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SEISMIC PERFORMANCE OF COLD FORMED NON-STRUCTURAL PARTITION USED FOR ENREGY RETROFIT

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Abstract

In the last years a great attention was focused on the behavior of the non-structural component as well as their influence on the overall seismic behavior of buildings. Cold formed steel (CFS) constructions made with drywall façade are one of the most widely investigated and adopted non-structural partition typology. In this framework, the Department of Engineering (DING) of University of Sannio (Italy) started a research activities to investigate the structural performance of the non-structural partition properly designed to provide both an energetic and structural benefit, limiting the partition thickness. The aim of the present work is to investigate the structural efficiency of the introduced innovative system and its effectiveness to avoid the overturning. To this aim a refined finite element model (FEM) was developed to numerically investigate the performance of the partition and the maximum capacity of the adopted cold formed steel profiles

Keywords: Non-structural elements, Cold formed steel, Seismic strengthening, Numerical analyses, Energy retrofit.

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1 INTRODUCTION

Masonry infills are widely used in the Mediterranean area as closing elements for buildings with a reinforced concrete or steel frame structure. In building design practice, infills are considered non-structural elements which take on considerable importance from an energy and acoustic point of view as they constitute the building envelope. However, the Italian code [1-2] pays particular attention to the issue of non-structural elements which, if not designed correctly, can generate collapses and reduce the safety of structures.

More specifically, the phenomenon of the expulsion of infills outside their plane appears to be a problem of crucial importance for the safety of users and appears to be the cause of huge economic losses as evidenced by the damage reported during the most recent seismic events which occurred both in Italy and worldwide [3-6].

These non-structural elements, when subjected to seismic action, are sensitive to in-plane displacement and out-of-plane accelerations. It should be underlined that the in-plane damage of the infill, caused by the deformation of the surrounding frame, causes a reduction in the out-of-plane resistance, increasing the weakness with respect to the overturning phenomenon. This latter mechanism depends on the geometrical (slenderness) and mechanical features (elastic modulus and strength) but it is substantially affected by the constraints along the structural frame [7].

For the evaluation of the seismic safety of masonry infills for out-of-plane actions, numerous scientific works are nowadays available in literature [8].

Different regulatory formulations can be used to calculate the demand for acceleration to the floors [9] while, for the assessment of capacity, a single, reliable and commonly accepted model has not yet been defined [10].

Many different strengthening interventions were investigated to increase the out-of-plane capacity of the infill belonging to the existing building [11]; among them, also steel cold formed (CFS) solutions, already largely adopted for the seismic resistant structures [12-14], are nowadays used as possible strengthening solution. In particular, the CFS solutions could be easily adopted for an integrated structural and energetic retrofit of the existing building.

Within this framework, the Favima s.r.l. introduced an external coating mainly designed to increase the energetic performance of the existing building but that allows at the same time to increase the local capacity of the existing infill against the out-of-plane failure.

Therefore, the main aim of the present work is to investigate the effectiveness of the out-of-plane strengthening provided by the innovative CFS non-structural partition; thus, a refined non-linear numerical model was properly developed to define the local capacity of the introduced strengthening solution.

The present work is divided into four parts: in the first part the main geometrical and mechanical features of the CFS non-structural partitions are presented; in the second part, the out-of-plane resisting system is presented and its design procedure is discussed. In the third part the main modelling assumptions are presented and finally in the last part the numerical results are discussed.

2 ISOLAREFLEX SYSTEM

2.1 General description

The Isolareflex system is an insulation solution to be applied on the external façade of existing buildings consisting in steel structure with a zinc magnesium coating, to which one or more layers of heat-reflecting insulation and a fiber cement panel are anchored, all interspersed with two air chambers (see Figure 1). This system has the main aim to provide summer/winter thermal protection as well as acoustic improvement.

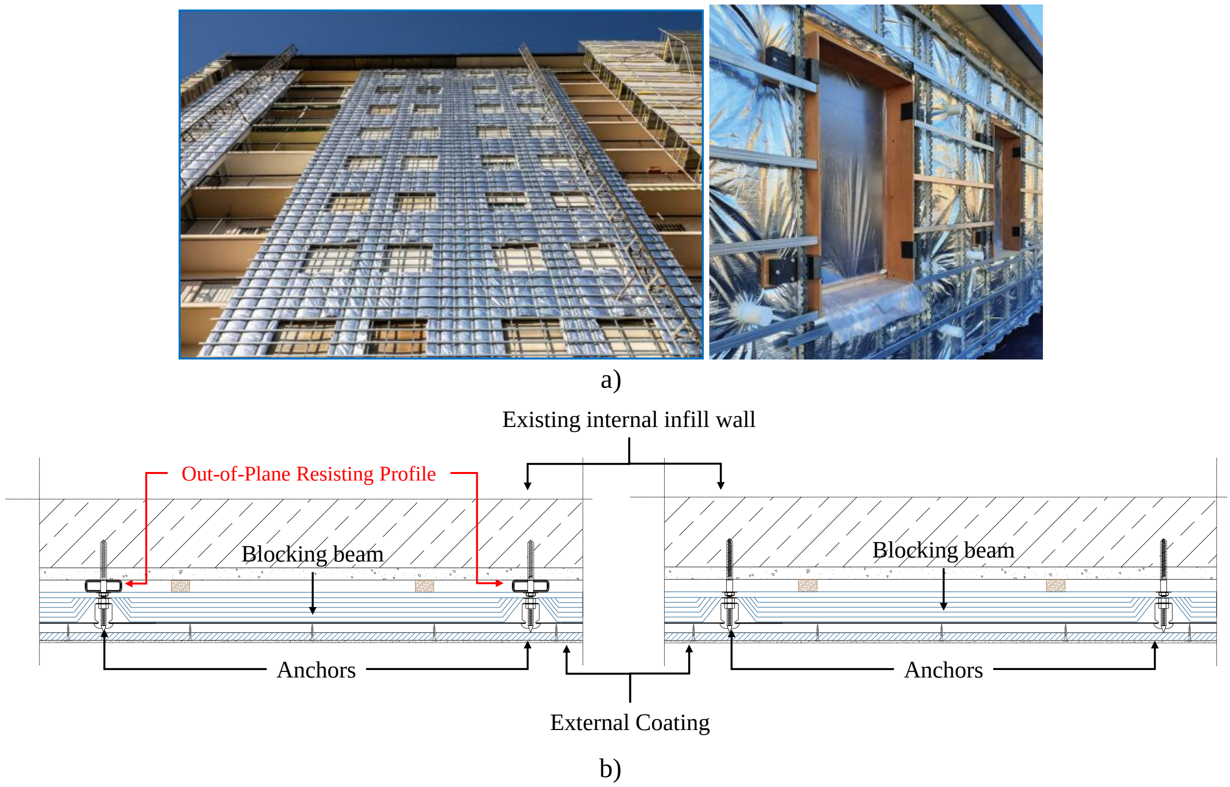


Figure 1: Isolareflex system features: examples of application (a), planar view of the system with and without the out-of-plane resisting system (respectively b and c).

Form the energetic point of view, the system effectiveness was experimentally investigated and certified, however this aspects were are not directly investigated in the present work.

From structural point of view, the Isolareflex system is constituted by a set of cold formed steel (CFS) vertical studs mechanically connected to horizontal blacking beams, at which the insulation panels are applied. The vertical U-Studs are connected to the existing infill by means of anchors distributed along all the height of the steel profile; while the insulation panels are supported by the blocking beams.

The systems is properly designed for seismic application, indeed the connection between the U-Stud and the beam is conceived to allow the horizontal displacements and in case of seismic action, to decouple the infill displacements with respect to the insulation system. The efficacy of this rigid connection was experimentally tested at San Giuliano Milanese headquarters of the Institute for Construction Technologies (ITC) of the CNR (National Research Centre) specific laboratory, where a rigid displacements, between the CFS profiles, was observed, preventing any damage within the coating elements (see Figure 2).

Moreover, additional experimental tests were performed to ensure the system resistance (as for instance against the wind action); all the experimental activities performed by the producer are listed below:

a. Seismic characterization test. A wall sample measuring 2800 mm x 3200 mm was subjected to an in-plane and out-of-plane quasi-static cyclic test and four dynamic tests. The test scheme of the wall sample is shown in Figure 2a;
b. Dynamic wind uplift test. A wall sample measuring 3400 mm x 3900 mm was subjected to incremental wind pressure load cycles;

c. Shear resistance of the support;
d. Pull-out;
e. Tensile strength of metal profiles;
f. Shear resistance of metal profiles.

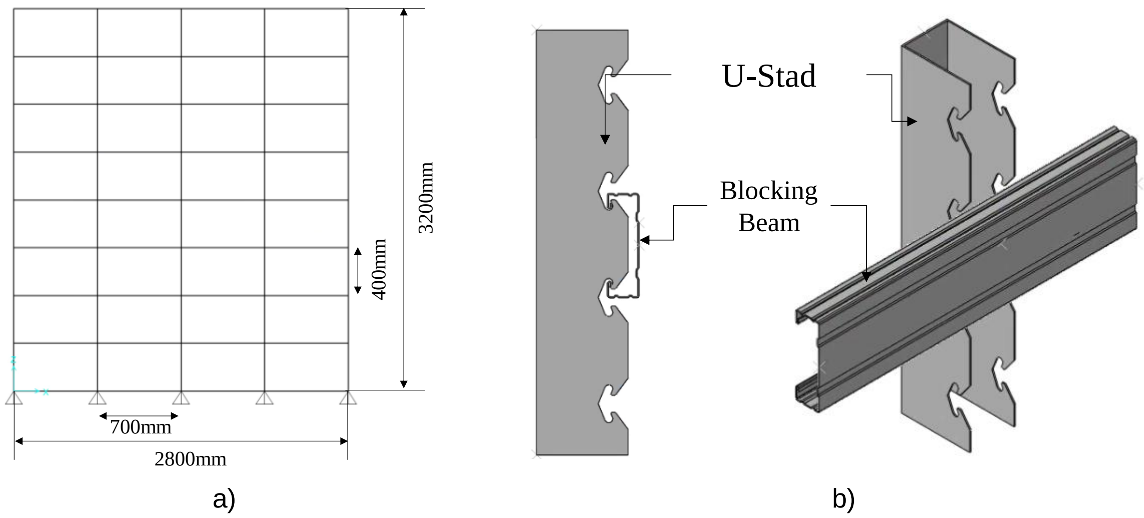


Figure 2: Geometrical features of the whole system (a) and the connection between the vertical "U-Stud" and the blocking beam (b).

2.2 Out-of-plane behavior

The Isolareflex system is also conceived to provide a local strengthening of the existing building increasing the infill partition out-of-plane resistance (see Figure 1a). In particular, this system could be designed to include, between the infill partition and the U-Stud, an additional steel hollow profile, connected to the structural elements of the existing building by means of steel anchors.

The steel profile should be connected at both top and bottom sides of the existing building beams as depicted in Figure 3. The steel profile as well as the connection features should be properly designed accounting for the seismic action at each floor of the building in function of the degree of constraint of the partition to the surrounding frame (i.e. connected or not to the top beam) and its resistance.

The design demand ($N_{Ed,OfP}$) on the out-of-plane system, in a conservative way could be defined equal to the whole action at the investigated plane; however this approach could imply a large use of the profile resulting uneconomical. Therefore, the adopted design procedure define the demand on the strengthening solution, accounting for the existing partition resistance.

In order to evaluate the maximum resistance of the proposed out-of-plane strengthening solution, three alternative configurations were numerically investigated. In the first configuration only the steel profile and the r.c. frame were modelled, thus totally disregarding the connection between then. Contrarywise, in the second and third configurations the connections and the anchors were properly modelled, in particular two and three anchors (for both top and bottom beams) were introduced respectively. Table 1 summarize all the investigated strengthening configurations and their assumptions.

It should be noticed that in the present work, an hollow rectangular steel profile and post-installed Shark-Pro anchors with a diameter of 12mm were adopted for all the investigated scenarios.

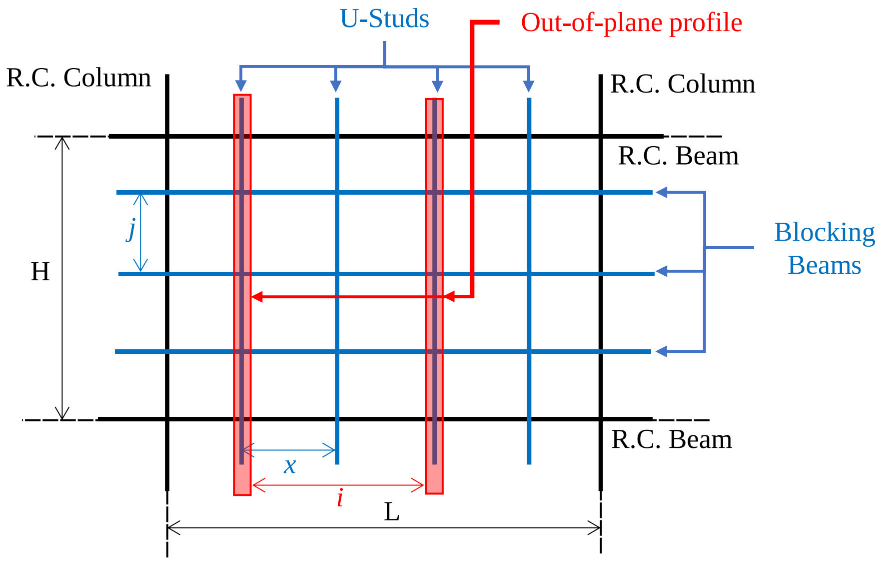


Figure 3: Description of the chord profile adopted and the global geometrical dimensions.

Investigated Configuration	Label	Applied load	Assumptions
1	Conf. Unif	Distributed and concentrated load	A perfect tie contact between the beam and the out-of-profile was assumed
2	Conf. 2 Anchors	Distributed and concentrated load	The connection was properly modelled and two anchors (for both top and bottom beams) were assumed
3	Conf. 3 Anchors	Distributed and concentrated load	The connection was properly modelled and three anchors (for both top and bottom beams) were assumed

Table 1: Investigated specimens

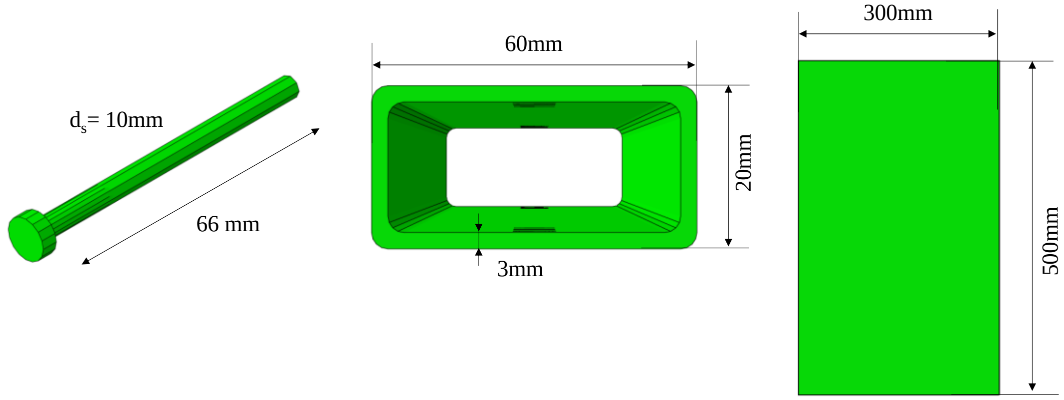
3 MODELLING ASSUMPTIONS

The advanced finite element analyses (FEAs) were performed using ABAQUS 6.13. The geometrical configuration of the adopted model is depicted in Figure 4. As it can be observed, in order to reduce the computational effort, in a simplified way, only one steel profile was modeled within a reinforced concrete frame.

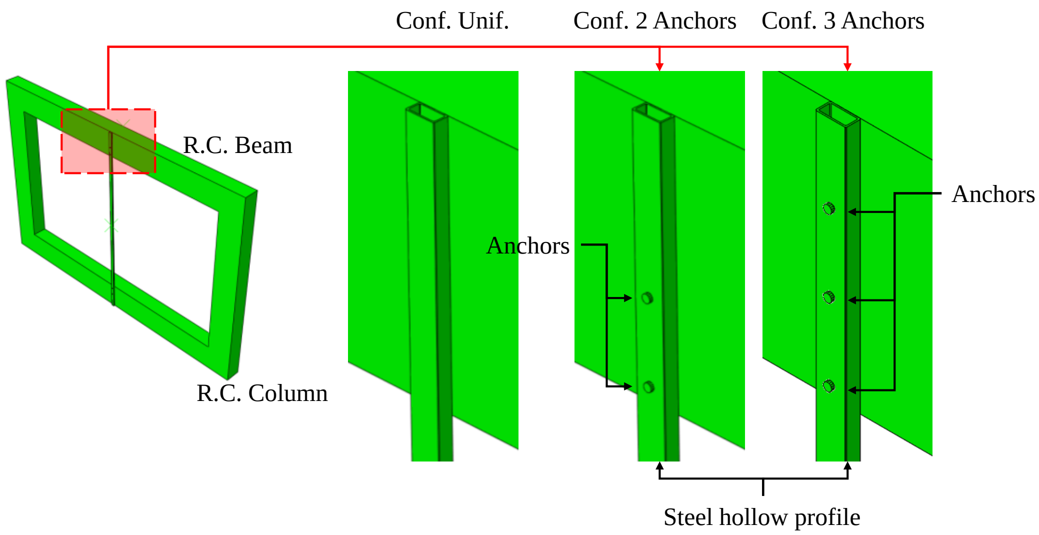
All the elements were modelled using C3D8R solid element type (i.e. 8-node linear brick, reduced integration), while the mesh density of each element was defined starting from the results of the sensitivity analyses reported by Milone et al. [15]. Thus, a mesh size equal to 20 mm was set for reinforced concrete elements as well as the hollow steel profile; contrariwise the anchors were discretized by means of a 5 mm mesh, with at least two elements through the thickness.

Von Mises criterion was used to model steel yielding, and both kinematic and isotropic hardening were accounted for by means of material parameters. Contrariwise, the concrete was modelled in line with the assumptions presented by [16].

The “Surface-to-Surface” interactions were adopted to model contact among the elements; in particular, “Hard contact” formulation was used to model normal contact while a “Penalty” formulation was considered for tangential behavior, with the friction coefficient being equal to 0.3. The contact between the screw and the concrete beams was modelled as perfectly rigid by the introduction of the “Tie” contact.



a)



b)

Figure 4: Finite element model (FEM) main features: all the modelled elements (a) and two investigated configurations(b).

Moreover, as anticipated, three systems configurations are hereinafter investigated: one considering a perfectly rigid connection between the r.c. beam and the steel profile (i.e. called “Conf.-Unif”), one in which the connection was properly modelled with its real dimensions and two anchors (for each beam) were modelled (i.e., called “Conf.-2 Anchors”). Finally in the last configuration (i.e., called “Conf.-3 Anchors”) three anchors were applied.

4 NUMERICAL RESULTS

The numerical results of all the investigated configurations are depicted in Figure 5 and Figure 6 in terms of force displacements curves and equivalent plastic deformation (PEEQ).

Comparing the model with a different connection it can be observed that for low value of imposed displacements, the three investigated configurations provide almost the same results, while increasing the applied displacements the connection behavior influence the system maximum capacity. In particular, the first configuration (i.e., Conf. Unif.) shows an linear behavior up to 450mm of displacement, after that a large concentration of plastic deformations on the hollow profile can be observed (see Figure 5a); the same behavior can be observed also changing the loading distribution (see Figure 5c).

Therefore, as expected, when the connection is not accounted for, and the contact between the steel reinforcements and the r.c. beam is modelled as "perfect tie", the capacity of the out-of-plane is mainly governed by the maximum capacity of the steel profile. In particular, the maximum resistance related to the steel profile is equal to 140kN (when a distributed load is modelled), while when the connection is properly accounted for a reduction 60% and 80% is observed respectively for the Conf.3 and Conf. 2 specimens. The same considerations can be observed also in Figure 5c, for the same model, but where a concentrated force was applied in the middle of the hollow steel profile; in these cases the resistance reduction between the Conf. Unif. and Conf. 3 and Conf. 2 is equal to 45% and 80% respectively

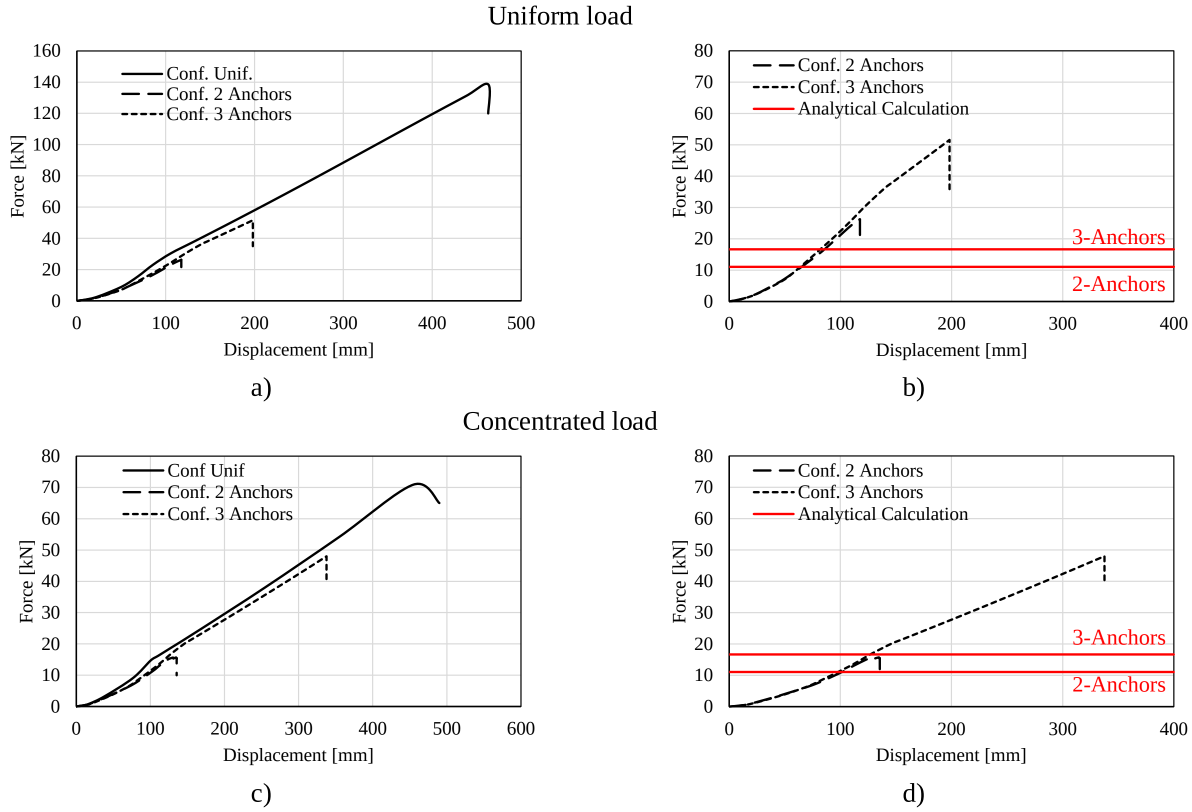
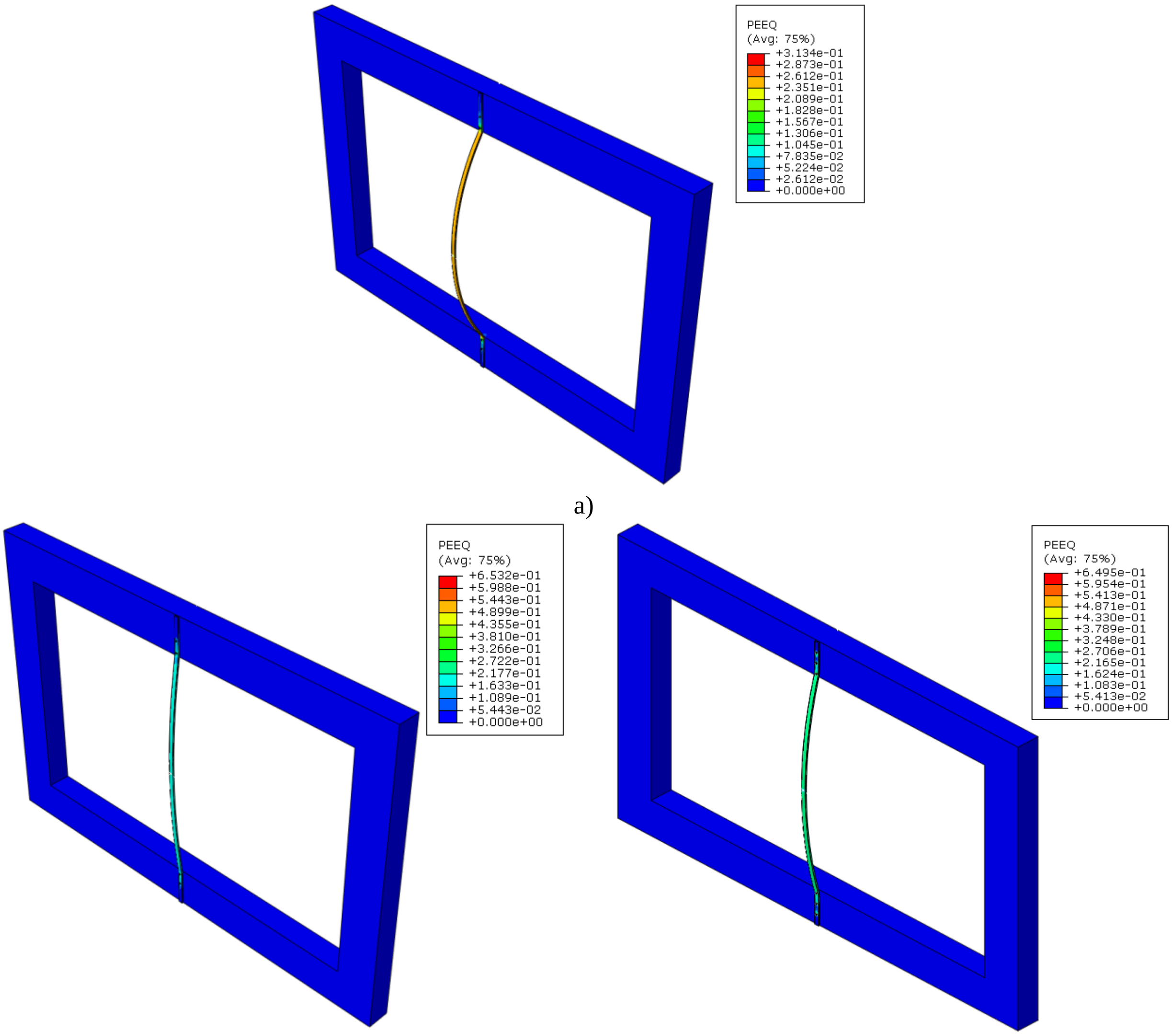


Figure 5: Numerical results of the investigated configurations in terms of Force – displacements curves in case of distributed loads (a and b) and concentrated force in the middle of the steel profile (c and d).

Comparing the behavior of the Conf. 2 and 3, it can be observed that the maximum system capacity is not directly proportional to the number of the adopted anchors; indeed the increase of the number of anchors allows to an increase of both resistance and stiffness of the connection (see Figure 5b and d). Therefore, the introduction of an additional anchors allows to better maximize the internal action on the second anchors row.

Thus, as pointed out in Figure 6, when the connection is properly modelled in the numerical simulation, all the damage is concentrated within the anchors while only small plastic deformation are localized within the steel profile, leading to a large reduction of the system capacity.

Finally, a quite good agreement could be observed comparing the analytical prediction (i.e., accounting for the design pull-out resistance of the anchors evaluated starting from experimental results) with the result of numerical simulations; in particular in all the investigated cases, the analytical procedure results the most conservative approach with respect to the numerical results.



c) b)

Figure 6: Results in terms equivalent plastic deformation distributions (PEEQ) of: Conf. Unif. (a), Conf. 2 Anchors (b) and Conf.3 Anchors (c) accounting for a distributed loads.

5 CONCLUSIONS

In the present work, the seismic performance of an external non-structural CFS system were numerically evaluated; in particular, the investigated system is intended as an external coating partition, mainly devoted to increase the existing structural energetic performance of existing buildings. In addition, the investigated system is designed to increase the local performance of the infill wall where it is applied. Thus, the present work was mainly focused on the definition of the strengthening contribution provided by the investigated system with respect to the out-of-plane failure.

In particular, the investigated system allows to insert a hollow steel profile positioned behind the U-studs and connected to the r.c. beam of the existing building to increase to out-of-plane capacity of the existing infill wall. The effectiveness and the resistance of the introduced strengthening system is numerically investigated; in particular three alternative configurations were investigated. Form the numerical results, the following conclusions can be pointed out:

- the introduction of the vertical steel profile connected to the surrounding structural elements allow to increase the whole out-of-plane resistance; however the effectiveness of this system is related not only to the adopted steel profile but also to the connections performances.
- The anchors are not only subjected to tensile action but, due to the profile deformation, also to shear and bending moment; therefore, in the design phase the nominal tensile resistance should properly take into account. In the present work, the analytical resistance was evaluated starting from the pull-out test results performed on the adopted anchors.
- The internal action on each screw is function of its position, in particular the fasteners closer to the beam edge are the most stressed and will the most subjected to the failure; thus, the assumption of an equal distribution of the internal action in all the screw could lead to a failure of the screw line.
- In all the investigated cases, the analytical assumptions ensure a design resistance conservative with respect to the numerical simulations.

It should be noticed that despite all the numerical analyses were performed considering only the rectangular hollow steel profile the obtained results could be extended to any steel profile and connection compatible with the maximum thickness requirements of the Isolareflex system.

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