Proceedings Paper:
Fiorino, L, Iuorio, O orcid.org/0000-0003-0464-296X, Macillo, V et al. (3 more authors) (2014) Seismic response evaluation of non-structural drywall building components: Planning of an □□□□experimental campaign. In: Landolfo, R and Mazzolani, FM, (eds.) Eurosteel 2014. Eurosteel 2014: 7th European Conference on Steel and Composite Structures, 10-12 Sep 2014, Naples, Italy. ECCS European Convention for Constructional Steelwork . ISBN 978-92-9147-121-8

SEISMIC RESPONSE EVALUATION OF NON-STRUCTURAL DRYWALL BUILDING COMPONENTS:
Planning of an experimental campaign

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INTRODUCTION

Past earthquakes have shown that the damage to non-structural elements can severely limit the functionality of most affected buildings and cause substantial economic losses. Among the non-structural building components, the ceiling-partition systems represent a large economic investment in construction sector. Nevertheless, their seismic performance is poorly understood, because information and specific guidance are very limited. In the last years, international studies have been conducted on the seismic behaviour of light gage steel stud partition walls (Lee et al. [1], Restrepo and Bersofsky [2], Tasligedik et al. [3], Retamales et al. [4], Magliulo at al. [5]), suspended ceilings (Badillo et al. [6], Magliulo et al. [7], Gilani et al. [8], Soroushian et al. [9],) and partition walls - ceiling systems (Filiatrault et al. [10], McCormick at al. [11]). Since the behaviour of these systems cannot be easily simulated with traditional structural analysis, experimentation is the main way to assess the seismic response. For these reasons, an experimental campaign has been planned at the University of Naples Federico II with the main aim to characterize the seismic response of different Cold-Formed Steel (CFS) partition drywalls and suspended continuous plasterboard ceilings. The current paper presents the research project, in terms of experimental program, prototypes and specifically designed set-up.

1 EXPERIMENTAL PROGRAM

The object of the research are the non-structural building components produced by Knauf company consisting of partition drywalls, outdoor drywalls, and suspended continuous plasterboard ceilings. The investigated partition drywalls are composed by studs and tracks (frame) and different panels (gypsum plasterboard and gypsum-fiber board). The frame is made with 0.6 mm thick CFS profiles made of DX51D+Z steel grade. The frame can by sheathed with one or two panels for each side. The type and number of panels are selected according to the required drywall performances. The partition drywall behaviour is also analyzed taking into account of interaction with other non-structural building components, such as outdoor drywalls, sheathed with cement-based board, and suspended continuous plasterboard ceilings, which have a suspended steel frame sheathed with gypsum plasterboard. In all the experimental campaign the interest is to investigate the seismic behaviour of CFS non-structural components within reinforced concrete buildings. In particular, in order to investigate a large number of possible applications, the following configurations are selected: (I) single partition drywalls, (II) subsystems made of a partition drywall and two outdoor drywalls, (III) systems composed by four partition drywalls, (IV) systems made of two partition drywalls, two outdoor drywalls and suspended continuous plasterboard ceilings. Variations of drywall configurations are also considered in terms of stud spacing, panel types, panel-to-frame connection type, and drywall-to-building structure joint type. The experimental activity involves a large number of tests: a) 111 tests on materials and main components, such as steel material, panels, screws and panel-to-frame connections; b) 14 in-plane quasi-static reversed cyclic tests on full-scale partition drywalls and subsystems; c) 20 out-of-plane quasi-static monotonic tests on partitions; d) 4 dynamic tests on shaking table on full-scale systems. The experimental campaign will be carried out at the Department of Structures for Engineering and Architecture of the University of Naples Federico II.

2 TESTS ON MATERIALS AND MAIN COMPONENTS

The local response of the partition drywalls and suspended ceilings will be investigated by experimental tests on the main materials and components. Therefore, tensile coupon test on steel material, bending tests on panels, shear tests on screws and shear tests on panel-to-frame connections will be performed.

The steel material adopted for profiles, consisting of 0.6 thick DX51D+Z steel grade, will be experimentally characterized by conventional tensile coupon tests carried out according to EN ISO 6892-1 [12]. In particular, starting from three different coils, three sample will be obtained from each of them, for a total number of 9 tests.

In order to evaluate the elastic modulus and bending strength of panels, bending tests will be carried out according to EN 520 [13]. The panels under investigation are: (i) 12.5 mm thick gypsum plasterboard type A ("GKB (A)"), (ii) 12.5 mm thick gypsum-fiber board ("GF Vidiwall"); (iii) 12.5 mm and 15.0 mm thick impact resistant special gypsum board ("Diamant"); (iv) 12.5 mm thick cement-based board ("Aquapanel Outdoor"). In particular, two different configurations for each panels will be investigated: samples obtained in the transverse (T) direction and in the longitudinal (L) direction of panels. Therefore, six bending tests will be carried out for each panel type, for a total number of 30 tests. The EN 520 [13] defines a three point bending test on a 400x300 mm (length x width) panel (Fig 1). The test matrix is shown in Table 1.

Table 1. Test matrix for the bending tests on panels

Type	Panels	Thickness [mm]	No. tests
1	GKB (A)	12.5	3L + 3T
2	GF Vidiwall	12.5	3L + 3T
3	Diamant (12.5)	12.5	3L + 3T
4	Diamant (15)	15	3L + 3T
5	Aquapanel Outdoor	12.5	3L + 3T
		Total tests	30

L: longitudinal direction; T: transverse direction

The screws adopted for panel-to-frame connections will be tested in order to obtain the shear strength. Therefore, the following screw typology are considered: (i) 3.5 mm diameter flat trumpet head ("TN 3.5x35"), (ii) 3.5 mm diameter flat countersunk trim head ("3.5x40"), (iii) 3.9 mm diameter flat trumpet head ("XTN 3.9x38"), (iv) 4.2 mm diameter flat countersunk head ("SN 4.2x39"), (v) 4.3 mm diameter lath head ("FN 4.3x65"). Six tests for each screw type will be carried out, for a total number of 30 tests. An ad hoc experimental test set-up, proposed by Fiorino et al. [14], will be used (Fig 2.). Specifically, the screw passes through three predrilled heat treated steel plates (hardness value ranging from 50 to 55 HRC) and it drills an additional squared DX 51D+Z steel plate, in order to avoid the screw pull out during the test. Test matrix is defined in Table 2.

The shear behaviour of panel-to-frame connections will be evaluated for different configurations: (i) 12.5 mm thick GKB (A) panel connected with TN 3.5x25, (ii) 12.5 mm thick GF Vidiwall panel connected with 3.5x30, (iii) 12.5 mm thick Diamant panel connected with XTN 3.9x23, (iv) 15 mm thick Diamant panel connected with XTN 3.9x38, (v) 12.5 mm thick Aquapanel Outdoor panel connected with SN 4.2x39, (vi) 12.5 mm thick GKB (A) double panels connected with TN 3.5x35, (vii) 12.5 mm thick GF Vidiwall double panels connected with 3.5x40. Six shear tests will be carried out for each connection type, for a total number of 42 tests. The adopted test set-up (Fig. 3) is a modified version of the one defined in EN 520 [13] for panel-to-wood frame connections. In particular, the tests will be carried out on connection specimens made of two (or four, in the case of two panels for each side) 300x100 mm (length x width) panel samples, which will be cut in the longitudinal direction of original board. The panel samples will be attached to the opposite flanges of the 75x50x7.5 mm (outside-to-outside web depth x outside-to-outside flange size x outside-to-outside lip size) lipped channel stud sections. Each panel will be connected to the stud using two screws with edge distance equal to 15 mm. Finally, the load will be applied by means of two steel holders, each of which will be bolted to the stud with four M8 8.8 grade bolts. Table 3 provides the test matrix.

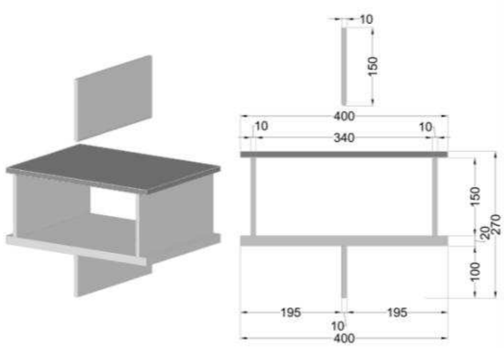


Fig. 1 Test set-up for bending tests on panels

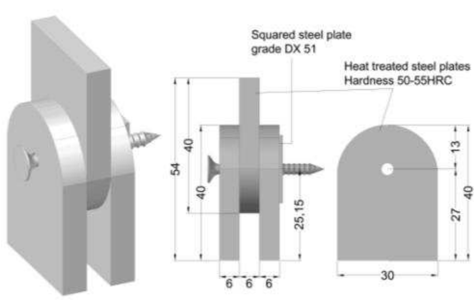


Fig. 2 Test set-up for shear tests on screws

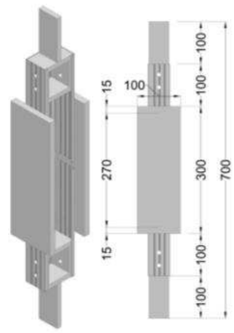
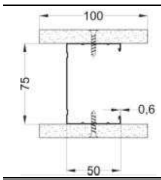
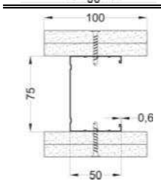


Fig. 3 Test set-up for shear tests on panel-to-frame connections

Table 2. Test matrix for the shear tests on screws

Type	Screws	Head type	Diameter [mm]	Length [mm]	No. tests
1	TN 3.5x35	Flat trumpet head	3.5	35	6
2	3.5x40	Flat countersunk trim head	3.5	40	6
3	XTN 3.9x38	Flat trumpet head	3.9	38	6
4	SN 4.2x39	Flat countersunk head	4.2	39	6
5	FN 4.3x65	Lath head	4.3	65	6
				Total tests	30

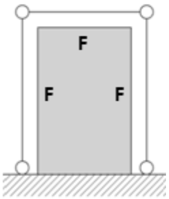
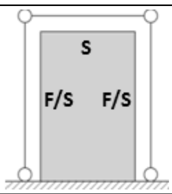
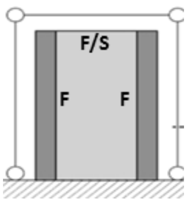
Table 3. Test matrix for the shear tests on panel-to-frame connection

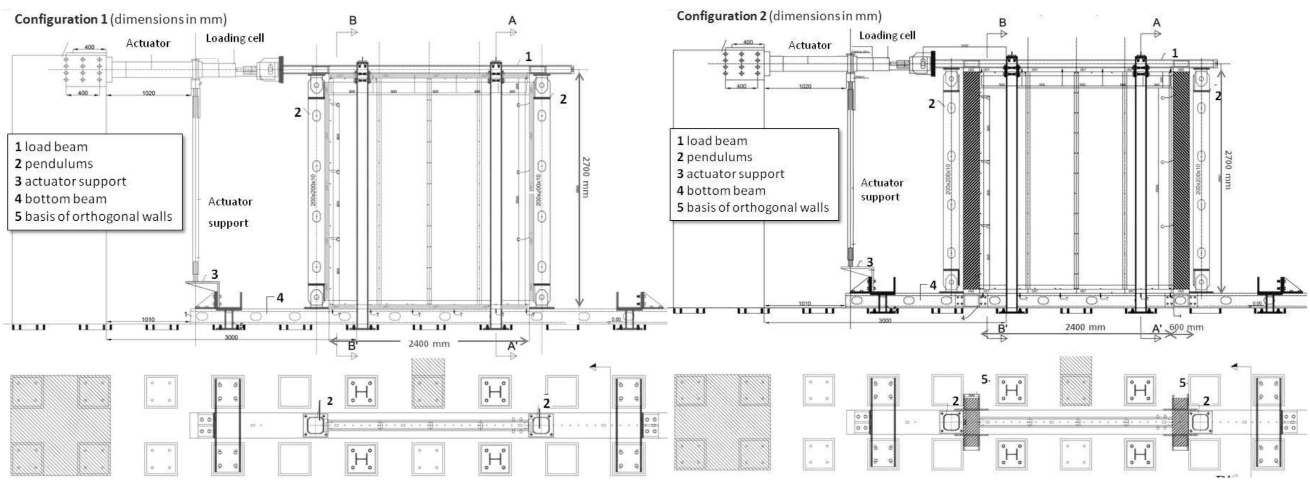
	Type	Panels	Panel thickness	Corresponding screws	No. tests
	1	GKB (A)	12.5	TN 3.5x25	6
	2	GF Vidiwall	12.5	3.5x30	6
	3	Diamant (12.5)	12.5	XTN 3.9x23	6
	4	Diamant (15)	15	XTN 3.9x38	6
	5	Aquapanel Outdoor	12.5	SN 4.2x39	6
	6	2xGKB (A)	12.5	TN 3.5x35	6
	7	2xGF Vidiwall	12.5	TN 3.5x40	6
				Total tests	42

3 IN-PLANE QUASI-STATIC REVERSED CYCLIC TESTS ON PARTITION DRYWALLS

In order to investigate the seismic response of partition drywalls and to evaluate the damage for the interstory drifts limits required by the Eurocode 8 [15], five configurations of single partition drywalls (I) and two configurations of subsystems made by a partition drywall and two outdoor drywalls (II) will be tested under horizontal in-plane loads. The variables under investigation are: (i) the stud spacing (300 mm or 600 mm), (ii) the panel typology (GKB or GF Vidiwall), (iii) the joint between partition drywalls and reinforced concrete building structure (fixed or sliding, Fig. 4), (iv) the position of sliding joints. The partition drywalls are 2400 mm x 2700 mm (length x height), while the outdoor drywalls, that are placed perpendicular to the partition drywalls, are 600 mm x 2700 mm (length x height). The configurations are shown in Table 4. Two tests for each configuration will be carried out in a quasi-static reversed cyclic loading regime, for a total number of 14 tests. Specifically designed 2D testing hinged steel frame (without lateral resisting elements) will be adopted for in-plane tests (Fig. 5). The set-up has been also designed in order to allow the interposing of any material (concrete, steel, wood) between the tested partition drywalls and steel testing frame, in such a way to give the possibility to simulate a large range of partition-to-structure interface behaviour. In particular, for this experimental campaign, concrete bricks have been selected as interface elements, in order to reproduce the behaviour of partition drywalls within reinforced concrete framed buildings. The drywall prototype will be constrained to the laboratory floor on the bottom beam of testing frame. Horizontal displacements will be applied to the top beam (loading beam) of testing frame. Two hinged rectangular hollow vertical profiles are placed at the two ends of the partition in order to simulate the columns behaviour of a building structure. The out-of-plane displacements will be avoided by two steel portal frames equipped with roller wheels. Moreover, a sliding-hinge will be placed between the loading actuator and the loading beam, in order to avoid vertical load components. The tests will be performed by using a hydraulic load actuator having 500 mm stroke and 500 kN load capacity.

Table 4. Test matrix for the in plane drywall tests.

	Conf.	Wall length [mm]	Wall height [mm]	Wall thickness [mm]	Panel number and type	Studs h [mm]	Studs spacing [mm]	Upper joint type	Lateral joint type	No. tests
SINGLE PARTITION DRYWALLS										
	1	2400	2700	125	2xGKB (A)	75	600	Fixed (F)	Fixed (F)	2
	2	2400	2700	125	2xGKB (A)	75	300	Fixed (F)	Fixed (F)	2
	3	2400	2700	125	2xVidiwall (GF)	75	600	Fixed (F)	Fixed (F)	2
	4	2400	2700	125	2xGKB (A)	75	600	Sliding (S)	Fixed (F)	2
	5	2400	2700	125	2xGKB (A)	75	600	Sliding (S)	Sliding (S)	2
SUBSYSTEMS MADE OF OUTDOOR AND PARTITION DRYWALLS										
	6	2400	2700	125	2xGKB (A)	75	600	Fixed (F)	Fixed (F)	2
		600	2700	200	Aquapanel outdoor	100 + 50	600	Fixed (F)		
	7	2400	2700	125	2xGKB (A)	75	600	Sliding (S)	Fixed (F)	2
		600	2700	200	Aquapanel outdoor	100 + 50	600	Sliding (S)		
									Total tests	14



a) b)

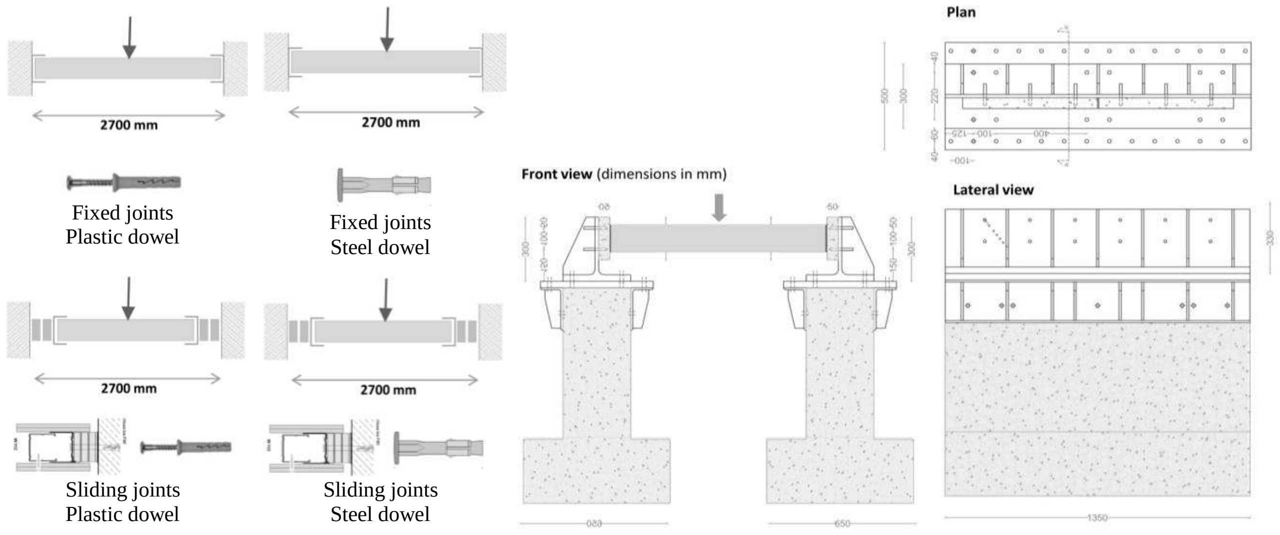
Fig. 5 Test set-up for in-plane tests: a) single partition; b) subsystem composed by partition and outdoor drywall

4 OUT-OF-PLANE QUASI-STATIC MONOTONIC TESTS ON PARTITION DRYWALLS

The out-of-plane quasi-static monotonic tests are aimed to evaluate the partition drywall strength to be used in Eurocode 8 [16] for non-structural elements verifications. The three-point bending tests will be carried out on four configurations of single partition drywalls (I). The investigated variables are: (i) the joint between partition drywalls and reinforced concrete building structure (fixed or sliding), (ii) the dowel type used to realize the joints (plastic or steel). All the partition specimens are 2400 mm x 2700 mm (length x height). Five tests for each configuration will be carried out, for a total number of 20 tests. The tests on the drywall prototypes will be performed in a horizontal position using a test set-up specifically developed (Fig. 6). The specimens will be connected by means of two steel profiles, having 300x300 (web depth x flange size) T-shaped cross section, to the reinforced concrete supports. Also in this case, the set-up has been designed in order to allow the interposing of concrete blocks. The test matrix is shown in Table 5.

Table 5. Test matrix for the out-of-plane monotonic tests on partition drywalls

Conf.	Wall length [mm]	Wall heigth [mm]	Wall thickness [mm]	Panel number and type	Studs		Joint type	Dowel type	No. tests
					h [mm]	spacing [mm]			
1	2400	2700	125	2xGKB (A)	75	600	fixed	plastic	5
2	2400	2700	125	2xGKB (A)	75	600	fixed	steel	5
3	2400	2700	125	2xGKB (A)	75	600	sliding	plastic	5
4	2400	2700	125	2xGKB (A)	75	600	sliding	steel	5
								Total tests	20

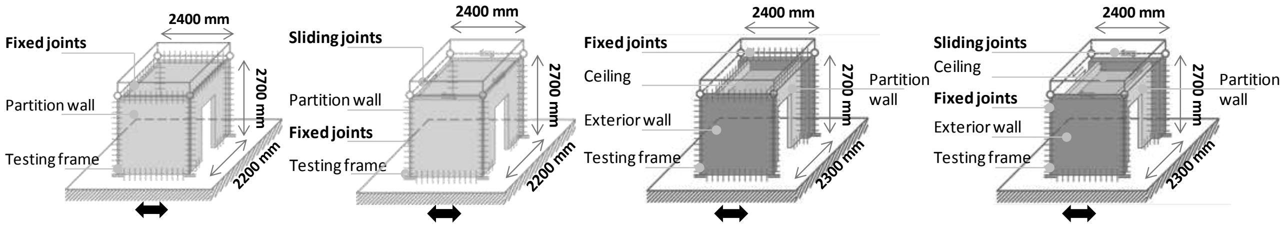


a) b)

Fig. 6 a) Joint and dowel types; b) Test set-up for out-of-plane quasi-static monotonic tests

5 DYNAMIC TESTS ON SHAKING TABLE ON FULL-SCALE SYSTEMS

In order to assess the response under seismic excitations of the non-structural systems object of the research, dynamic tests on shaking table have been included in the experimental campaign. The shaking table has a square plan of 3.00x3.00 m and its main characteristics are: two degrees of freedom, maximum payload equal to 20 t, acceleration peak of 1.0 g and displacements in the range +/-250 mm. The foreseen tests will be performed on three dimensional specimens by applying the seismic input in only one horizontal direction. In particular, two different specimen typologies will be considered. The first typology aims at investigating only the behaviour of partition drywalls. The specimen consists of four partition drywalls infilled between the columns of the set-up frame (III). Along the loading direction, the partition drywalls are 2400x2700 mm (length x height), while in the other perpendicular direction they are 2200x2700 mm (length x height). Two different joint configurations will be considered (Fig. 7a,b): (i) fixed joints all along the drywall perimeter and (ii) fixed joints along the drywall vertical sides and sliding joint at the top drywall horizontal side. The second specimen configuration is representative of a constructive systems consisting of two partition drywalls, two outdoor drywalls and a suspended ceiling (IV). In this case, the outdoor drywalls will be placed in the set-up frame along the testing direction, while the partition drywalls will be directly connected to them in perpendicular direction. The outdoor drywalls are 2400x2700 mm (length x height), while the partition drywalls are 2300x2700 mm (length x height). In the top field between the drywalls, a suspended continuous plasterboard ceiling will be installed. Also in this case, the two joint configuration above defined will be considered (Fig.7c,d). Table 6 summarises the test program and the different specimen configurations.



a) Fixed single drywalls b) Sliding single drywalls c) Fixed coupled drywalls and ceiling d) Sliding coupled drywalls and ceiling

Fig.7 Specimen configurations

Table 6. Programme of shaking table tests

Conf	System Position	System type	Wall length [mm]	Wall height [mm]	Wall thick. [mm]	Panel number and type	Studs h [mm]	Studs spacing [mm]	Upper joint type	Lateral joint type	No. tests
1	Load direction	Partition	2400	2700	125	2xGKB (A)	75	600	fixed	fixed	1
	Perp. direction	Partition	2200	2700	125	2xGKB (A)	75	600	fixed	fixed	
	Ceiling	-	-	-	-	-	-	-	-	-	
2	Load direction	Partition	2400	2700	125	2xGKB (A)	75	600	sliding	fixed	1
	Perp. direction	Partition	2200	2700	125	2xGKB (A)	75	600	sliding	fixed	
	Ceiling	-	-	-	-	-	-	-	-	-	
3	Load direction	Outdoor	2400	2700	200	Aquapanel outdoor	100+ 50	600	fixed	fixed	1
	Perp. direction	Partition	2300	2700	125	2xGKB (A)	75	600	fixed	fixed	
	Ceiling	Susp. ceiling	-	-	-	Diamant 15	-	-	-	-	
4	Load direction	Outdoor	2400	2700	200	Aquapanel outdoor	100+ 50	600	sliding	fixed	1
	Perp. direction	Partition	2300	2700	125	2xGKB (A)	75	600	sliding	fixed	
	Ceiling	Susp. ceiling	-	-	-	Diamant (15)	-	-	-	-	
										Total tests	4

The shaking table tests will be performed by using a purposely designed set-up structure. The set-up is a versatile 3D steel frame, which has been designed with aim of simulating the elastic behaviour, in terms of mass and stiffness, of different building interstorey. The lateral structural system of the 3D steel frame, along the loading direction, is a special eccentric bracing system with pre-tensioned diagonals (Fig. 8a). In fact, its diagonals can have different slope (angles from 64° to 83°) and cross-section area, in such a way to allow to the system different lateral stiffness. Therefore, changing the applied mass together to the variation of lateral stiffness, it is possible to obtain SDOF systems with a large range of period values. In order to obtain a structural response in the elastic range, the diagonals must not be loaded by an axial compression. In addition, the yielding stress of the diagonal members must exceed the maximum acting tension stress, which is a function of the maximum interstorey drift achieved during the test. Therefore, considering interstory drift angles of about 1%, diagonal members made of a ultra high strength steel grade (yielding and ultimate strength equal to 1200 and 1500 MPa, respectively) are required. In these diagonal members the

preloading force is applied by means the tightening of a system composed by three M39 high strength bolts. The 3D frame is stabilized in the direction perpendicular to the load by means of a X-bracing system in which the diagonals are made of S355 steel rods (Fig. 8b).
The base of the set-up frame is a grid of rectangular hollows beams connected to the base plate of the shaking table. In particular, these beams are arranged in such a way to provide a base for the different specimen configurations (Fig. 8c). A similar grid of beams, made with HEB 200 profiles, defines the top level of the set-up frame (Fig. 8d). On the top of this grid, steel plates are welded in order to provide a restraint for the concrete blocks, which reproduce the mass of the system. The bottom and top beam grids are connected by means of four hinged columns, having 200x200x14.2 mm hollow sections. The columns hinges are unidirectional along the loading direction. All the frame elements are made of S355 steel grade, with exception of the hinges plates, which are realized with S460 steel grades. Beams and columns have holes on the surfaces in contact with the partition/outdoor drywalls, in order to interpose the bricks that simulate the interface with a reinforced concrete building structure.

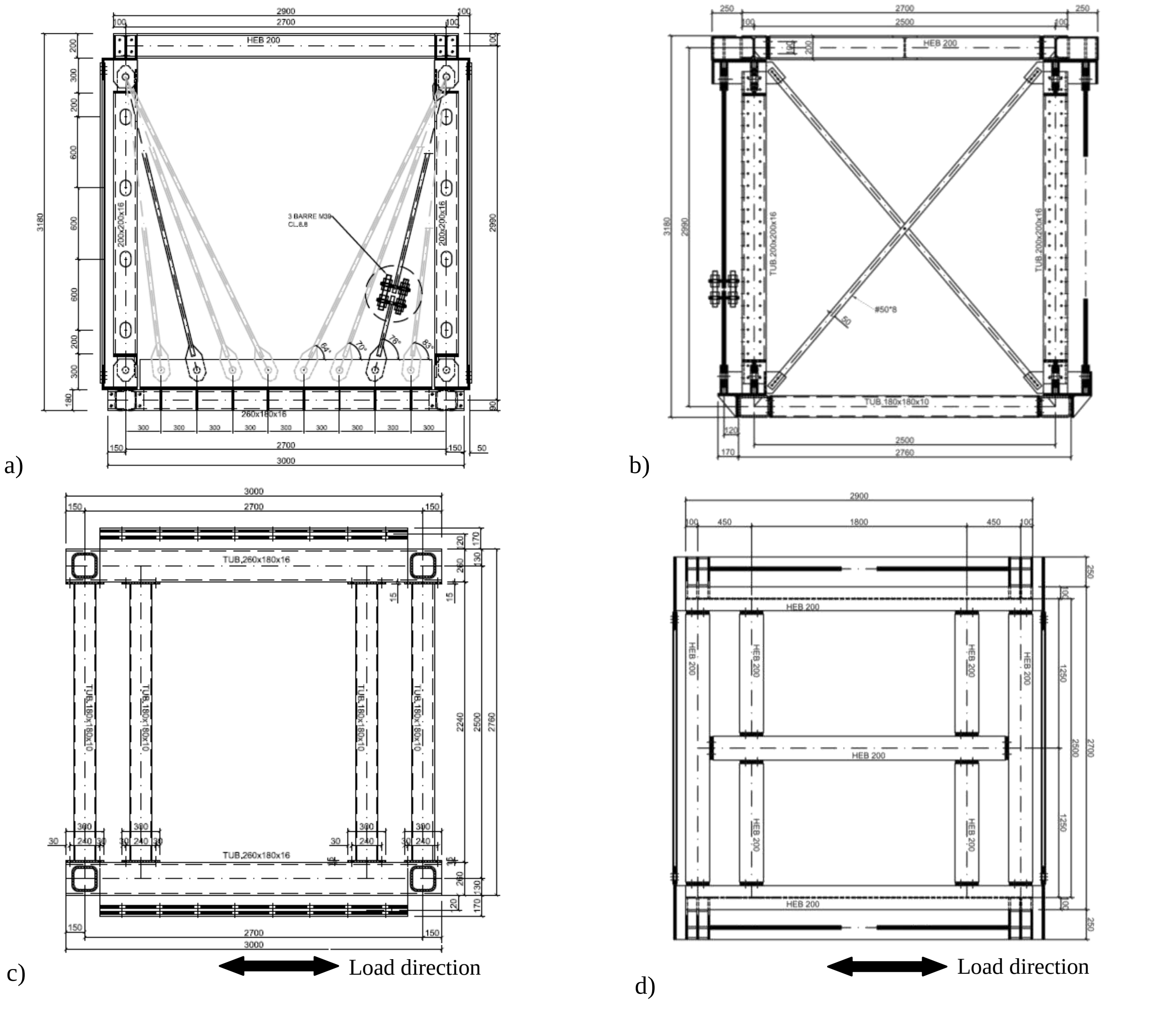


Fig. 8 Set-up for shaking table tests: a) special eccentric bracing system, b) X-bracing system; c) bottom beam grid, d) top beam grid

6 CONCLUSIONS

The paper presents the planning of a very extensive experimental campaign devoted to study the seismic response of non-structural building components produced by Knauf company, consisting of partition drywalls, outdoor drywalls, and suspended continuous plasterboard ceilings. The main activities of the research will involve tests on materials and main components, quasi-static tests on partition/outdoor drywalls and shaking table full-scale tests on whole systems made of partition drywalls, outdoor drywalls and suspended ceilings. In particular, for each test typology, test matrix, specimens and prototypes and tests set-up are described in the paper.

ACKNOWLEDGMENT

The authors acknowledge the Knauf company for the financial support to the research activity.

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