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The application of external post-tensioning system to a damage masonry arch

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Abstract

The rehabilitation and the maintenance of masonry arch bridges is a current necessity for the infrastructure owners. In fact, masonry bridges represent a large portion of the existing bridges in the world's road and rail networks. In this contribute, external post-tensioning system has been used to strength single span pre-damage masonry arches. The specimens, that represents in scale a typical geometry of the Italian single-span railway masonry bridges, was strengthened with a post-tensioned cable system anchored at the arch intrados and then it was tested with a cyclic concentrated eccentric vertical load. The strengthened masonry arch shows a load bearing capacity greater respect to that in the undamaged condition.

Keywords: Masonry arch bridges, Post-tension, Damaged masonry bridges

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1. Introduction

The Italian roadway and railway network, comprehends a large number of bridges and viaducts constructed over 100 years ago. Between these structures, there are numerous masonry arch bridges still in service.

The evolution of the Standards which defined higher safety standards, the lack of consideration of the seismic actions in the design stage, the increasing of traffic loads and the normal deterioration of the materials for construction are the main reasons for the planning of restoration and structural strengthening interventions of masonry bridges from railway and roadway infrastructure managers.

Referring to masonry arch bridges, strengthening interventions that are localized in the intrados of the arch are preferred. The strengthening system need to increase the resistance of the arch, and at the same time it can't modify drastically the mass of the element.

Jurina (2016) introduced a strengthening method easy and fast to apply and that can lead to better performances for the masonry arch. The intervention consists in the post-tensioning of the arch by means of steel cables and mechanical anchorages. The purpose is to increases the bearing capacity of the structure postponing the opening of cracking hinges, without altering the structure mass and stiffness. In this work the previous results of experimental destructive test performed on masonry arch specimens with haunching strengthened post-tensioning system applied to the intrados of the arch are presented.

2. Arch specimen

The arch specimen is composed by fired-clay bricks (120 × 250 × 55 mm^3) and hydraulic lime-based mortar joints with span length around 3 m arch rise of and there is an Haunching composed by a conglomerate made of aggregates and hydraulic lime-based mortar. The arch was tested under displacement control imposed a vertical displacement not symmetric respect to the arch mid-span as it is reported in Zampieri et al (2022). After this first test, the arch shows the final damage reported in Fig. 1. There are some cracks in the arch section (where the hinges were open during the test), there are the partial detachment between arch and haunching and an arch portion where shear-sliding rupture occurred.

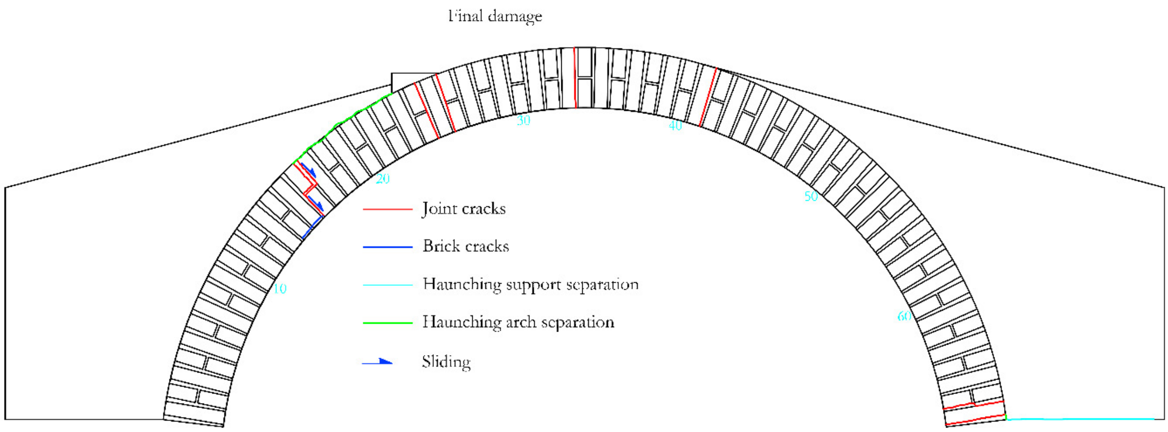

Fig. 1. State of damage of the masonry arch.

The masonry arch has been restored mechanically only in the portion where was localize the shear-sliding mechanism. The sliding was deleted repositioning the arch in its initial configuration and high-performance mortar was used to refurbish the mortar layers damaged an. Then the post-tensioning system was applied onto arch intrados. This is composed by two 6mm diameter cables able to transfer radial forces thank to an anchoring system as illustrated in (Fig. 2(b)). And two 10 kN load cells were used to monitor the tensile force in each cable during the tensioning phase and during the entire test.

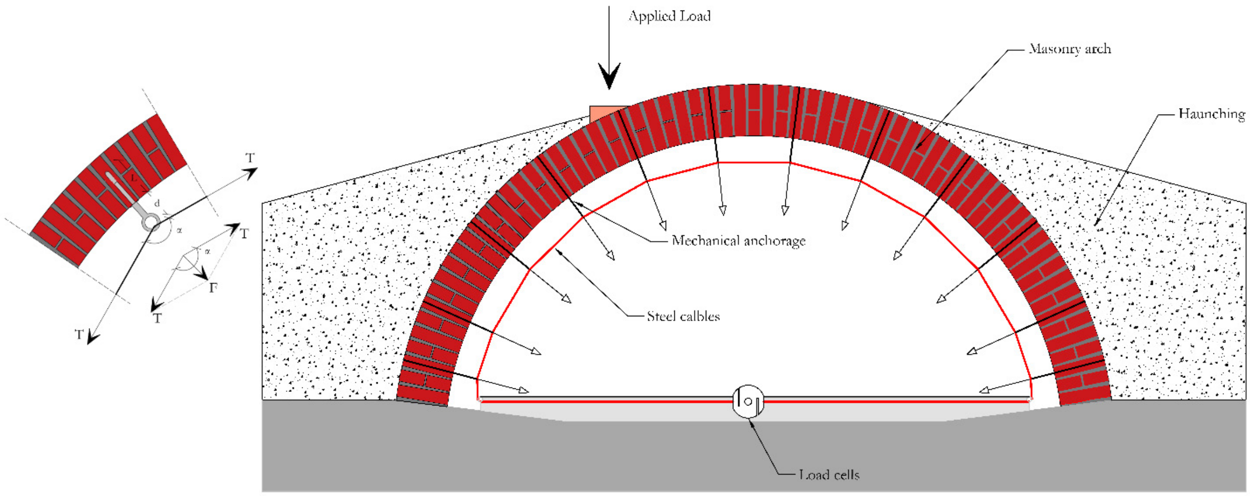

Fig. 2. (a) Detail of the anchoring system and post-tensioning forces representation. (b) Graphical representation of the post-tensioning system applied to the arch intrados.

The post-tensioned system transfer at the arch a system of forces that creates opposite work respect to the external load applied to the structure (Fig. 2(a)). Moreover, the post-tensioning increase the compressive axial forces at each arch cross section with a reduction of the eccentricity of the arch internal forces. The increased compressive arch axial forces besides increment the arch capacity close the arch cracks developed during the first test. the eccentric load is applied in the vertical direction by means of a servo-hydraulic actuator under load control considering incremental load cycles that increases of 5 kN from the previous.

3. Experimental results

The post-tensioned arch shows an initial elastic behavior, essentially reproducing the initial slope of the load-displacement curve carried out from the first test. The first peak in the load-displacement curve is compatible with the peak load of the undamaged test and represents the first opening of the hinge, in particular the one in proximity of the load axis. The post-tensioning system manifests its contribute especially on the phase after the first peak, permitting the increasing of the registered load even if with a decreasing stiffness.

The strengthened arch reaches a maximum load of 85.05 kN that it is 2.62 respect the peak load obtained during the first test in the undamaged and unstrengthened conditions (32.39 kN). Even if, to evaluate the post-tensioning efficiency the comparison should be make considering the first test residual load (around 19 kN).

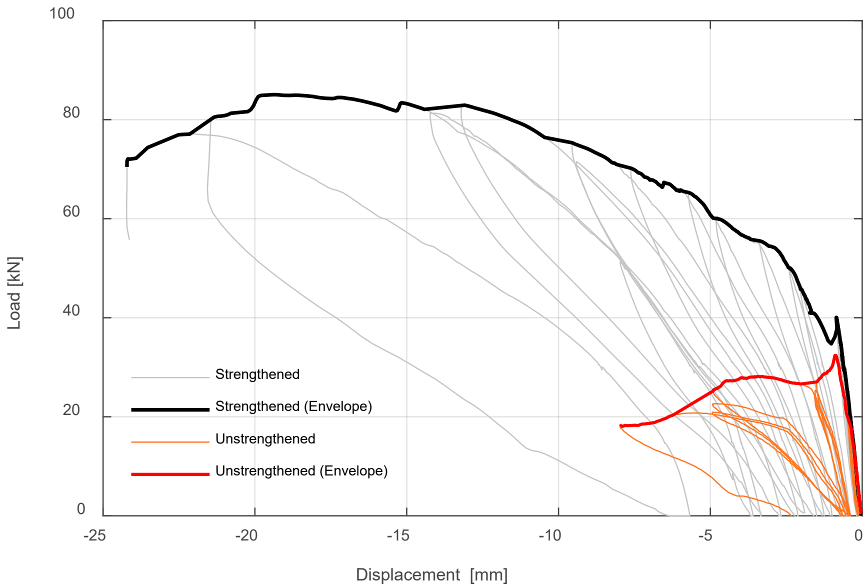

Fig. 3. Comparison between the capacity curves of the Unstrengthened and strengthened arches.

Another important result obtained from the test is the diagram of the cable tension as function of the arch displacement in the load application point. Because there is no friction between the cables and the anchoring system (a lubricant was used) in the first phase (as it is theoretically deducible) when the displacement is small (lower than about 2 mm) the cable tension remains almost constant. When the arch mechanism is open and consequentially the cables geometry changes it was possible to observe a cable stress variation according to the load cycles.

Fig. 4. Deformed shape of the strengthened arch at the last load cycle.

4. Conclusion

In this work, an application of the strengthening method consisting in the laying steel cables in the intrados of the arch and tensioning it, is presented. This method permits to reach higher performances without modifying the mass and the stiffness of the masonry arch. In this experimental test, a pre-damaged arch is loaded with an asymmetrical vertical load, highlighting the results of increasing of the peak load and improving the ductile behavior of the arch. This strengthening method is suitable for the seismic retrofitting of the masonry arch bridges because of the incrementing of the bearing capacity and the simplicity of implementation.

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