory drift and extensive damage for displacement close to 1.0%. The tested partition exhibits a very large frequency, i.e. about 30 Hz, which is larger than the fundamental frequencies of typical structures. A 1.93% damping ratio is assessed for the tested brick partition. It is also concluded that very simple models can adequately approximate the dynamic behavior of the tested nonstructural components.*

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. Taghavi and Miranda [1] pointed out that NSCs give represent a large portion of 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 exceed the replacement cost of the building [2].

Very limited studies were conducted in the past on the seismic behavior of hollow brick internal partitions, even though they are very common in the European area. Furthermore, recent earthquakes, such as L'Aquila earthquake in 2009, evidenced that brick partitions usually exhibit extensive damage jeopardizing the practicability of the whole building, in which they are installed.

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, i.e. AC156, 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 nonstructural components, as well as the structural elements, should be subjected to a careful and rational seismic design, in order to reduce the economic loss and to avoid threats to the life safety. They are subjected to severe seismic actions due to the dynamic interaction with the primary system. The design of acceleration-sensitive nonstructural components is based on the evaluation of the maximum inertia force, which is related to the floor spectral accelerations. The floor spectral accelerations are, in turn, influenced by the dynamic properties, i.e. the natural frequency and the damping ratio, of the nonstructural components. At this purpose, low-intensity random excitations are selected as input motions for the bare and infilled test frame in order to evaluate the influence of the internal partitions on the natural frequency of the undamaged test setup in both the horizontal directions. Moreover, the natural frequency of the component in the out-of-plane direction is evaluated.

2 EXPERIMENTAL TESTS

The shake table tests are performed in the laboratory of the Department of Structures for Engineering and Architecture of the University of Naples Federico II, Italy. As shown in Figure 1, 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 [3], able to transfer the seismic input to the partitions; (c) the specimen, i.e. hollow brick partitions.

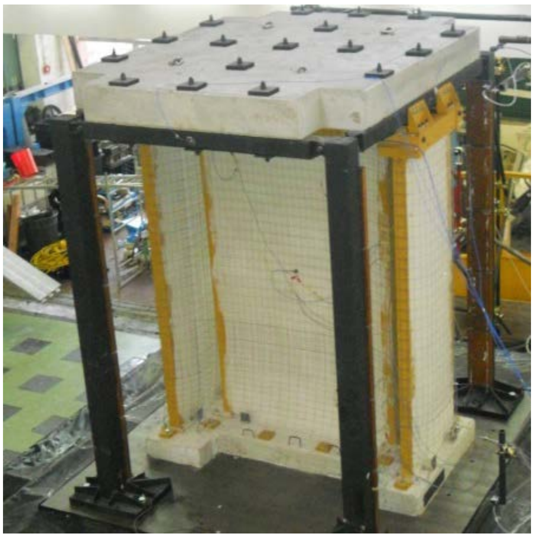


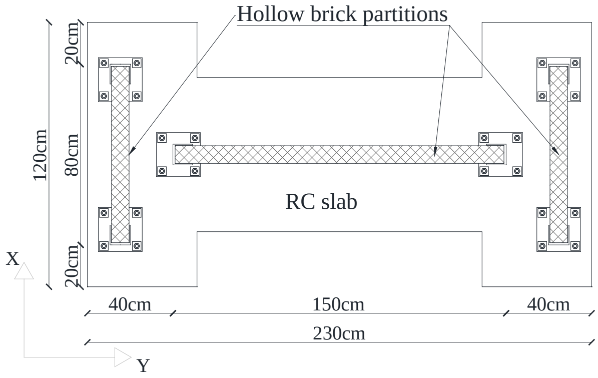
Figure 1: Global view of the test setup.

The function of the existing test frame is to dynamically excite the specimen, subjecting the partitions to a wide range of interstory 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 behavior of a generic story of a structure located in a high seismicity area [3]. In particular, it is characterized by: (a) a realistic value of mass, i.e. specific mass ratio equal to 1.0 t/m^2; (b) a realistic stiffness: the interstory displacement d_r is assumed to be equal to 0.005 times the interstory height, for a “frequent” (i.e. 50 years return period) earthquake typical of high seismicity areas.

The columns of the test frame are 150x150x15 mm box sections; each column is 2.9 m high. Steel horizontal beams, consisting of 120x120x15 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 x 2,65 m and its thickness is equal to 250 mm. The total mass of the test frame is 5.215 t.

The specimen consists of three partitions and steel frames surrounding them placed on an “I” shape RC slab (Figure 2): 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. 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 direction.

A steel frame is defined around the partition (Figure 2b) in order to connect the specimen to the existing test frame and to reproduce the partition typical conditions, in which it is disposed between two restraining orthogonal panels. The total mass of the specimen, i.e. RC slab, partitions and surrounding steel frame, is 2.24 t. The plan layout of the panels ensures the global system to have a comparable stiffness in both orthogonal directions; indeed, two 80 cm wide walls are arranged orthogonally with respect to the larger, 150 cm wide, partition (Figure 2a).



(a)

(b)

Figure 2: Specimen: (a) plan view; (b) general view.

The width of the larger partition is determined by making a compromise between two different requirements. In particular, the width should be:

- sufficiently large, i.e. a width larger than 1.00 m, in order to test a realistic partition;
- sufficiently narrow to allow the investigation of the whole damage states range of the nonstructural component up to the failure of the component.

The partition width should be less than one meter according to the typical amount of partitions contained in the floor area of the test setup. However, a 1.50m wide partition is chosen in order to test a more realistic specimen.

Preliminary analyses are conducted to evaluate the capacity of the chosen partition, in order to define the partition as large as possible and, simultaneously, bring the partition to collapse at least at the highest intensity level. Preliminary nonlinear dynamic analyses (omitted for the sake of brevity) show the collapse of the partition in Y-direction at the test no. 5.

Accelerometers, strain gauges and displacement laser sensors are used to monitor the response of both the test frame and the specimen. One accelerometer, placed inside the shake table, measures the input accelerations in both the directions. Seven accelerometers are also arranged in order to monitor different points of the setup. Six laser-optical sensors are used to monitor the displacements in specific points of the test setup. Three lasers are placed at steel base plate mid-height (base plate that connects column to shaking table); the other three ones are placed halfway on the concrete slab.

The input to the table is obtained from time histories representative of a target ground motion and acting simultaneously along the two horizontal directions; the time histories are artificially defined to match the required response spectrum (RRS) provided by the AC156 code “Acceptance criteria for seismic qualification testing of non-structural components” [4]. According to AC156, the RRS is obtained as a function of the spectral acceleration at short periods, i.e. SDS. Two artificial acceleration time histories are defined so as their response spectra, i.e. test response spectra, envelope the target spectrum over the frequency range from 1.3 to 33.3 Hz. Further details are given in [5].

The input levels for the test campaign range from SDS equal to 0.30 g to SDS equal to 1.50 g [6], in order to generalize the execution of the test and to make it representative of a large range of real earthquakes. Five bidirectional tests with increasing intensity values, i.e. a 0.30g SDS increase is considered, are defined.

3 RESULTS AND DISCUSSION

The top acceleration, representative of the total inertia force, is plotted versus the relative displacement for different intensity levels (Figure 3) in order to analyze the partition behavior and its contribution to the global behavior of the test setup. A dotted line denotes the behavior of the bare test frame based on its natural frequency and assuming to be in absence of damping.

From the analysis of the so-obtained hysteretic curves it can be noted that:

- a significant interaction between the partitions and the hosting structure is exhibited during the first tests; during the fifth test, the hysteretic behavior is very close to the bare frame response;
- the secant stiffness, evaluated at the maximum displacement of each test, decreases as the relative displacement increases;
- the negligible influence of the partitions during the fifth test denotes the collapse of the specimen.

In this study three damage states are considered for the seismic response definition of the partitions, i.e. minor damage state (DS1), moderate damage state (DS2) and major damage state (DS3).

DS1 achievement implies the need of repairing the specimen, in order to restore its original condition, e.g. plaster replacing. DS2 achievement, instead, implies that the nonstructural component is damaged so that it must be partially removed and replaced. DS3 implies that the damage level is such that the partition needs to be totally replaced or the life safety is not ensured. The damage state definitions and their correlation to the visual damage are indicated in Petrone et al. [6].

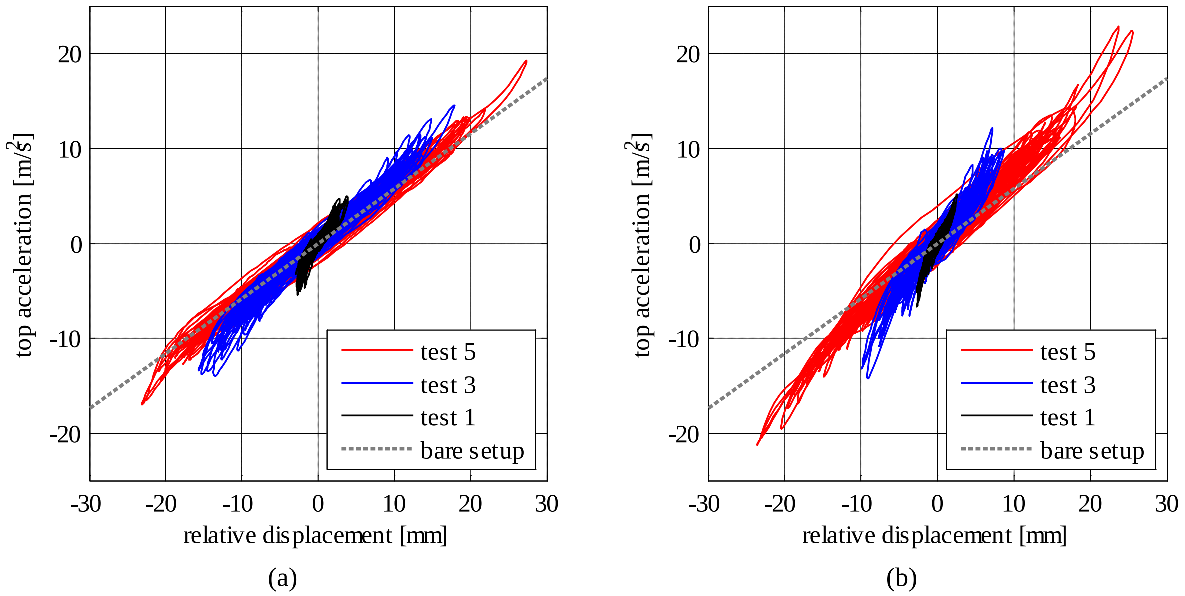


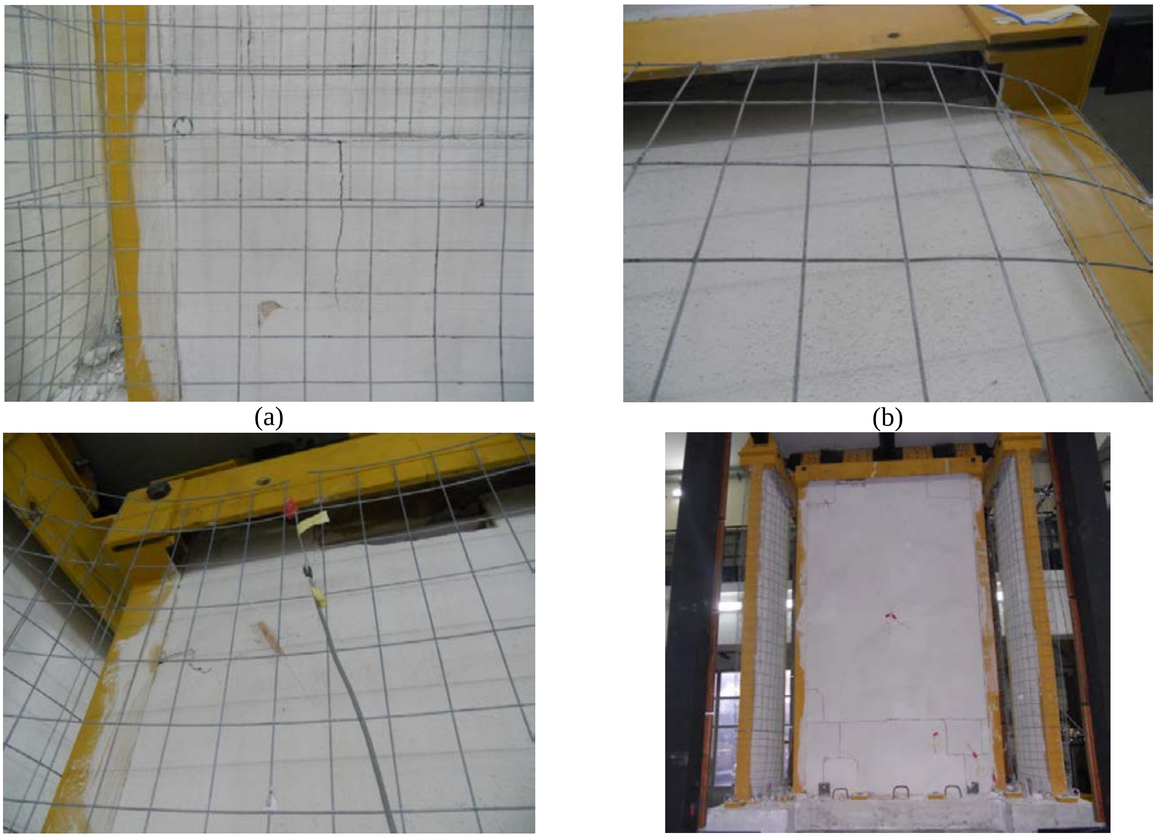
Figure 3: Top acceleration vs relative displacement plot for different seismic tests in (a) X direction and (b) Y direction.

Bidirectional tests show a slight damage already up to 0.35% drift in X direction and 0.20% in Y direction. The damage level increases according to the shaking test intensity and the following damages are noticed:

- cracks along the perimeter of the specimen due to the partitions slip from the surrounding frame in test no. 2;

- fall of plaster and pieces of brick from the top of the specimen from test no. 3 with increasing intensity as the demand increases;
- horizontal cracks, wider than 0.3 mm, in the lower part of the walls in test no. 3 (Figure 4a);
- wide sliding cracks in the mortar, crushing of the mortar at the corner of the specimen and collapse of a brick in the top of the partition in test no. 4 (Figure 4b and Figure 4c);
- deep extended horizontal cracks in the mortar in the lower part of the walls, that let the part above the crack moves as a rigid block with a rocking behavior with respect to the surrounding frame in test no. 5 (Figure 4d). At this damage level, the specimen does not offer any resistance against lateral displacements since it rigidly moves and rotates within the surrounding frame that restraints it in the out of plane direction.

It should be noted that during the tests the specimen is wrapped with a metallic grid without any connection, only for safety purposes. The grid does not give any contribution to the specimen in absorbing the horizontal load.



(a) (b) (c) (d)

Figure 4: Recorded damage after different shaking tests: (a) wide sliding cracks in mortar in the joints between the bricks; (b) crushing of mortar at the corner; (c) collapse of a brick in the top of the partition; (d) deep extended horizontal cracks in mortar in the lower part of the wall.

A correlation between EDP (Engineering Demand Parameter), i.e. interstory drift, and the DS (Damage State) is also established (Table 1). DS1 is attained in test 2 due to the need of restoring the cracked plaster along the perimeter of the wall; DS2 is attained in test 3, due to the formation of cracks wider than 0.3 mm and the need of partially replacing the partition; finally DS3 is attained for an interstory drift close to 1% in the three specimens, due to the significant damage and the consequent need of replacing the whole partition. The correlation between the damage states and the engineering demand parameters is based upon the assumption that the damage occurs at the maximum engineering demand parameter that the specimen experiences during a single test.

test no.	Direction	1	2	3	4	5
drift [%]	X	0.13	0.36	0.67	0.99	1.01
Damage State		DS0	DS1	DS2	DS3	DS3
drift [%]	Y	0.12	0.21	0.34	0.66	0.97
Damage State		DS0	DS1	DS2	DS2	DS3

Table 1: Interstory drifts and damage states in X and Y directions for the different tests.

In order to evaluate the natural frequency in the out-of-plane direction of the tested brick partition, the transfer curve method is applied considering the base acceleration and the partition out-of-plane acceleration recorded by an accelerogram at the centroid of the tested component. The method is applied to a random vibration test in which the partition is subjected to acceleration in the out-of-plane direction. The shaking is performed on an undamaged specimen. The random vibration is characterized by a root mean square amplitude equal to 0.90 m/s^2.

The transfer function in Figure 5 yields two peaks: one with lower frequency, denoting the natural frequency of the test frame, while the latter peak is associated to the natural frequency of the brick partition in the out-of-plane direction. The frequency of the undamaged component is slightly larger than 30 Hz, i.e. 31.25 Hz.

The results confirm that the frequency of the tested brick partition is well above the typical structural fundamental frequencies. Hence, the ratio between the period of the nonstructural component (T_a) and the period of the building (T_1), considered in Eurocode 8 [7] for the evaluation of the seismic demand on the component, could be assumed equal to zero.

The damping ratio, estimated according to the half power bandwidth, is equal to 1.93%. This value is smaller than the typical damping ratio assumed for the estimation of the floor response spectrum.

The need to estimate the natural frequency of the component during the design phase is related to the definition of the acceleration seismic demand on the component. Question arises as to whether simple models are able to estimate the fundamental frequency of the components. At this aim, an attempt to estimate the natural frequency through simple model is included in this paragraph.

The tested partition is modelled as a simply supported beam with distributed mass and stiffness. The natural frequency of a simply supported beam [8] with a uniform mass and stiffness distribution is equal to:

$$f_n = \frac{\pi}{2} \cdot \sqrt{\frac{E \cdot I}{\mu \cdot L^4}} \tag{1}$$

where E is the Young's modulus, I is the moment of inertia, μ is the mass per unit length of the beam, and L is the length of the beam.

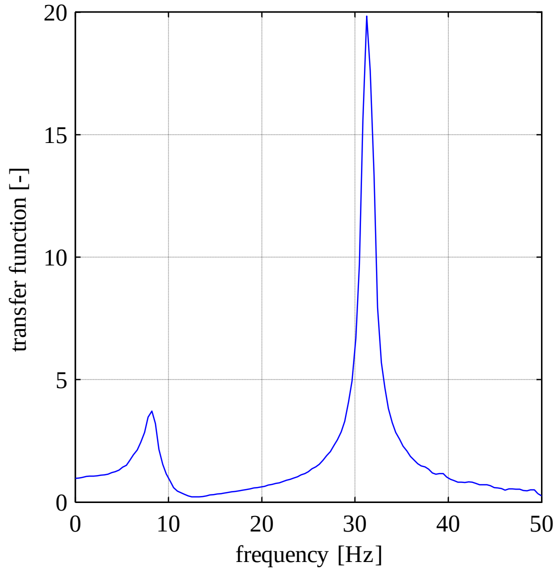


Figure 5: Transfer function from the base to the partition center in the out-of-plane direction for random vibration tests.

In particular, a horizontal 1 m wide strip is considered, since the tested brick partition is characterized by a 1.50 m width and 2.60 m height (Figure 6). The 2-D panel is therefore modelled with a simply supported horizontal beam, which neglects any contribution in the vertical direction, for the sake of simplicity. As above mentioned, the brick partition panel is made with hollows bricks 250x250x80 mm connected together and plastered with mortar. The weight per unit area of the panel is 75 N/m^2. The modulus of elasticity is assumed to be equal to 3500 N/mm^2, according to typical literature values [9].

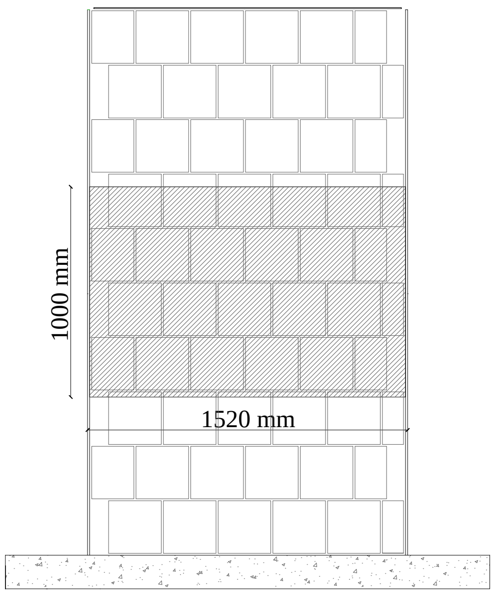


Figure 6: Horizontal strip of the brick partition considered in the analysis.

The flexural stiffness EI of the considered cross-section is equal to 149333 Nm^2 whereas the mass per unit length is equal to 75 kg/m and the total length of the horizontal strip is equal to 1.52 m. The resulting natural frequency, equal to 30.32 Hz, gives a good approximation of the experimental natural frequency.

Finally, it can be concluded that very simple models can adequately approximate the elastic dynamic behavior of the tested nonstructural components.

4 CONCLUSIONS

Shaking table tests are carried out by the earthquake simulator facility available at the Department of Structures for Engineering and Architecture at the University of Naples Federico II in order to investigate the seismic behavior of hollow brick internal partitions. The tested nonstructural component is widespread in the European area.

A steel test frame is adopted in order to simulate the seismic action acting at a generic building story and the specimen boundary conditions. The tests are performed shaking the table simultaneously in both horizontal directions in order to subject the partition simultaneously to interstory relative displacements in its own plane and accelerations in the out of plane direction. A set of five couples of accelerograms are selected matching the target response spectrum provided by the U.S. code for nonstructural components to investigate a wide range of interstory drift demand and damage. Three damage states are considered in this study in order to characterize the seismic behavior of the specimen. The dimensions of the specimen are adequately chosen in order to (a) test a realistic partition and (b) allow the investigation of the whole damage states range.

The hollow brick partition is subjected to interstory drift up to 1.0%. It exhibits minor damage for 0.2% interstory drift, moderate damage for 0.34% interstory drift and major damage for 0.97% interstory drift.

The transfer curve method is applied for the evaluation of the natural frequency of the tested component, i.e. a brick partition, in the out-of-plane direction. The results highlight that the frequencies of the tested partitions in the out-of-plane direction are larger than the typical structural fundamental frequencies. The damping ratio of the tested component in the out-of-plane direction is also estimated, since the damping ratio of the nonstructural component strictly influences the maximum acceleration acting on the component. A 1.93% damping ratio is assessed for the tested brick partition.

An attempt to estimate the natural frequency through a simple model is also performed. In particular both the partition is schematized with a simply supported beam with uniform mass and stiffness. The resulting natural frequencies give a good estimation of the experimental natural frequencies, considering the very simple models adopted for this assessment. It is concluded that very simple models can adequately approximate the elastic dynamic behavior of the tested nonstructural components.

ACKNOWLEDGEMENTS

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