PLASTERBOARD PARTITIONS SEISMIC PERFORMANCE EVALUATION VIA SHAKE TABLE TEST

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ABSTRACT
Shaking table tests performed to investigate the seismic behaviour of innovative plasterboard partitions at a large scale of intensity levels are addressed in this paper.
A steel test frame is properly designed in order to simulate the seismic effects at a generic building storey. An additional concrete mass is fixed on the top of the test frame simulating realistic inertia forces during the shaking. Partitions are inserted within the test frame without fixing them rigidly to the structure; this allows to obtain significant interstorey drift, without inducing large stresses in partitions.
The plasterboard partitions exhibit a good seismic behaviour, both in their own plane and out-of-plane, showing light damage up to 0.8% interstorey drift ratio and 2g top frame acceleration.
Moreover, a comparison of the dynamic characteristics, i.e. fundamental period and damping ratio, between the bare steel structure and the infilled one is also performed using different dynamic identification methods in order to evaluate the influence the partitions have on the dynamic response of the structures.

Keywords: infill plasterboard partitions, nonstructural components, seismic performance, shaking table test.

1. INTRODUCTION

Plasterboard partitions certainly belong to non structural components category, whose seismic behaviour is nowadays recognized to be a relevant issue within the framework of Performance-Based Earthquake Engineering. The damages on nonstructural components cause the largest part of the economic loss (Taghavi and Miranda, 2003), besides causing evacuation of buildings and their use interruption (Magliulo et al., 2009).
Nevertheless few experimental studies on plasterboard partitions are available in literature. The behaviour of partitions and suspended ceilings during earthquakes is discussed in Rihal et al. (1984). Full-scale drywall partitions with light-gage steel stud framing were tested to observe damage in cyclic loading conditions in Lee et al. (2007). In Matsuoka et al. (2008) a shake table test on a full-scale 4 story steel building, in which various non-structural components were installed (i.e. both plasterboard partitions and suspended ceilings) to evaluate their seismic performance, is presented.
In this paper the influence of innovative plasterboard partitions on a steel frame structure is investigated. Such partitions are designed in order to not interfere with the hosting structure up to moderate level of drifts (~0.5%).

2. DESCRIPTION OF THE EXPERIMENTAL TESTS

The seismic qualification of infill plasterboard partitions is carried out by the earthquake simulator system available at the laboratory of Structural Engineering Department of University of Naples Federico II.

The tests aim at investigating the seismic behaviour of innovative drywall partitions. With the purpose of simulating the seismic effects on the partition, a steel test frame is properly designed and built (Fig. 1). The geometry of the test frame is defined taking into account two requirements: (a) realistic value of mass; (b) lateral stiffness resulting in interstorey displacement dr = 0.005 h (being h the interstorey height) for a 50 years return period earthquake typical of a high seismicity zone.
The result is a 2.50 m (X dir.) x 2.00 m (Y dir.) x 2.89 m (Z dir.) inverted pendulum text fixture. The test frame is composed of welded square hollow columns (150 mm x 150 mm x 15 mm) of C45 steel material and rolled square hollow beams (120 mm x 120 mm x 12.5 mm) of steel S275; the beam-column connections are bolted. A reinforced concrete slab of class C45/55 is placed on the roof of the structure (Fig. 2.1).

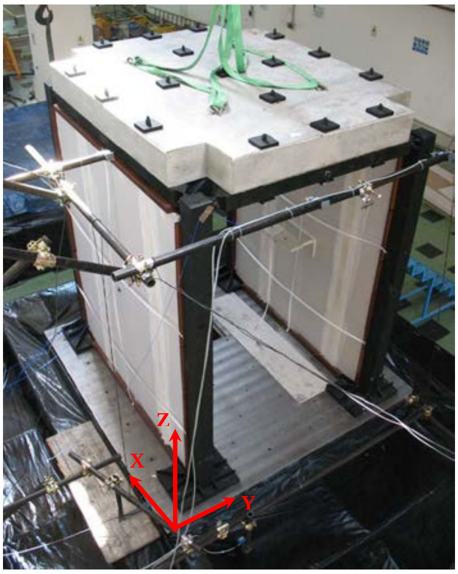


Figure 2.1. Scheme of test setup: overview

Two partitions are contemporary tested in order to maintain symmetry in the test setup configuration.
Two layers compose the drywall partitions: the so-called “PREGYPLAC BA13 plasterboards” and “PREGY LaDURA BA13 plasterboards”, weighing 90 N/m^2 and 128 N/m^2 respectively (Fig. 2.2). The latter is a plasterboard with high mechanical resistance conferred by wood fibers. Each layer is 12,5mm thick and with thinned edges. The plasterboards are screwed only on vertical studs. The gap, properly defined between the plasterboards and the perimeter, is filled with acrylic silicone. Such system is designed in order not to interfere with the relative displacement of the housing structure up to 0.5% drift.

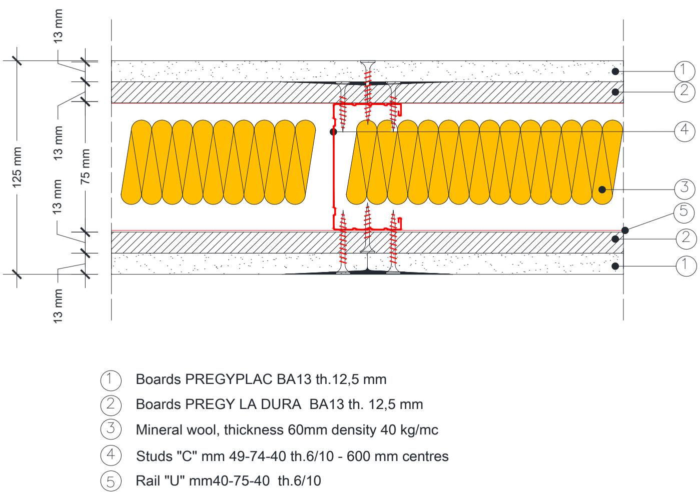


Figure 2.2. Cross section of the double layer of drywall partition

Accelerometers, strain gauges and laser-optical sensors are used to monitor the response of the test frame and partitions, as described in Figs. 2.3 and 2.4.

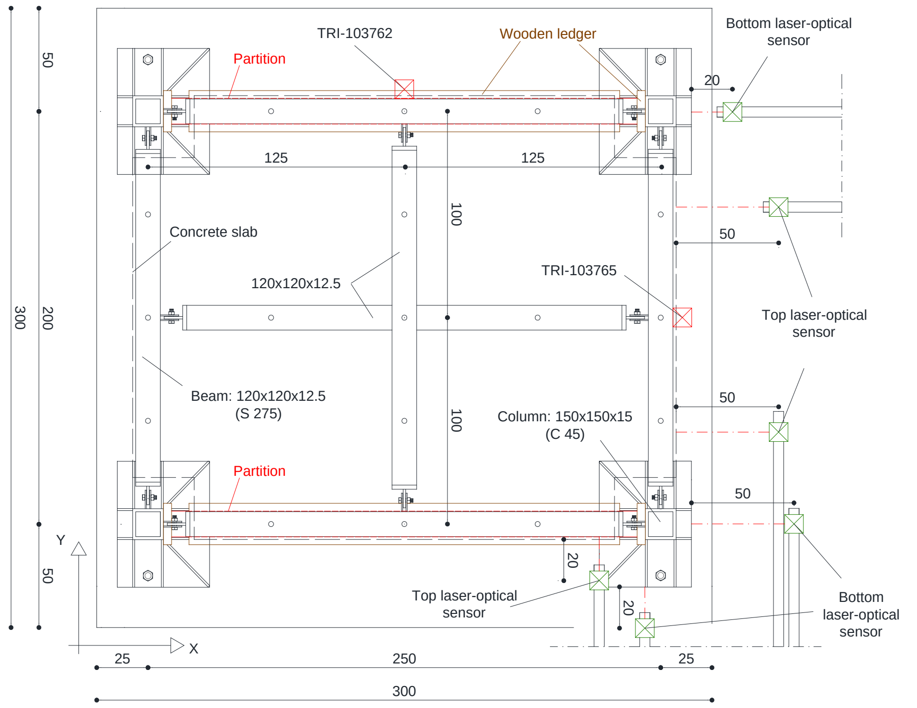


Figure 2.3. Location of the instrumentation: plan view

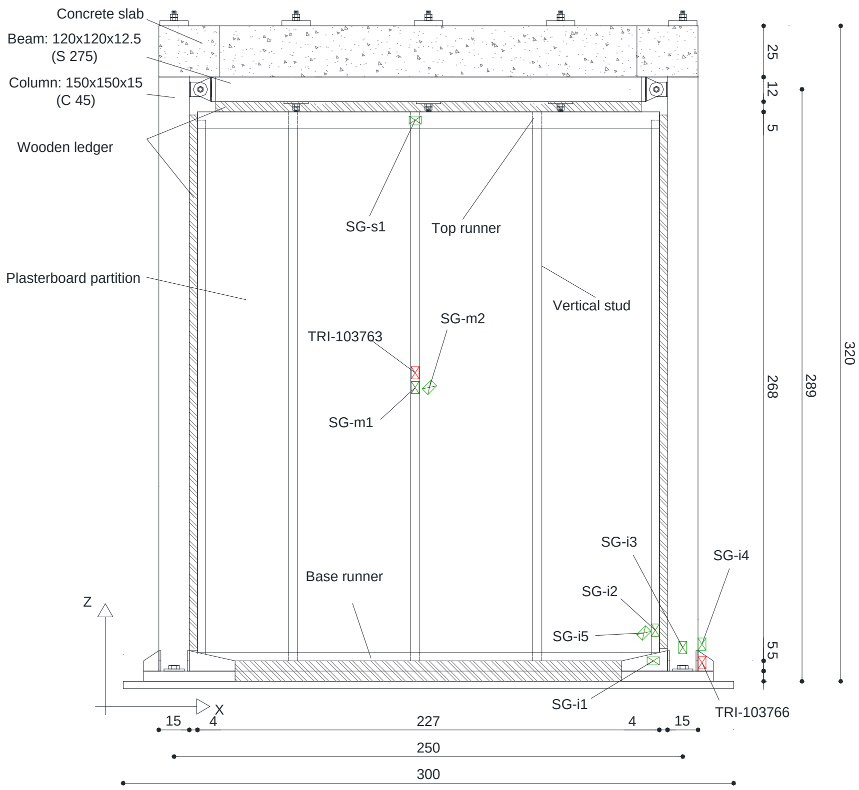
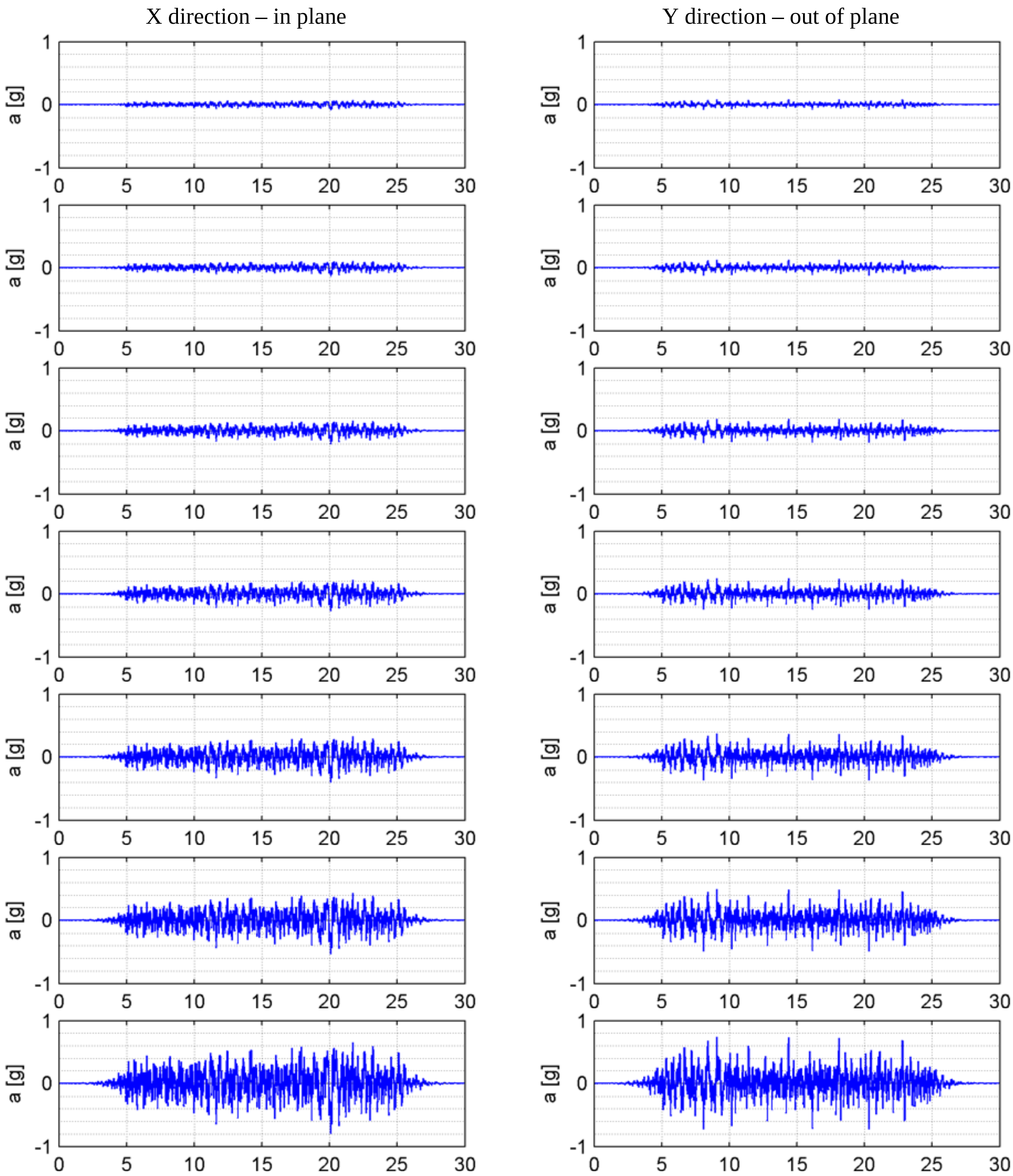


Figure 2.4. Location of the instrumentation: lateral view

The input to the table is provided through acceleration time histories representative of expected/target ground motion and acting simultaneously along the two horizontal directions; the time histories are artificially defined in order to match the required response spectrum (RRS), provided by the ICBO-AC156 code “Acceptance criteria for seismic qualification testing of nonstructural components” (ICBO, 2000).
The RRS is obtained as a function of the design spectral response acceleration at short periods, S_{DS}, depending on the site soil condition and the mapped maximum earthquake spectral acceleration at short periods (for more details see section 6.5 in ICBO-AC156).
The selection procedure of the accelerograms is performed, for a RRS corresponding to S_{DS}=1.05g; the so obtained record is then scaled to match other seven levels of the target spectrum (corresponding to S_{DS} 0.10g, 0.15g, 0.22g, 0.30g, 0.45g, 0.60g and 0.90g). The input motion for the different intensities are presented in Fig. 2.5



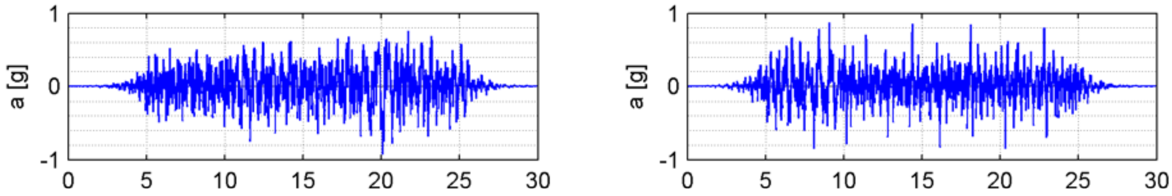


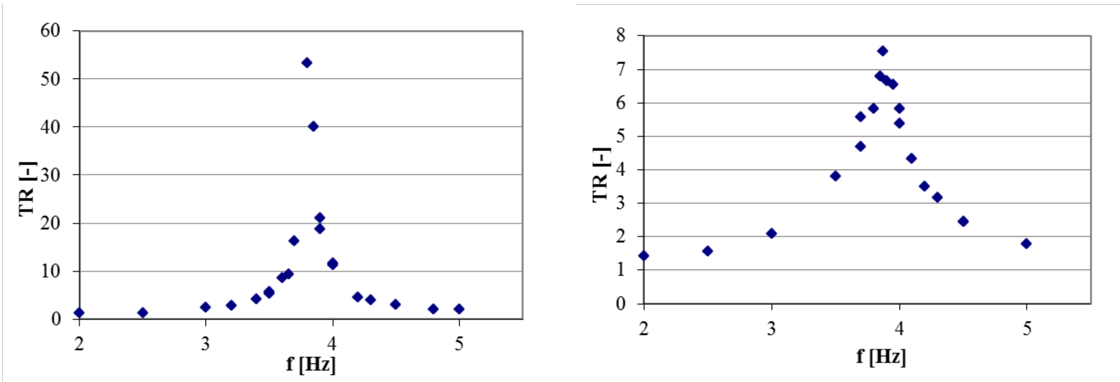
Figure 2.5. Input acceleration time histories for partition in-plane direction (X dir) and out-of-plane direction (Y dir) corresponding to SDS equal to 0.10g, 0.15g, 0.22g, 0.30g, 0.45g, 0.60g, 0.90g and 1.05g.

3. DYNAMIC IDENTIFICATION

Different procedures are used to evaluate the fundamental period and the damping ratio ξ of the test setup. Two methods are illustrated in the following. For each method, the results concerning the bare steel test frame are presented; the method no. 1 is also applied on the infilled frame.

3.1. Method 1

This method consists of applying to the base of the test frame a harmonic drive motion with predefined amplitudes and frequency f. The maximum acceleration on the roof of the bare test frame and the harmonic base amplitude are recorded for each frequency f. The transmissibility ratios (TR), i.e. the ratio between the roof acceleration and the base one, are then evaluated (blue dots in Figure 3.1(a)). The peak gives the natural frequency f_n equal to 3.81 Hz while the damping ratio is evaluated applying the half-bandwidth method (ξ=0.92%).
The procedure is also applied on the infilled frame in order to evaluate the influence of the partitions on the dynamic parameters of the test setup. The peak occurs at 4.02 Hz (Figure 3.1(b)), defining a very light increase of the natural frequency and a significant influence of the partitions on the damping ratio. The half bandwidth method, instead, gives out a 5.42% damping ratio.



(a) (b)

Figure 3.1. Transmissibility ratios curve of the bare steel frame (a) and for the infilled structure (b).

3.2. Method 2

The transfer curve method is also used to evaluate the natural frequency f_n and the damping ratio ξ of the bare test frame. The transfer function is defined as the ratio of the roof acceleration response to the input base motion, (i.e. a white noise time history), in the frequency domain.
The half-bandwidth method is used for the damping ratio evaluation, while the peak denotes the natural frequency of the system.
A 3.86 Hz natural frequency and 1.5% damping ratio are evaluated for a white noise input motion (Figure 3.2).

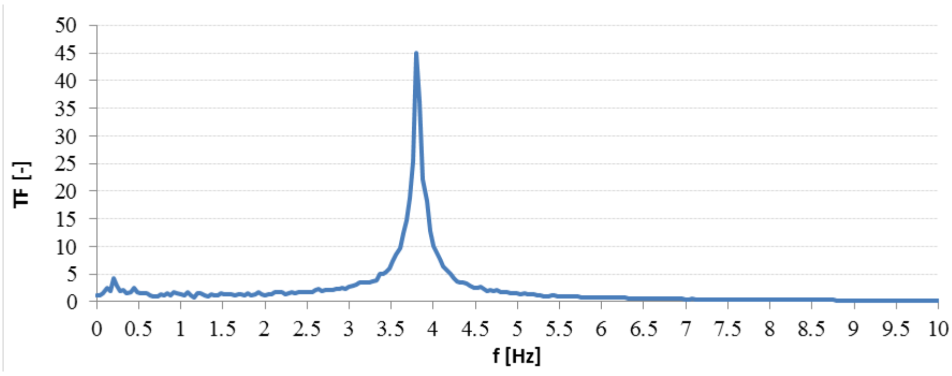


Figure 3.2. Transfer function generated by a white noise input on the bare structure.

The results of the dynamic identification procedures are summarized in the Table 3.1.

Table 3.1. Summary of the results obtained with the different procedures.

Method	Transmissibility curve		Transfer curve	
Structure	f_n [Hz]	ξ [%]	f_n [Hz]	ξ [%]
Bare frame	3.81	0.92%	3.86	1.55%
Infilled frame	4.02	5.42%	-	-

Upon these results, it can be concluded that:

- the innovative plasterboard partitions do not influence the natural frequency of the test frame. The goal of not interfering with the hosting structure is achieved;
- the damping ratio of the setup significantly increases with the insertion of the partition within the test frame, causing a benefic effect in the dynamic response.

4. TEST RESULTS AND COMPARISON

Using the selected drive motions, eight bidirectional shaking tests are performed; the results are summarized in Table 4.1 in terms of maximum base input, base recorded and roof recorded acceleration. The maximum recorded values of acceleration at the base and at the roof of the test frame are 1.03g and 2.22g respectively; the maximum accelerations on the partitions are 1.82g and 1.81g, in plane and out-of-plane respectively.

Table 4.1. Maximum acceleration input $a_{base,inp}$ and recorded $a_{base,rec}$ at the base compared to maximum roof acceleration a_{roof} for each test of the campaign.

		X			Y		
Test ID	S_{DS} [g]	$a_{base,inp}$ [g]	$a_{base,rec}$ [g]	a_{roof} [g]	$a_{base,inp}$ [g]	$a_{base,rec}$ [g]	a_{roof} [g]
1	0.10	0.09	0.10	0.09	0.08	0.17	0.20
2	0.15	0.13	0.13	0.13	0.12	0.22	0.32
3	0.22	0.20	0.19	0.19	0.19	0.27	0.43
4	0.30	0.27	0.23	0.27	0.25	0.35	0.54
5	0.45	0.40	0.35	0.47	0.37	0.47	0.76
6	0.60	0.53	0.50	0.81	0.50	0.57	0.97
7	0.90	0.80	0.81	1.66	0.74	0.90	1.32
8	1.05	0.93	0.95	2.22	0.87	1.03	1.54

Relative displacements are also evaluated using the laser sensors records. The maximum recorded relative displacements are 20.1mm in X direction and 22.7mm in Y direction. The maximum interstorey drifts are evaluated considering the column height, i.e. 2740 mm. Values up to 0.83% drift are recorded, representative of a moderate earthquake intensity level.

In this study three limit states are considered for the seismic response definition of the plasterboard partitions and in particular:

- OLS → Operational limit state (damage state 1 limit);
- DLS → Damage limit state (damage state 2 limit);
- LSLS → Life safety limit state (damage state 3 limit).

After each test, damage is observed inspecting the specimen components. The recorded damage in each component is then correlated to one of the three limit states defined above. Indeed, in Table 4.2 the level of damage required to reach a limit state is defined for each damage typology of each system component (i.e. plasterboards, studs, runners and screws). This damage is defined quantitatively, if possible; in the opposite case a qualitative definition of the damage level is defined.

Table 4.2. Damage state definition upon the damage recorded within each component of the partition system.

System component	Damage typology	OLS (damage state 1 limit)	DLS (damage state 2 limit)	LSLS (damage state 3 limit)
		need for minor repairs	need to remove and replace the partition	human life hazard
Plasterboard	collapse / cracking	cracks that compromise partition use	cracks extended at least for partition half dimension / not repairable break (edges)	partition portion collapse (>0,75mq) with consequent dislocation
Plasterboard	overturning	\	\	partition overturning
Stud	collapse	small permanent deformations	track movement with respect to its initial position/ great deformations/ flange opening	track collapse (shear, bending, instability)

Runner on the floor	collapse	small permanent deformations	track movement with respect to its initial position/ great deformations/ flange opening	guide crisis (failure, total detaching of the connection)
Runner beneath the roof	collapse	small permanent deformations	track displacement with respect to its initial position/ great deformations/ flange opening	guide crisis (failure, total detaching of the connection)
Screws	fracture	release of small number of screws respect their initial position (at least 10%)	some screws loosening or breaking that causes partial separation of one or more components / breaking and/or release of at least 30% of screws	breaking of many screws that lead the partition to collapse or overturning / break of at least 50 % of screws

The shake table tests show a very slight damage (Figure 4.1) including:
- Acrylic silicone detachment (inserted in the separation between partition and wooden vertical support);
- Chalk dust fall.

Such level of damage was assessed unable to reach even the limit state 1.

(a) (b) (c)

Figure 4.1. Photos of the light damages recorded after the bidirectional shake table tests: (a) and (b) acrylic silicon detachment, (c) chalk dust fall

4. CONCLUSIONS

In order to investigate the seismic behaviour of infill plasterboard partitions, shaking table tests are carried out by the earthquake simulator system available at the laboratory of Structural Engineering Department of University of Naples Federico II.
The tests aim at investigating the seismic behaviour of particular drywall partitions made by the Lafarge Plâtres industry and a steel test frame is properly designed and built to the purpose.
Using drive motions properly selected for the tests, eight bidirectional shakings are performed. The maximum recorded values of acceleration at the base and on the roof of the test frame are 1.03g and 2.22g respectively; the maximum accelerations on the partitions are 1.82g and 1.81g, in plane and out-of-plane respectively.
Test results show a very light damage also for an acceleration level equal to 2g and 0.8% interstorey drift.
A comparison of the dynamic characteristics, i.e. fundamental period and damping ratio, between the steel structure and the infilled structure was also performed using different dynamic identification methods. It can be concluded that the partitions do not affect significantly the structural fundamental period; the damping ratio, instead, is strongly influenced by the plasterboard partitions.

The dynamic identification procedure and the experimental evidence show that the tested partitions do not contribute to the structural stiffness. Indeed, no variations in terms of stiffness and structural period are recorded after introducing the partitions within the test frame; moreover, the partitions implies a damping increase, resulting in a beneficial effect in relation to the earthquake. For this reason, they can be catalogued as non-interacting partitions in the framework of the non-structural components defined in Eurocode 8 (CEN, 2004). This allows the benefit of designing much more flexible and economic structure.

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