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Carbon-FRCM materials for structural upgrade of masonry arch road bridges

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A B S T R A C T

Background/Purpose: Numerous bridges of the Italian arterial road network were designed for live loads significantly lower than those produced by the current vehicular traffic. Many of them are masonry arch bridges whose load carrying capacity should be assessed for defining the necessary strengthening interventions. In the present paper the design criteria for strengthening masonry bridges with carbon fiber reinforced cementitious matrix (C-FRCM) materials are presented with reference to a masonry arch road bridge built right after the second world war.
Methods: The structure is analyzed both in its original and in its strengthened configuration following the approach of the collapse mechanisms. The considered approach allows to capture the strengthening effect of the C-FRCM material in terms of modification of the collapse mechanism and increase of the load collapse multiplier. Two different configurations of C-FRCM strengthening material applied at the extrados have been considered. In the first configuration the ends of the C-FRCM material are anchored at the vaults imposts, while in the second configuration they are not anchored at the imposts.
Results: To obtain load collapse multipliers greater than one three layers of C-FRCM strengthening material have to be applied at the extrados of all the three vaults in the case of end anchored strengthened material, while in the case of unanchored strengthening material four layers of C-FRCM strengthening material have to be applied at the extrados of all the three vaults.
Conclusion: The performed analyses show a lack of load carrying capacity of about 60% with respect to the load carrying capacity required by current codes. This lack can be filled up adopting the considered strengthening technique.

1. Introduction

The Italian road network is constituted by 6000 km of highways and by 180,000 km of other major and minor arterial roads (national, regional and provincial roads). Currently the speed and the heavy vehicular traffic mainly travels on the highways, however the arterial roads are still used by a large volume of vehicular traffic. On the Italian arterial roads network there are numerous masonry bridges designed and built by the end of the 19th century considering live loads significantly lower than those produced by the nowadays vehicular traffic. Indeed since the construction of many of these bridges, the number of vehicles per day and the axle load have increased inducing significant increments of the internal stresses and a consequent acceleration of the structural degradation phenomena. These structures are presently in service and should be assessed considering the loads provided by the current Italian code to schedule and design the necessary strengthening interventions.

Masonry arch bridges have been traditionally strengthened with steel profiles placed at the arches intrados, cementitious mortar injection, reinforced concrete elements cast at the intrados or at the extrados, insertion of steel rebars. An alternative strengthening technique for masonry arch bridges consisting in the application of unbounded tendons placed at the extrados of the vaults has been more recently utilized [1]. This technique is very efficient to increase the load carrying capacity of arch structures [2] but it has the significant disadvantage of requiring invasive interventions at the extrados that necessary imply the traffic interruption. Innovative

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techniques based on the use of tuned-mass-dampers [3] are instead devoted to flexible pedestrian bridges and unlikely can be applied to masonry arch bridges.

In the last twenty years a huge amount of experimental and theoretical studies has been performed on the use fiber reinforce polymer (FRP) materials for the strengthening of existing reinforced concrete, masonry [4], and timber [5] structures and for the construction of new structures [6,7]. By the middle of the '90 many strengthening interventions have been realized with FRP materials bonded at the intrados or at the extrados of the masonry vaults [8–15]. The FRP materials advantages are their light weight, high strength and stiffness, resistance to corrosion, flexibility, and rapidity of application, while their disadvantages are the moderate matrix heat and fire resistance due to the matrix (epoxy resin) low glass transition temperature, difficulty of application at low temperatures, impossibility of application on humid surfaces, and lack of vapor permeability. In the last ten years innovative composite materials made of cement-based matrix reinforced by continuous fibers (fiber-reinforced cementitious matrix, FRCM) have been proposed to overcome or reduce the disadvantages of the FRP materials. Cementitious matrix indeed exhibits significant heat resistance, allows vapor permeability, and can be applied at low temperatures and on wet surfaces. The mechanical behavior of FRCM materials has been recently investigated in Refs. [16,17] performing tensile tests. The effectiveness of the FRCM strengthening materials has been investigated in experimental and theoretical researches in the cases of concrete columns confinement [18–21], shear and flexural strengthening of concrete beams and slabs [22–28], and seismic upgrading [29], while the bond between the FRCM materials and the concrete support has been investigated in Refs. [30–35]. The effectiveness of FRCM material for the strengthening of masonry structural elements has been investigated in Refs. [36–38], while the bond between the FRCM materials and the masonry support has been investigated in Refs. [39–41].

Among the possible strengthening interventions for masonry arch bridges, the application of FRCM strengthening materials at the intrados or at extrados of the masonry vaults is particularly advantageous. Indeed this kind of intervention is often able to sufficiently increase the load carrying capacity of the structure and, in the cases of application at the intrados, can be realized with the bridge in operating conditions. Moreover, contrarily to the FRP materials, the FRCM materials can be applied on wet surfaces.

In the following the design criteria for strengthening masonry arch bridges with carbon fiber reinforced cementitious matrix (C-FRCM) materials are presented with reference to a three bays masonry arch bridge built right after the Second World War. The considered bridge has been analyzed both in its original configuration and in its strengthened configuration following the approach of the collapse mechanisms analysis. The collapse analysis of the unstrengthened structure has evidenced a lack of load carrying capacity of about 60% with respect to the load carrying capacity required by current Italian code.

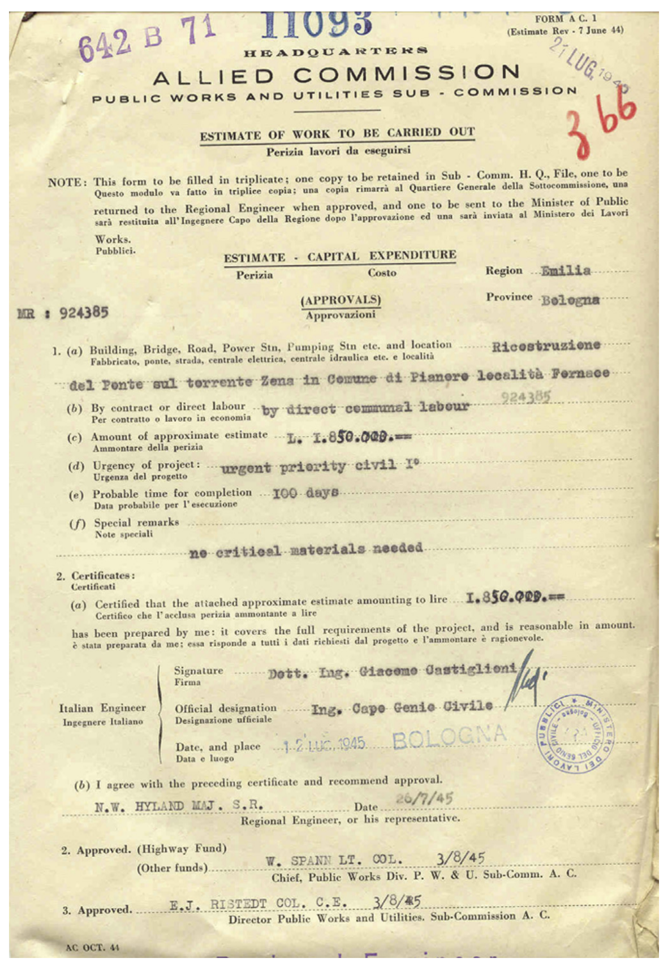
2. The road bridge

2.1. Geometrical characteristics

The considered road bridge is located on the SP 36 "Val di Zena", 1.6 km south of San Lazzaro, Bologna, Italy. The bridge (Fig. 1) was built right after the Second World War to substitute a pre-existing bridge, destroyed during the war [42] (Fig. 2).

It is constituted by three masonry barrel vaults supported by two masonry piers and two masonry abutments (Fig. 1). The piers and the abutments are made of clay bricks masonry. The main geometrical characteristics of the structure are shown in Fig. 3. The bridge deck is 27.29 m long and 5.50 m wide. The bays are numbered from 1 to 3, while the piers are numbered from 2 to 3. The center-to-center distance among the vaults is 9.43 m. The piers have an height of 3.0 m, a width at the imposts of 2.00 m, a width at the foundation level of 2.20 m and a depth of 7.7 m. All vaults have the same dimensions. The vaults have span of 7.43 m at the intrados and span of 8.43 m at the extrados, an intrados radius of 4.45 m, an extrados radius of 5.05 m and a thickness of 0.6 m. At the extrados the vaults have an infill up to the vaults apex. The infill is covered by a 0.35 m thick layer of ballast.

Fig. 1. Considered bridge.



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FORM A C. 1
(Estimate Rev - 7 June 44)

27 LUG 1945

HEADQUARTERS
ALLIED COMMISSION
PUBLIC WORKS AND UTILITIES SUB - COMMISSION

366

ESTIMATE OF WORK TO BE CARRIED OUT
Perizia lavori da eseguirsi

NOTE: This form to be filled in triplicate; one copy to be retained in Sub - Comm. H. Q., File, one to be returned to the Regional Engineer when approved, and one to be sent to the Minister of Public Works.
Questo modulo va fatto in triplice copia; una copia rimarrà al Quartiere Generale della Sottocommissione, una sarà restituita all'Ingegnere Capo della Regione dopo l'approvazione ed una sarà inviata al Ministero dei Lavori Pubblici.

ESTIMATE - CAPITAL EXPENDITURE
Perizia Costo

Region Emilia
Province Bologna

(APPROVALS)
Approvazioni

MR : 924385

1. (a) Building, Bridge, Road, Power Stn, Pumping Stn etc. and location — Ricostruzione del Ponte sul torrente Zena in Comune di Pianoro località Fornace
Fabbricato, ponte, strada, centrale elettrica, centrale idraulica etc. e località

924385

(b) By contract or direct labour — by direct communal labour
Per contratto o lavoro in economia

(c) Amount of approximate estimate — L. 1.850.000.==
Ammontare della perizia

(d) Urgency of project: — urgent priority civil I°
Urgenza del progetto

(e) Probable time for completion — 100 days
Data probabile per l'esecuzione

(f) Special remarks
Note speciali
no critical materials needed

2. Certificates:
Certificati

(a) Certified that the attached approximate estimate amounting to lire 1.850.000.== has been prepared by me: it covers the full requirements of the project, and is reasonable in amount.
Certifico che l'acclusa perizia ammontante a lire è stata preparata da me; essa risponde a tutti i dati richiesti dal progetto e l'ammontare è ragionevole.

Italian Engineer / Ingegnere Italiano
Signature / Firma — Dott. Ing. Giacomo Castiglioni
Official designation / Designazione ufficiale — Ing. Capo Genio Civile
Date, and place / Data e luogo — 12 LUG. 1945 BOLOGNA

(b) I agree with the preceding certificate and recommend approval.
N.W. HYLAND MAJ. S.R. Date 26/7/45
Regional Engineer, or his representative.

2. Approved. (Highway Fund)
(Other funds) W. SPANN LT. COL. 3/8/45
Chief, Public Works Div. P. W. & U. Sub-Comm. A. C.

3. Approved. E.J. RISTEDT COL. C.E. 3/8/45
Director Public Works and Utilities. Sub-Commission A. C.

AC OCT. 44

Fig. 2. Estimate of the works for the bridge construction drown by the Allied Commission in 1945.