Concept, prototyping and application of a tensioning system for FRP ties into masonry structures

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Abstract. The present paper deals with concept, prototyping and application of a tensioning system for FRP ties into masonry structures. The proposed system, based on the use of FRP strands instead of traditional steel ties, has the aim to produce a compression stress state on masonry walls where it is applied. Given the objective difficulty in tensioning a FRP strand, it has been necessary to both characterize and prototype a suitable connection system between the strand and the pulling system. The experimental phase concerned both the manufacturing of the pulling system and the study of used materials, as well as the characterization of the impregnation technology of FRP ties. The above described system has been produced and used in the framework of the structural retrofitting of the "Real Albergo dei Poveri" building in Naples.

Introduction

Metal chains for structural reinforcement and seismic improvement of masonry buildings have been widely used over the years as regards both minor built and monumental interest buildings, such as the nineteenth-century interventions accomplished for the Northern and Southern part of the amphitheater Flavio.

The real effectiveness of these reinforcing elements, which represented one of the most used techniques all over the centuries, is confirmed from investigations conducted after the earthquakes that affected Umbria, Marche and Molise, which showed that the absence of metal chains has favored, in some cases, the activation of out-of-plane collapse mechanisms [1].

The chains can be used as a mere passive protection system, if they are not properly tensioned, or as active defense system against earthquakes, when an adequate preload is applied.

The growing number of earthquakes that affected the country in recent years caused a strong and growing interest in novel materials, different from traditional ones, which the composite materials, especially under form of Fiber Reinforced Polymers (FRP), belong to.

The reinforcing interventions with the most common composite materials, represent passive reinforcement systems, which are not coupled to any pretension intervention that could ensure an active reinforcement. Over the years, numerous reinforcement systems have been studied, experimented and patented in order to allow, with more or less simple technologies, the tension of some reinforcement systems with composite materials.

In order to combine the advantages arising from the use of chains and those arising from FRP systems, in the current paper a FRP chain system and the relative tensioning system has been studied and characterized (Figure 1) [2].

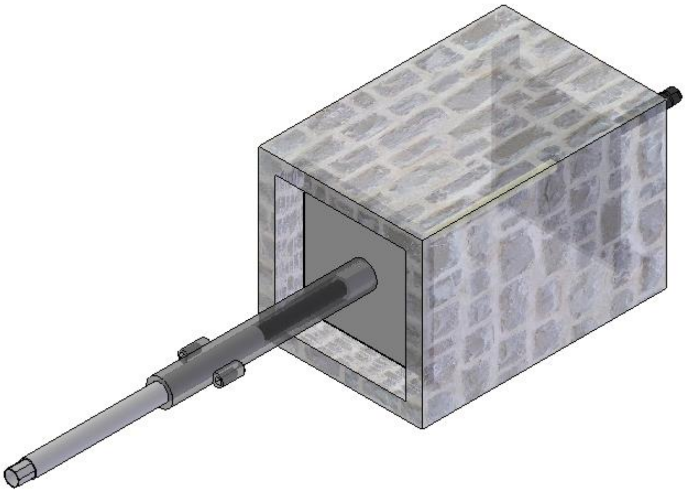

Figure 1: Pre-tensioning system for FRP.

The tensioning system for FRP ties

Subject of the present work is the characterization of the tensioning system of a FRP tie, which is implemented through the execution of the process described below.

The fibrous material chosen for the realization of the pull system can be glass, aramid or carbon.

The performance of FRP materials under fatigue conditions are generally satisfactory. They depend on the composition of the matrix and, marginally, on the type of fibers. The latter, in fact, counteracts the formation of cracks and impede their propagation.

To avoid the FRP materials breaking under long-term or cyclic loads, it is possible to contain the stress state under operating conditions, reducing the design value by a conversion factor, η_l, whose value is suggested by the technical document CNR DT 200/04 R1 and, subsequently, by the Guidelines of the Italian Public Works Superior Council, as reported in Table 1 [3, 4].

Under persistent loads, the materials that provide the best mechanical characteristics to the system in terms of long-term duration are the carbon fibers, while the matrix is always of epoxy type.

The tensioning system consists of the following elements also shown in the exploded view of Figure 2:

1. Torque wrench;
2. Torque Wrench Connection element to the clamp bolt;
3. Clamping nut;
4. Plate for the load distribution;
5. Perforated metal bar with internal and external thread;
6. FRP rope;

7. Masonry element;
8. Injection tube.

Table 1: Conversion factor for long-term effects ηl for several FRP systems (Guidelines of the Italian Public Works Superior Council) [3,4].

Loading mode	**Fiber / resin type**	η_l
Persistent (Creep and relaxation)	Glass / Epoxy	0.30
Persistent (Creep and relaxation)	Aramid / Epoxy	0.50
Persistent (Creep and relaxation)	Carbon / Epoxy	0.80
Cyclic (fatigue)	All	0.50

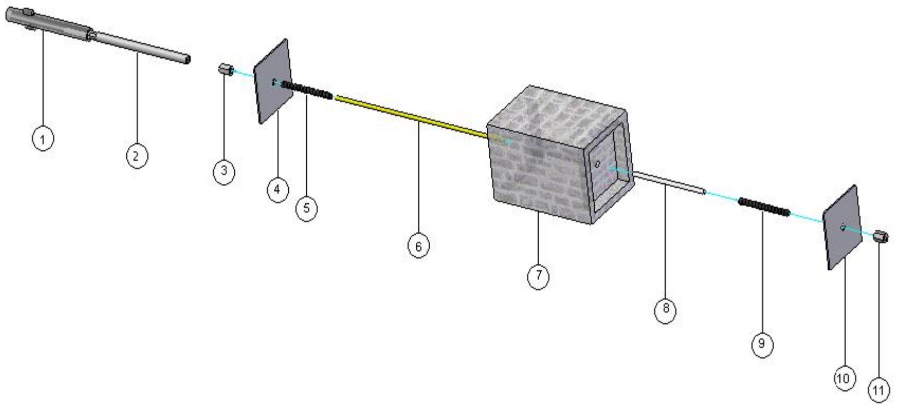

Figure 2: Exploded view of the pre-tensioning system.

For the accommodation of the system on the masonry, it is necessary the realization of a special area inside the walls subjected to consolidation that is contained between the plates used for the distribution of the loads, and that will be, at the end of the process, characterized by a state of compression stress. After the completion of the accommodation hole for the FRP rope, two size pockets must be made at the two ends of the masonry. The two size pockets have variable size as a function of the applied load. Inside of these the metal plates, designed to distribute the load on the masonry, and the nut necessary for the tightening of the system will be hosted.

After the completion of both the hole and the system accommodation pockets, a perforated tube must be inserted inside the hole (see element 5 in Fig. 2) for the accommodation of the fibers and for their subsequent impregnation. At the two ends of the tube two perforated metal bars with internal and external thread are positioned (see element 8 in Fig. 2). These bars serve as links between the bar composite end the rest of the system for the next pull phase. The length of metal bars varies according to the load, which must be applied to the FRP chain and must be sized case by case. Placed the metal bars, it is necessary to position the two plates (see elements 4/10 in Fig. 2) that ensure the distribution of loads, which are determined by the subsequent tension. The geometry of such plates is dimensioned in function of the geometrical and mechanical characteristics of the element to be reinforced and also of the load to be applied. On the outer surface of the two sleeves, two nuts are then manually screwed (see elements 3/11 in Fig. 2). These latter will allow for the load application to the system, by transforming the torque, applied through the use of guy screwing torque, into a tensile stress, which will determine a compression stress state within the masonry. Positioned all the above elements, the FRP rope must be inserted (see element 6 in Fig. 2).

Constituted the first part of the system, it is necessary to proceed to the impregnation stage of the fibers with low viscosity epoxy resin by means of the injection with a special pump. The injection must be done positioning a nozzle at one end of the metal bars, where the FRP rope is located inside, and proceeding with the injection of resin until it leakages from the opposite end of the system.

After conducting the injection of resin, as described above, and after waiting for the time necessary to the polymerization of the same resin, it is then possible to start with the pull operations.

In order to perform the pull operation, after having eliminated all injection systems, it is necessary to use a suitable metal key divided into two elements (see elements ½ in Fig. 2) that has the purpose of transferring the torque applied, through the use of a torque wrench, to the nut of the clamping system. After placing the two keys to lock both the sleeve and the nut, the pull operation is done by blocking the internal key and then placing a torque wrench into one of the supports present on the external key. After positioning the torque wrench, the pull phase until the desired value is finally carried out.

Subsequently, the physical and mechanical study and characterization of the proposed tensioning system has been done with the purpose to apply the system for the consolidation of the “Real Albergo dei Poveri” palace in Naples. The consolidation project of this structure included the use of aramid (A-FRP) rope with 12 mm diameter. Before moving on to the actual installation of the system, a first test phase has been performed in laboratory (Fig. 3) in order to evaluate the connection between the metal bar of the FRP system, having length 25 cm, and the same composite system.

Figure 3: Realization of the specimen for laboratory tests.

A set of 5 specimens composed by A-FRP rope, connected to the metal bar and injected with epoxy resin having high viscosity, have been pulled through the use of a MTS Alliance RT machinery having loading capacity of 500 KN and used as Material Test System.

The characteristics of the AFRP rope are described in Table 2 [5].

Table 2: Mechanical properties of the AFRP rope.

Density	1,44 g/cm^3
Strain at break, ε_{fk}	2,9 %
Tensile strength, f_{fk}	2.951 MPa
Flastic modulus, E_f	99 GPa
Equivalent area of dry tissue Φ 12	40,19 mm^2

The test has shown, for all the specimens, the failure of the FRP element in the system centerline without phenomena of delamination between the metal bar and the system.

The theoretical failure load is: 2.951 MPa x 40,19 mm^2 = 118.600,69 N and an average value of 92,82 KN, achieved from test values reported in Table 3, has been detected for the ultimate tensile load of specimens.

Table 3: Failure loads of tested specimens.

Test #	Ultimate tensile load
1	91,40 KN
2	92,60 KN
3	91,30 KN
4	95,40 KN
5	93,40 KN

For comparison purpose, the ultimate load values achieved in the experimental activity on aramid and carbon chains have been associated to the correspondent values attained for traditional steel chains, as shown in Table 4.

Table 4: Comparison among failure loads of steel, carbon and aramid chains.

Material	Yield Strength	Diameter	Failure load
	[N/mm^2]	[mm]	[KN]
STEEL (S235)	235	26	125
		28	145
		30	166
		32	189
		34	213
STEEL (S275)	275	26	146
		28	169
		30	194
		32	221
		34	250
STEEL (S355)	355	26	188
		28	219
		30	251
		32	286
		34	322

CARBON ROPE	4.830	6	77
		8	103
		10	129
		12	152
ARAMID ROPE	2.951	8	79
		10	99
		12	119

Other than laboratory tests, it has been decided to include the characterization tests of the system at the construction site in order to verify its actual functionality inserted inside the masonry (Fig.4).

Figure 4: Tests conducted in situ.

Also the tests carried out in the pipeline have demonstrated the absence of delamination phenomena between the firing system and the FRP rope (Fig. 5), highlighting the correct functionality of the connection system.

Conclusions

The experimental results made in laboratory and in the construction site, have demonstrated the proper functioning of the pull system of FRP chains under investigation. The designed system allows for exploitation of the intrinsic characteristics of the composite FRP materials, instead of steel. The advantage deriving from the use of FRP materials instead of steel are the reduced section of the chain at constant tensile strength, the absence of oxidation phenomena and the high resistance to long-term or cyclic loads in particular for carbon (C-FRP) composite.

Figure 5: Result of the in situ test.

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