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MODELING WITH FIBER BEAM ELEMENTS FOR LOAD CAPACITY ASSESMENT OF EXISTING MASONRY ARCH BRIDGES

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Abstract. *In this work non-linear beam elements with fibre cross-section approach has been adopted for modelling the multi-span masonry arch bridges and evaluating the ultimate capacity. This numerical model approach is validated by some recent experiments on masonry prisms under eccentric compression, where it has been demonstrated that the classical hypothesis that plane sections remain plane after deformation is still valid also in the non-linear range, when cracks initiation occurs. This approach is then applied for modelling the main arch of the Italian ancient brick masonry arch bridge. Then, it is also discussed the effect on the ultimate of the C-FRP reinforcement on the ultimate capacity.*

1 INTRODUCTION

The conservation and safety assessment of old masonry arch bridges represent nowadays a research field of considerable interest. When handling with these structures, which have been designed with empirical rules and have been subjected in time to an increase in service loading, there is a definite need of simple tools to be used for assessment and determination of the load-carrying capacity. To date it is more copious the bibliography concerning the theoretical aspects for dimensioning and modelling the brick arches. Rankine, Stephenson, and Baker (Heyman, 1982) [1] proposed empirical methods for calculating the arch thickness, the intermediate piers and many other dimensions. In order to determine the load capacity several numerical assessment packages and computer-based applications have been proposed as, for example, RING (1992) [2]. In literature also works based on yield design of masonry arches (Heyman, 1982) [1] have been published, such as the contributions of Gilbert and Melbourne (1994) [3]. With this approach, it is assumed a plastic behavior of the material, although the masonry, as demonstrated during laboratory tests, shows a softening branch after the peak strength with a limited ductility. Nevertheless, this method is still largely applied when the possible failure due to the material crushing is also taking into account, since it represents the simplest assumption for avoiding solution convergence problems. The influence of the limited ductility on the load carrying capacity of masonry arch bridges may be found, for example, in de Felice (2007) [4]. While a complete and more refined bridge simulation should be preferable, a general modelling may reveal excessively time-consuming from a computational point of view, especially when many spans are present. The aim of this paper is to propose an approach for preliminary assessment of multi-span masonry arch bridges that makes use of non-linear incremental analysis, using beam elements. This modelling approach is validated by some recent experiments on masonry prisms under eccentric compression, where it has been demonstrated that the classical hypothesis that plane sections remain plane after deformation is still valid also in the non-linear range, when cracks initiation occurs, de Felice 2007 [4]. The use of beams with fibre cross-section has become current for the analysis of reinforced concrete structures, but, as far as the author knows, has never been used for structural analysis of masonry arches.

2 FIBER BEAM ELEMENTS MODEL AND NUMERICAL RESULTS

The numerical model has been implemented into OpenSees (2009) [5], by using rectilinear fibers beams having the unit width section reported in Figure 1.

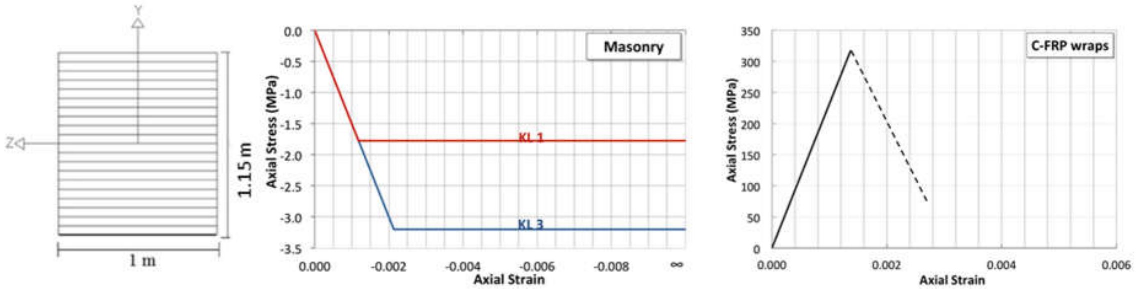

Figure 1: Fiber section of the arch and uniaxial stress-strain relationships assigned to the fibers of masonry and CFRP.

Analyses methods based on plane section assumption may be found also in Chen (2002) [6], and CNR-DT 200/R1 (2013) [7]. The backfill passive pressure is as well taken into account with the classical assumption that the magnitude of the horizontal backfill pressure is proportional to the vertical weight pressure exerted by the backfill material, in according to the work of Gelfi (2002) [8].The masonry material has been modelled with an uniaxial elastic-perfectly plastic relationship having strength only in compression Figure 1, with infinite ductility for avoiding solution convergence problems during the numerical simulations. On the other hand, the infinite ductility will permit of evaluating, in the case of main arch typology, the ultimate carrying load although this assumption may lead, as demonstrated in de Felice, (2009) [9], to an overestimation of the actual arch capacity. However, for the aim of this work this assumption is considered acceptable. The CFRP wraps are supposed to be completely bonded with resin and continuously applied along the width and the longitudinal length of the arch, starting from the impost. They have a Young's modulus of 230000 MPa, a rupture tensile strength of 4800 MPa and, in this study, a total thickness of 0.33 mm (two layers of CFRP). The reinforcement has been modelled as an additional layer with an elastic uniaxial stress-strain law only in tension, having an axial strength fdd evaluated in accordance with CNR-DT 200/R1 (2013) [7], and corresponding to the debonding failure from the masonry support. In this study, the fdd strength is equal to 316 MPa. After reaching the maximum strength fdd the CFRP material law suddenly reduces (Figure 1), for simulating the fibers detachment invalidating the plane section assumption. As regards as the masonry compressive strength is concerned, the following values are assumed for the two simulated knowledge levels: Limited Knowledge Level (KL1) and Full Knowledge Level (KL) with compressive strength equal to 2.40 MPa and 3.20 MPa rispectivley and confidence factor CF 1.35 for KL1 and 1 for KL3. The investigations are performed by varying the debonding strength between the CFRP wraps and the masonry support as shown in Figure 2. The numerical simulations are conducted by imposing an increasing monotonic displacement in correspondence of the key and haunch sections, until the arch failure.

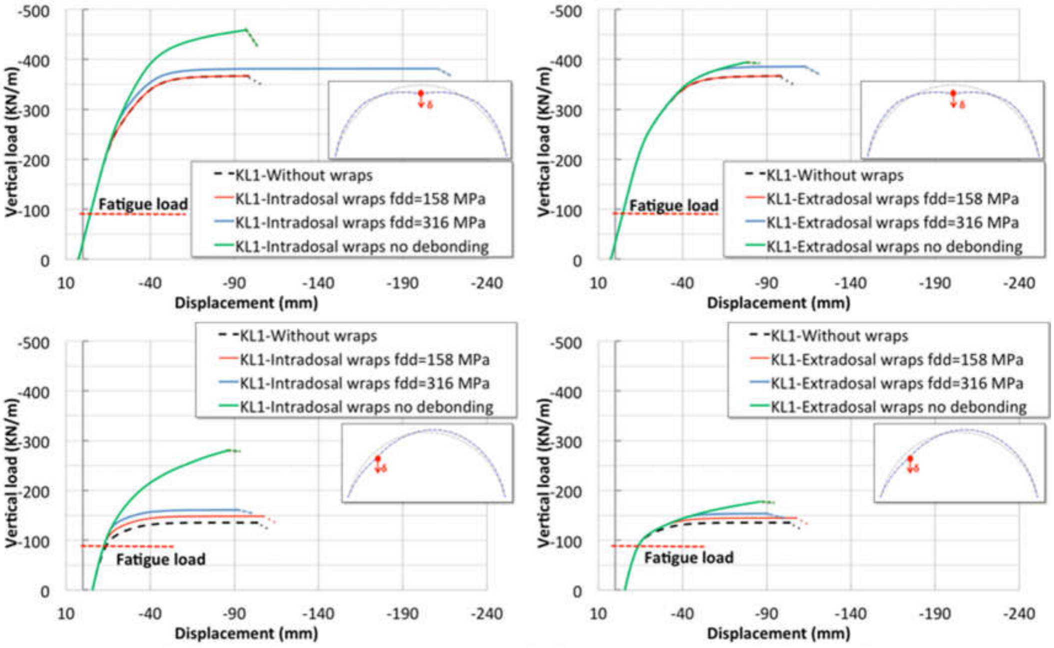

Figure 2: Vertical carrying capacity evaluated with respect to the haunch and key section

The obtained results are shown in Figure 2, where the ultimate carrying capacity without any reinforcement is also plotted (indicated with a dashed line). The analyses are conducted by applying at first all the weights along the arch, and then by imposing an increasing vertical force at the monitored section.

3 CONCLUSIONS

An approach for a preliminary estimate of the load-carrying capacity of masonry arch bridges that takes is presented and applied to an ancient italian masonry arch bridge.The results clearly show that all the diagrams have a linear branch, confirming that the CFRP wraps modify only the main arch ultimate capacity. In particular, the higher the debonding strength the higher the ultimate carrying capacity. One of the advantages of the proposed approach is that it makes use of available general-purpose engineering software, having recourse to analysis methods accepted and widely used in other fields of structural engineering and consistent with the philosophy of modern design and assessment codes. In conclusion, the paper makes a contribution towards the development of analysis tools for assessing and preserving existing masonry arch bridge.

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