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Numerical model for the in-plane seismic capacity evaluation of tall plasterboard internal partitions

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ABSTRACT

A finite element model capable to capture the interstory drift which causes the failure of a 5 m high plasterboard partition with steel studs is defined by employing the Direct Strength Method (DSM) to assess the occurrence of different buckling failure modes. The model is validated comparing the numerical behavior with the experimental evidence of a quasi-static test campaign on a plasterboard partition. It is concluded that the model well catches the interstory drifts which cause either the local or the global buckling in the partition. This conclusion is also confirmed by the strain trend in the steel studs.

1. Introduction

Nowadays the seismic performance of nonstructural components is recognized to be a key issue in the framework of the Performance-Based Earthquake Engineering (PBEE). Four main issues motivate several studies related both to the evaluation of the seismic capacity and the demand of nonstructural components. Firstly, nonstructural components can cause injuries or deaths after an earthquake; for instance the 64% of the fatalities caused by 1995 Great Hanshin Earthquake was due to the compression (suffocation) of the human body [1]. Such a phenomenon could be caused by the damage to nonstructural components, that may also obstruct the way out from the damaged building. Moreover, nonstructural components generally exhibit damage for low seismic demand levels. The seismic performance of nonstructural components is especially important in frequent, and less intense, earthquakes, in which their damage can cause the inoperability of several buildings. Furthermore, the cost connected to nonstructural components represents the largest portion of a building construction. Taghavi and Miranda [2] evidenced that structural cost typically represents a small portion of the total cost of a building construction, corresponding to 18% for offices, 13% for hotels and 8% for hospitals. Finally, nonstructural components may participate in the lateral resisting system of the primary structure, i.e. varying its lateral strength and stiffness.

Plasterboard internal partitions with steel studs are very common nonstructural components, since they are typically employed in several building typologies all over the world. Different experimental studies aiming at the evaluation of the seismic capacity of such components are available in literature [3,4]. The seismic evaluation is typically expressed in terms of the Engineering Demand Parameter (EDP) that is required to reach a certain Damage State (DS). The interstory drift is typically selected as the EDP; the aim of these studies is therefore to evaluate the interstory drift that induces different damage states, i.e. from minor to major damage states, in the partition systems. In Kanvinde and Deierlein [5] a macro-model is presented in order to evaluate the seismic behavior of plasterboard partitions. The authors propose an analytical model to determine the lateral shear strength and initial elastic stiffness of wood and gypsum wall panels. In such a case, a uniaxial spring model is defined, by a series of parameters defining the backbone curve, which represents the nonlinear monotonic response that envelopes the cyclic response, and the cyclic nonlinear response including strength and stiffness degradation and pinching phenomenon. The parameters validation is performed by using experimental tests on full-scale wall panels. In Davies et al. [4,6] a description of the experimental results of full-scale tests performed on several cold-formed steel-framed gypsum partitions is reported. The experimental data, including different partition wall configurations, in terms of wall dimensions, material type, testing protocol and boundary conditions are used in order to create seismic fragility curves for such nonstructural partition walls. Moreover, on the base of experimental results, a tri-linear hysteretic macro-model is proposed to reproduce the in-plane mechanical behavior of the partitions: it allowed to include partitions in

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the model of an existing steel building in order to demonstrate the effect on the seismic behavior of the whole structure. A numerical macro-model for plasterboard partition is proposed by Wood and Hutchinson [7]; a pinching material model, available in OpenSees [8], is used in order to reproduce the in-plane behavior of the partitions. The 24 parameters of the model are calibrated by a large number of experimental data obtained from about fifty tests performed on plasterboard partition walls [4]. Telue and Mahendran [9] conducted experimental studies on cold formed steel walls lined with plasterboard. These studies point out that the stud compression strength increases when the steel internal frame is covered by plasterboard on one or both sides. A finite element model was developed and validated using experimental results. However, the behavior of the walls is investigated under compressive vertical loads. Fiorino et al. [10] proposed a seismic design procedure for sheathed cold-formed steel shear walls: through linear dynamic and nonlinear static analysis three nomographs are obtained in order to determine the features of a seismic resistant shear wall. An iterative procedure for the prediction of the pushover response curve of sheathed cold-formed steel shear walls is also presented. A computational model was proposed by Buonopane, Tun and Schafer [11] for the prediction of the seismic behavior of sheathed cold formed steel shear walls, based on experimental tests performed both on shear walls [12] and on screwed panel-to-stud connections [13]. Buonopane et al. [14] also developed a numerical model for the in-plane lateral behavior of cold-formed steel shear walls with wood panels, which captures the nonlinear behavior at the interface between cover panels and fasteners. Indeed, full scale lateral load tests on thirteen shear walls exhibited collapse due to the failure of the fasteners. The modeled walls, having a height of 2.74 m and widths of either 1.22 or 2.44 m, were able to predict the cyclic response of the tested specimens, up to the peak point of lateral strength. However, these research studies focused on steel stud shear walls, whose characteristics, e.g. stud typology, restraint at the base, failure mode, are different than in internal partition walls.

The evaluation of the seismic capacity of a plasterboard partition system is typically pursued through the experimental method. The development of a FEM numerical model of such a component would allow to investigate the seismic behavior of a generic partition, taking into account all its features, e.g. studs geometrical and mechanical properties, layer of plasterboards, etc. A detailed numerical model of cold-formed steel-framed gypsum partition walls is proposed by Rahmanishamsi, Soroushian and Maragakis [15]. The model, built in OpenSees, provides nonlinear behavior of studs and tracks, and nonlinear behavior of gypsum to stud and stud to track connections. The gypsum boards are simulated by linear shell elements. The contact between boards/tracks and concrete slabs as well as the contact between adjacent boards are also considered in the model. The model, validated by the comparison with experimental results on gypsum partitions walls, is able to predict the trend of the response and the observed damage mechanism. The failure of the tested partitions typically consists in the failure of gypsum-to-tracks/studs screws connections and/or crushing of gypsum boards. The developed numerical model does not incorporate failure due to buckling of the steel stud, which is the typical failure mode in tall plasterboard partition walls, as shown by Petrone, Magliulo, Lopez and Manfredi [16]. Moreover, the experimental tests used for numerical validation are performed on partition walls representative of US partition systems, whose features might be different than European ones.

The aim of this research study is the definition of a finite element model able to evaluate the interstory drift that induces the failure of tall plasterboard partitions representative of European partition systems commonly mounted in commercial and industrial buildings. Even if partition walls can be subjected to both the in-plane interstory drift and the out-of-plane acceleration, this study is focused only on the in-plane seismic performance assessment of partitions in existing structures. It is therefore assumed that the investigated partitions would not fail in the out-of-plane direction and that they are rigidly connected in their own plane to the main structure. A simple modelling technique is proposed and validated. The validation is performed comparing the numerical behavior of a specific specimen with the experimental results achieved in a quasi-static test campaign conducted at the Laboratory of the Department of Structures for Engineering and Architecture at the University of Naples Federico II. The quasi-static test is performed on a 5 m tall plasterboard internal partition [16], which is representative of the typical partitions used in industrial and commercial buildings in the European countries.

2. Methodology

2.1. Experimental test on the plasterboard partition specimen

In this Section the experimental test performed on the considered plasterboard partition specimen is illustrated. The test campaign, exhaustively reported in a previous paper [16], is here briefly described. Particular attention is given to the description of the tested partition and the mounting procedure in order to justify the finite element modelling of the specimen, included in Section 2.2. The test system consists of a steel frame setup, the specimen, i.e. a plasterboard partition, a hydraulic actuator and a reaction wall (Fig. 1).

The steel test frame is conceived as a statically indeterminate scheme, since it is not designed to simulate the performance of the structure itself but just in order to transfer the load provided by the hydraulic jack to the partition without absorbing lateral forces. Moreover, since the reaction wall cannot reach the height of the system, the actuator is placed at the middle height of the test setup (Fig. 1). In this way, a given displacement produced by the actuator is doubled at the top of the setup, assuming a rigid behavior of the vertical column. The different elements are connected by pin connections, according to the assumed mechanism.

The specimen is 5.0 m high and 5.13 m wide and it is constituted, according to the mounting sequence, by:

- two horizontal U guides made of 0.6 mm thick galvanized steel, screwed, both at bottom and at top, in the wooden beams by 200 mm spaced screws;
- two vertical U guides made of 0.6 mm thick galvanized steel, screwed in the wooden beams by 500 mm spaced screws;
- five C-shaped studs made of 0.6 mm thick galvanized steel, 900 mm spaced; they are placed in the horizontal guides without any mechanical connection (see Fig. 2a);
- two steel plates (Fig. 2b), with a rectangular cross-section 100 mm × 0.6 mm, connected to the studs at two different heights of the partition, i.e. 1200 mm and 3800 mm from the base; the steel plates

Fig. 1. Global view of test setup.