IMPROVING DUCTILITY AND ENERGY-DISSIPATION CAPACITY OF INFILLS BY MEANS OF POLYMERIC NETS

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SUMMARY

The role of first line of defence against earthquake played by masonry infill panels has been recognised by many researchers. Provision for increasing the ductility and the energy dissipation capacity of masonry infill panels are under study in the framework of a currently active research programme, funded by the European Commission. The problem has been focused on the possibility of confining the panels by using polymeric grids. The effectiveness of this solution was investigated by performing tests on differing patterns of infills.

The effectiveness of the adoption of the proposed methodology has been studied at the European Laboratory for Structural Assessment (ELSA). Two infill layouts with dimensions of 4.6m x 2.6m, one without openings, the other with non-symmetrical openings (a door and a window) have been analysed. In the paper the results of full-scale in plane cyclic tests on panels confined with the grids are compared with the behaviour of the panels in the same configuration, but constructed by using the conventional technique. The comparison between the response of the different panels seems to demonstrate that the energy dissipation capacity of infills can be strongly increased by confining the walls by means of the polymeric grids.

INTRODUCTION

In many highly seismic prone countries in southern Europe, a commonly used structural system consists of reinforced concrete frames with masonry infill panels. Many researchers have already demonstrated that, even though infills are regarded as non-structural elements, they can significantly modify the seismic response of the structure [e.g. Mainstone, 1971; Bertero and Broken, 1983; Zarnic and Tomazevic, 1985; Negro and Verzeletti, 1996]. One of the effects of the presence of the panels is the increased capability of the building to dissipate energy.

By increasing the capacity of the infills to dissipate energy, the structure as a whole could become less vulnerable with respect to earthquakes. In particular, for the case of earthquakes characterised by a low return period, this capability of the panels can preserve the structural elements from being damaged.

A research program, funded by the European Commission, aimed at investigating the possibility to increase the intrinsic ductility and the energy dissipation capacity of panels, was started in 1997. After the necessary numerical studies and material testing, it was proposed to confine the masonry infill panels by using high-density polymeric grids [Sofronie and Popa, 1998]. It was suggested to adopt this methodology both for new construction and for existing buildings. For the second case, this technique could be used for repairing damaged infills or for improving the mechanical properties of existing infilled structures. The polymeric grids were intended to be fixed on both sides of the infill panels by special connection devices that are polypropylene elements with stainless steel core. These elements ensure that the plastic nets are fully encompassed by the sprayed mortar. In the case of new construction, the additional insertion of horizontal layers of plastic grid every three or four brick rows was proposed.

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As a part of the research programme, both material testing and full-scale confirmation tests were conducted, with the aim of assessing the proposed technique as well as of providing the necessary data for the calibration of the numerical models to be used in the following parametric analyses.

In the current research practice there are two approaches to the infilled frame modeling: refined models of the nonlinear Finite Element type and phenomenological Macro models (typically of the equivalent diagonal strut type). For engineering practice macromodels are more suitable, since they are computationally efficient and most appropriate for nonlinear seismic response analyses of complete structures. Accordingly, considerable effort has been devoted by many authors [e.g. Klingner and Bertero, 1976; Panagiotakos and Fardis, 1994; Zarnic, 1994; Combescure and Pegon, 1996] to the development, calibration and computer implementation of such models. The main parameters of the multilinear loading curve to be identified are those that determine the location of the cracking and ultimate strength. The slope of the post-ultimate softening branch and the residual strength, also important in order to better represent the behavior of panels, are usually more difficult to identify. This fact is mainly due to the impossibility to extract, from the available test results, the contribution of the surrounding frame.

Important information regarding the strength degradation of panels was also obtained from the tests. In particular, the modifications caused by the strengthening of the panels on the envelope curve describing the seismic behavior of masonry infills, is discussed in details.

DESCRIPTION OF THE EXPERIMENTAL ACTIVITY

The effectiveness of the proposed provisions has been investigated by performing full-scale in-plane cyclic tests. The behaviour of solid infills and infills with non-symmetrical openings (Figure 1) has been analysed. It was decided to re-use a three-storey steel frame already available at the ELSA Laboratory. The panels were constructed on the ground floor (dimension 4.60m x 3.15m) of the two parallel frames on a 0.55m high concrete base in order to preclude any influence of the stiffeners at the base of the columns. With the aim of further reducing the contribution of the frame to the behaviour of the panels, the columns were partially cut at both ends.

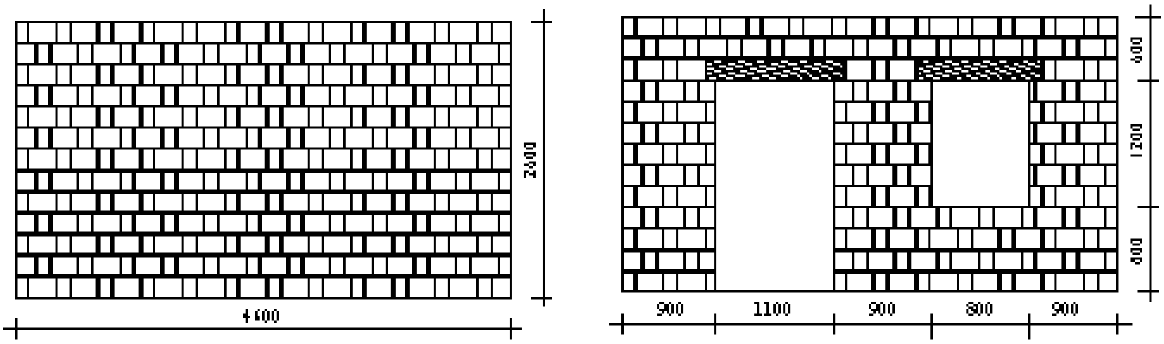

Fig. 1: Layout of the panels (dimensions in mm).

The same bricks used in previous experiments carried out at the ELSA Laboratory were used. They were vertically perforated bricks of dimensions 250x190x120mm with 42% void ratio. The panels had a thickness of 250mm, achieved by using a Flemish bond pattern. A large amount of data about the mechanical properties of the bricks and the corresponding plain masonry was available from the above-mentioned studies [Negro et al., 1995, 1996]: the compressive strength of the bricks was respectively 13.3MPa in direction normal to the bed joints and 3.3MPa parallel to the bed joints. Using a class M3 mortar, the compressive strength of 120mm thick wallettes was 7.3 MPa normal to the bed joints and 2.4 MPa in the orthogonal direction. The mechanical properties of 250mm thick wallettes are not yet available.

The design of the reinforcement was performed by ECOLAND, one of the partners of the project. The adopted polymeric net had a 40x40mm ribbed mesh. The plastic material had strength of 30kN/m, determined in accordance with BS 6906. The scheme adopted for the panel with openings is reported in Figure 2. This configuration was proposed for the construction of new infills. A simplified configuration, suitable for the rehabilitation of existing structures, is also being studied as a part of the project. A slice of the polymeric net, bent at 90 degree in order to obtain a “C” shape, was inserted all around the openings and between the frame and the panel. Other “C” shaped elements were inserted every three or four brick rows. A sheet of the net was then fixed on both sides of the infill panels by the special connectors, the purpose of which was to ensure that the grids were fully encompassed by the sprayed mortar. This scheme was expected to ensure the full global confinement of the panels by the confinement of reasonably sized portions of it.

Fig. 2: Scheme of the plastic net for the wall with openings.

One of the two parallel frames was equipped with a conventional plain panel, whereas the other with the same configuration of openings, but strengthened with the plastic grids. This solution allowed the direct comparison of the behaviour of the panels to be made.

The imposed cyclic history consisted of a set of cycles of pre-defined displacement, the level of which was increased up to the collapse of the panels.

In the following paragraphs the behaviour of the panels is discussed in details. The differences in the performance of the panels with and without polymeric nets have been identified by analysing the envelope curve of the hysteresis loops expressed in terms of shear force vs. storey rotation.

Solid panels

The envelope curves extrapolated from the hysteresis loops of the panels without openings are presented in Figure 3 for both the plain masonry panel and the panel with polymeric net. It can be observed that the application of the displacement cycles of small amplitude (corresponding rotation smaller that 0.002rad) resulted in substantially similar behaviour in the two panels. By increasing the amplitude of the load beyond this level, the maximum shear strength of the conventional panel was very soon reached. Whereas the rotations corresponding to the ultimate strength for the plain and reinforced panels are quite close, the maximum force of the strengthened panel resulted 12% larger than the one of the conventional panel. Both panels were characterised by a non-symmetrical response in the two direction of loading, thus confirming that the behaviour of the masonry panels is strongly influenced by the previously suffered deformations [Zarnic, 1994].

The most significant stage of the panel response is the softening branch. The effects of the confinement obtained by the insertion of the plastic net can be seen from the diagrams as a change of the envelope slope. Plain walls are usually characterised by a large drop in the shear strength. By using the polymeric grids, this drop is strongly reduced. This result is of particular importance as for the ability of the panels to dissipate a larger amount of energy.

These curves allow the evaluation of some basic properties of panels, needed for the calibration of numerical models, to be made. In particular, some important information regarding the strength degradation can be obtained. Klingner and Bertero (1976) proposed a skeleton curve in which the softening branch falls exponentially with the amount of deformation. According to Panagiotakos and Fardis (1994), the strength decay should be described as a linear function of the deformation. The results presented in this paper show that the strength degradation of the unreinforced panel can be modelled with good approximation by an equation of the type $F = a \cdot \theta^{\beta}$, where F is the maximum shear force, θ is the storey rotation, a is a constant depending up on the mechanical characteristics of the panels, and β is the parameter defining the strength degradation. The coefficient β turns out to be 0.60 for the branch of the curve characterised by the maximum strength (positive side for this test), and 0.50 for the opposite one. In terms of initial and cracked stiffness, apparently there is no difference between the plain and the strengthened panels. On the other hand, the strength decay characterising the reinforced panel turns out to be a linear function of the deformation, which is in agreement with the model proposed by Panagiotakos and Fardis. The results obtained are given in Figure 3 in dotted lines.

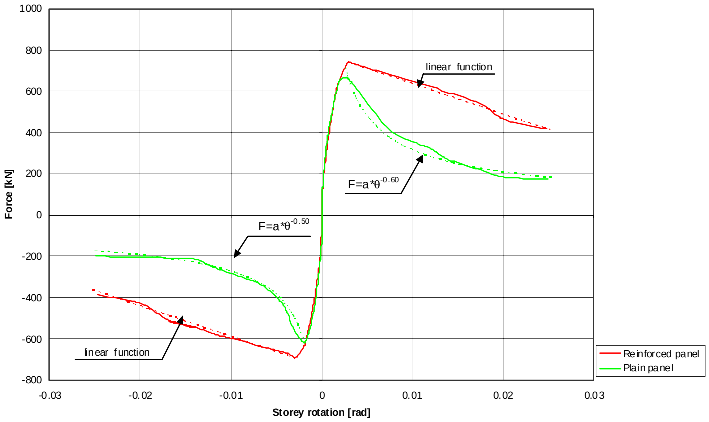

Fig. 3: Envelope curves for the solid infills.

Finally, it has to be mentioned that the failure mechanisms of the two panels were noticeably different. This could be noted by looking at the final resulting damage pattern reported in Figure 4. A mechanism of the diagonal type took place for the conventional panel. The failure of the strengthened infill was caused by a shear mechanism, as clearly shown by the large horizontal cracks that appeared in the central part of the wall.

a) **b)**

Fig. 4: Failure mechanism of the plain panel a) and of the reinforced panel b).

Panels with openings

The difference in the responses of the plain and the confined panels was much more significant for the case of panels with non-symmetric openings (Figure 5). The unreinforced infill totally collapsed at a displacement corresponding to a storey rotation of about 0.03. At this level of deformation the panel with the plastic grid, even though dramatically damaged (see Figure 6), was still able to provide 65% of its maximum strength. The effects of the confinement accomplished by the insertion of the net resulted in a significant shift of the yielding point up to larger forces (the difference on the shear resistance was about 40%) and larger rotations (from 0.006 to 0.015).

The other parameters defining the energy dissipation were not affected by the insertion of the polymeric grids. The shape of the cycles of the plain and reinforced panels turned out to be almost identical as far as the unloading branches are concerned, as it can be seen in Figure 7. This means that by the adoption of the proposed methodology, the panel could be able to dissipate an important amount of energy without major strength decay up to large storey rotations. This level of deformation is close to the limit fixed by the Eurocode 8 for the check of the serviceability Limit State. As a result of the capability of the panels to dissipate such a large amount of energy, these elements could act as dissipation devices, strongly reducing the damage in the structural elements.

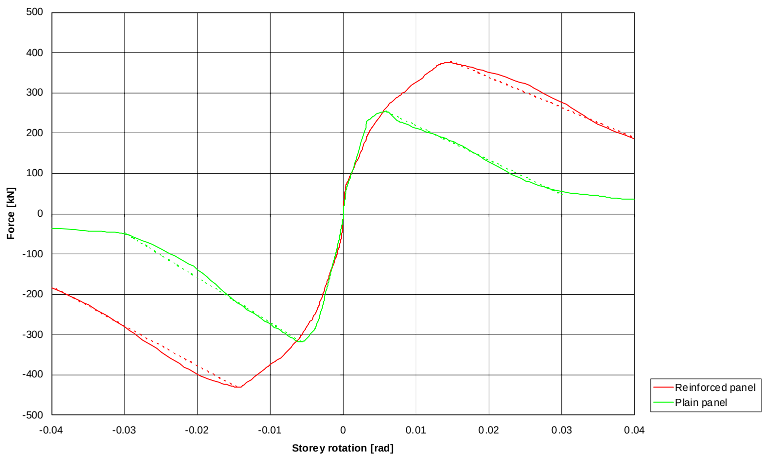

Fig. 5: Envelope curves for infills with openings.

Fig. 6: Damage pattern in the panel with openings, with polymeric nets.

As for the previous test, the response of panel with openings was a non-symmetrical function of the imposed load. In this respect, one can note that the difference in the response of the masonry wall in the two directions was reduced by the confinement accomplished by the plastic net.

The decrease of the resistance in both curves seems to be a linear function of the rotation, as reported in Figure 5 in dotted lines.

CONCLUSIONS

The results of the tests presented in the paper seem to demonstrate the effectiveness of the adoption of the plastic net in increasing the energy dissipation capacity of masonry infill panels.

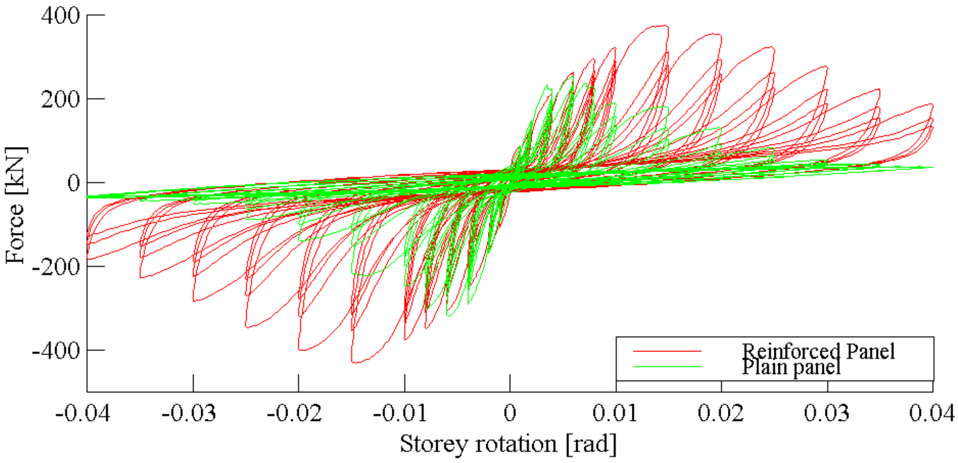

Fig. 7: Comparison of cycles for plain and reinforced panels.

The comparison between the behaviour of the tested panels showed that the adoption of this methodology could strongly modify the strength-decay characteristics of the panels. In particular, it was observed that the severe drop characterising the softening branch of the strength-deformation relationship for traditional infills can be replaced by a linear decrease of the strength. This modification may allow a significantly larger amount of energy to be dissipated. For the case of panels with openings, the proposed provisions also result in a shift of the ultimate shear strength towards larger forces and deformations.

With reference to earthquakes characterised by low return period the strengthened panels could act as the main line of defence against the earthquake. Being able to dissipate a larger quantity of energy, they could strongly reduce the storey deformation and, consequently, the damage in the structural elements.

According to these results, the insertion of plastic grids in the plaster may also represent a viable solution for the seismic rehabilitation of existing structures.

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