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Retrofitting of R/C shear walls by means of high performance jackets

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ABSTRACT

A new technique for the strengthening of existing R/C shear walls based on the application of thin high performance jackets is presented in this paper. The strengthening jacket is made of high performance concrete, having a compression resistance higher than 150 MPa, and reinforced by means of an high strength steel mesh. The experimental study is carried out on a 1:3 scale R/C wall, proportioned to resist vertical loads only, and reinforced by means of a 15 mm thick high performance jacket. Cyclic loads of increasing magnitude are applied to the experimental shear wall up to collapse. The effectiveness of the technique is also verified numerically. The results show the efficiency of the proposed solution in significantly increasing the structure resistance, deformation capacity and ductility.

1. Introduction

In earthquake engineering, a growing interest is nowadays shown for the assessment and retrofit of existing R/C buildings. Different approaches can be followed in the seismic rehabilitation of R/C structures. Possible solutions include: the retrofit of existing R/C frames, the use of resisting shear walls (either by strengthening existing R/C walls or inserting new shear walls) or the adoption of dissipative devices.

In existing buildings R/C walls are often present, commonly located near the stair blocks and the elevator areas, or along the structure perimeter. These elements are often reinforced to resist the vertical loads only, without considering the seismic actions. In few cases, the elements may be reinforced against horizontal wind loads but may be ineffective against the design seismic actions recommended by modern standards.

The transformation of the existing R/C walls into anti-seismic shear walls is a solution that is often preferred [1]. It is worth noting that regardless of the strengthening strategy, the presence of the existing R/C walls should be considered anyway: as a matter of fact, even if new anti-seismic devices are adopted, the seismic action transferred to the existing R/C walls can be rather large as a result of their significant stiffness. This in turn could result in severe damage of the R/C walls, prior to the activation of the devised anti-seismic systems.

In order to transform the existing R/C walls into seismic resistant shear walls, different retrofit techniques are traditionally proposed. The retrofit can be obtained by applying either traditional reinforced concrete jackets, external post compression or externally bonded FRP [1–4]. However, these techniques are not always easy to apply to existing structures. For example, the strengthening of an existing R/C wall by means of traditional R/C jackets might require excessive thicknesses (80–100 mm), which could jeopardize the future usage of the structure; whereas the application of FRP may be problematic because of the difficult anchorage of the fibers.

A new technique based on the use of jackets made of high performance fiber reinforced concrete has been recently proposed for the strengthening of existing R/C beams [5,6]. The method resulted in a significant increase of the structure resistance; as a drawback, however, a limited ductility was observed.

The application proposed in this paper can be regarded as an enhancement of this technique, obtained by adding a high strength steel mesh in the jacket with the aim to increase the ductility. The solution is based on the use of a high performance jacket made of high strength steel mesh, having a tensile resistance higher than 1200 MPa, embedded in a thin layer of high performance concrete, having a compressive strength higher than 150 MPa. By using these high performance materials, the jacket thickness can be significantly reduced with respect to a traditional solution in ordinary reinforced concrete.

In this paper, the proposed technique is validated by means of an experimental test on a 1:3 scaled shear wall. The experimental specimen was designed by reference to an existing three storey R/C building, which was proportioned to resist the vertical loads only. As a proportioning criteria, the high performance jacket was

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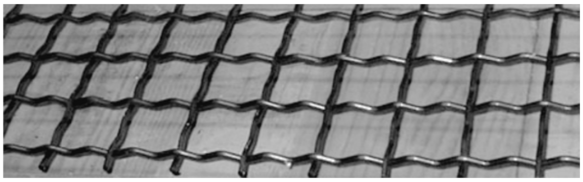

Fig. 1. High strength steel mesh made of bent wires. Single wires are weaved with each others to mechanically prevent their threading from the mesh.

designed to entirely resist the seismic actions. Note that this assumption leads to a conservative proportioning of the strengthening solution. However, the assumption was made based on the fact that the resisting contribution of the existing wall is difficult to evaluate, due to the uncertainty in assessing the effectiveness of the transfer of shear forces at the base of the wall. The experimental results showed the efficiency of the proposed technique in increasing the structure bearing capacity and ductility.

A numerical study was also carried out to compare the performance of un-reinforced R/C and strengthened shear walls. The numerical model was validated against the experimental results and was used to analyze the performance of a full scale strengthened shear wall.

2. Materials

When performing a scaled test, a correct choice of the materials is necessary for the scaled model to be effectively representative of the full scale structure.

For the construction of the R/C wall, the concrete mix design was defined by reference to a scaled aggregate grading curve, by adopting a maximum aggregate size of 15 mm.

As for the reinforcement, hot rolled bars, having a diameter of 5 mm, were used. It is worth noting that, unlike hot rolled large diameter bars, smaller diameter bars are usually produced with cold formed steel. The different production process results in different deformability and ductility. Therefore, appositely hot rolled bars were produced and adopted for the construction of the scaled shear wall.

As for the jacketing, a high strength steel mesh was used. The mesh is made of 2 mm diameter bent wires, assembled with a spacing of 20 mm (Fig. 1). Since the high strength steel cannot be welded, the high strength steel mesh is made of bent weaved wires. The bend of the single wires mechanically prevents their unthreading from the mesh. The single wire geometry is illustrated in Fig. 1. The typical results of the tensile test performed on single wires are plotted in Fig. 2. The measured maximum strength was always higher than 1200 MPa.

For the reinforcing jacket, a high strength fiber concrete with a very compact matrix and with a maximum aggregate size of 2.7 mm was adopted. This material has also been used in other researches, in which the R/C strengthening jackets were made of concrete only, without any reinforcing steel meshes [5]. In those applications, fibers having a length of 12 mm were used. In this case, given the reduced scale of the model, 6 mm fibers having a diameter of 0.16 mm were selected, with a content equal to 2.5% by volume. The resulting high performance fiber concrete exhibits a hardening behaviour under tensile forces, and shows a compressive strength, measured on 100 mm cubes, higher than 150 MPa.

In order to assess the experimental behaviour of the reinforcing jacket, preliminary tests were performed on small specimens obtained with high strength steel mesh pieces embedded in a thin layer of high strength fiber concrete (Fig. 3). Different thicknesses of the high performance fiber concrete layer were considered (10 mm and 20 mm).

The tensile behaviour of the specimens was compared with the behaviour of the bare mesh. The experimental results are shown in

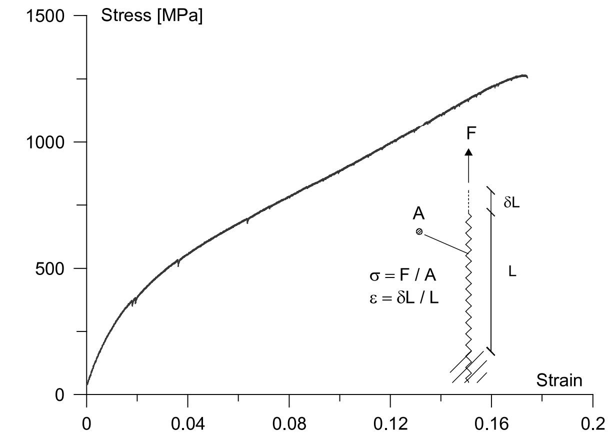

Fig. 2. Single mesh wire stress versus ideal strain relation-ship. Ideal strains are the result of both the wire straightening and deformation.

Fig. 4. As expected, the presence of the concrete layer remarkably increases the stiffness of the bare mesh wires.

In the 10 mm thick specimen several smeared cracks developed throughout the test. Their location matched the position of the mesh transverse wires. Conversely, in the 20 mm thick specimen crack localization occurred, resulting in the specimen anticipated failure and in a small overall ductility.

It is worth noting that, in order to avoid crack localization and to guarantee larger structural ductility, mindful attention should be paid to the proportioning of the strengthening jacket. The coupling effect of the high strength steel mesh (having a small hardening behaviour) and the high performance concrete should be taken into account by controlling the ratio between the mesh diameter and the jacket thickness. To this purpose, further research is needed. At this stage, the aim can be pursued and the effective ductility of the jacket can be assessed, by performing preliminary tests on small specimens for varying ratios between mesh diameter and jacket thickness.

3. Wall specimen and test set-up

In order to verify the effectiveness of the proposed strengthening technique an experimental test was carried out. Reference was made to a typical R/C wall of an existing three storey building. The R/C experimental wall was built in a reduced 1:3 scale.

The specimen, reproducing a typical stair block element of an existing building, was designed to resist the vertical loads only. The geometry of both the prototype R/C wall and the scaled specimen is shown in Fig. 5(a)–(c). The scaled wall specimen has a height equal to 3.2 m (reproducing a 9.6 m real R/C wall) and a 100 mm × 800 mm cross section. The reinforcement is made of 5 mm diameter longitudinal rebars, having a spacing of 70 mm, and 4 mm diameter stirrups having a spacing of 100 mm. The R/C wall foundation block is anchored to the testing bench.

Upon completion of the R/C wall casting and curing, the reinforcing jacket was applied. In order to ensure perfect bond to the high performance jacket, the R/C wall surface was previously sandblasted in order to obtain a surface roughness of approximately $1 \div 2$ mm was obtained. This roughness was demonstrated to prevent any slip of the jacket [5].

After the steel mesh was fixed to the wall lateral surface, the high performance self-leveling fiber high performance concrete mix was poured into the moulds. A 15 mm jacket thickness was selected in order to obtain both a homogeneous casting and a sufficient mesh cover. The selected thickness results in a 45 mm jacket in a full scale application (Fig. 5(c)).