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Analysis of masonry structures strengthened with polymeric net reinforced cementitious matrix materials

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ABSTRACT

The seismic rehabilitation techniques of masonry structures based on the use of plasters reinforced with steel nets have been widely utilized in the last decades. More recently nets made of materials other than steel have been used as plaster reinforcement, among them there are the polymeric nets. These nets allow to overcome some of the limitations of the other strengthening materials and present a good cost–benefit ratio. Experimental campaigns performed on masonry panels reinforced with polymeric nets have allowed to define their mechanical properties for practical design applications and for assessing their seismic capacity. Considering the results of these experimental campaigns in the present study analysis methods of masonry structures made of masonry brick panels strengthened with plasters reinforced with polymeric nets are proposed. The strength and ductility increments of the strengthened panels are accounted for in the global analysis of the construction adopting suitable values of the behavior factor. In the ambit of the limit analysis of the in plane and out of plane collapse mechanisms criteria that allow to account for the contribution of the polymeric net in the containment of the evolution of these mechanisms are defined.

1. Introduction

Masonry buildings constitute a significant part of the construction heritage existing in Italy and are typically characterized by a high seismic vulnerability. This vulnerability is due to the poor strength characteristics of masonry, to the insufficient monolithicity of the structural elements and to the inadequacy of the connections between the structural elements. The improvement of the seismic performances of masonry buildings has to be pursued with interventions that reduce these problems.

One of the most common techniques for the seismic strengthening of masonry structures is represented by the plasters reinforced with steel nets. This technique presents however some critical aspects as the lack of reversibility, the uncontrolled stiffening of the masonry panels and the uncertainty on its actual effectiveness, that significantly depends on the proper realization of the executive details. It has to be also considered the potential steel corrosion and all the functional, technological and systems problems related to the use of this retrofitting technique.

In the last two decades structural strengthening techniques based on the use of composite materials have been proposed together with refined analysis models [1–16]. In this ambit as regards masonry structures it has been introduced the use of plasters reinforced with fiber reinforced plastics (FRP) [17,18]. The FRP nets, unlike the steel net, do not have corrosion problems and can then be used also with non cement-based plasters in historical constructions. Furthermore the FRP nets are thinner than the steel nets and allow to reduce the thickness of the plasters. However they present technological problems associated to the fibers brittleness and in addition are less competitive in terms of cost–benefit ratio.

A valid alternative to the techniques utilized until now for the reinforcing of the plasters is constituted by the use of polymeric nets. In this case the net, characterized by a high molecular orientation, is a mesh of wires constituted by polymeric fibers equioriented along the directions defined by the mesh geometry. The plaster reinforced with polymeric nets results therefore in a composite material in which the wires of the polymeric net supply tensile strength, ductility and toughness to the cementitious matrix.

They allow to overcame the constructive and technological critical aspects evidenced for the other strengthening techniques and at the same time result more competitive in terms of cost–benefit ratio.

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Current Italian code [19] accounts for the strength increment of the masonry panels strengthened with reinforced plasters through a factor differentiated for the various masonry typologies with reference to the reinforcement with steel nets. It is however necessary to define the specific methodologies to account for the strength increment ensured by the reinforcement with polymeric nets instead that with steel nets, the ductility increment of the panels evidenced in the tests, the containment of the development of the in plane and out of plane collapse mechanisms due to the presence of the polymeric net.

The mechanical behavior of clay brick masonry panels strengthened with plaster reinforced with polymeric nets has been experimentally analyzed in [20] with the aim of defining the mechanical properties of the strengthened masonry panels for practical design applications and for assessing their seismic capacity. On the base of the results of these experimental tests in the present paper analysis methods for masonry structures made of clay brick masonry panels strengthened with plaster reinforced with polymeric nets are formulated. In particular values of the behavior factor that account for the strength and the ductility increments of the strengthened panels and criteria that account for the presence of the net in the limit analysis of the collapse mechanisms are defined.

2. Plaster reinforced with polymeric nets

2.1. Reinforcing technique

The considered reinforcing technique consists of polymeric nets applied at the masonry with appropriate connectors and embedded in a 2 cm thick plaster layer. The plaster can be both cement-based and lime-based. The construction process of the reinforced plaster is shown in Figs. 1 and 2.

The reinforcing nets are integral node polymeric nets characterized by a high molecular orientation that proceeds with continuity through the node. Various types of nets that differ for the mesh geometry and for the value of the tensile strength can be utilized. The plaster reinforced with polymeric nets is actually a composite material constituted by the cementitious matrix and the polymeric wires of the net.

To evaluate the effect of the polymeric nets on the mechanical behavior of the strengthened masonry panels and in particular on their seismic resistant capacity an experimental program has been performed [20]. The performed experimental campaign includes diagonal compression tests, shear–compression tests and strength and stability tests for out-of-plane loads on clay brick masonry panels. The tests have been performed to define the effects of the nets on the shear capacity of the masonry panels and on the collapse mechanisms.

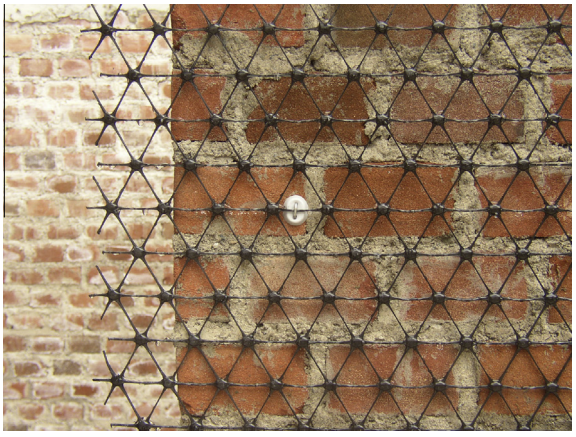

Fig. 1. Application of the polymeric net at the masonry panels with appropriate connectors.

Fig. 2. Plaster application.

2.2. Effect of the reinforced plaster on the panel strength

The diagonal compression tests have shown that the panels strengthened with the reinforced plaster on both sides have an ultimate shear strength substantially equal to that of the panels with unreinforced plaster [20], in accordance with the experimental results obtained by Drdácký and Lesák [21]. In the shear–compression tests the strengthened panels have instead shown a shear strength significantly larger than that of the unstrengthened panels [20].

In the assessment of the existing buildings strengthened with plasters reinforced with polymeric nets it is therefore possible to consider a shear strength increment of the masonry panels. This increment can be conservatively assumed equal to 1.2, considering that in the performed tests values up to 1.5 have been obtained [20].

2.3. Effect of the reinforced plaster on the panel ductility

The results of the performed experimental tests have shown significant increments of the displacement ductility of the masonry panels strengthened with plaster reinforced with polymeric nets with respect to that of the unstrengthened panels [20]. These increments are evident both in the diagonal compression tests that in the shear–compression tests.

The shear stress–shear distortion diagrams relative to the experimental tests on the strengthened panels present values of the ultimate shear distortion larger than 0.4%. The ultimate shear distortion of the unstrengthened panels results instead equal to 0.2%. Therefore the ductility of the strengthened panels results at least the double of that of the unstrengthened panels.

3. Global analysis of strenghtened masonry structures

3.1. Linear analysis

The linear analysis of the masonry structures is usually performed utilizing the design spectrum method that is based on the use of a design spectrum reduced through the behavior factor q [22,19]. In the case of masonry structures $q = 2.0\ \alpha_u/\alpha_1$ for buildings regular in elevation and $q = 1.5\ \alpha_u/\alpha_1$ in the other cases. The α_u/α_1 factor is a post-elastic overstrength factor. The α_1 coefficient is the multiplier of the horizontal seismic force for that the first