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Photogrammetric 3D modelling and mechanical analysis of masonry arches: An approach based on a discontinuous model of voussoirs

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ABSTRACT

This article shows the application of close range photogrammetry to the generation of accurate 3D geometric models for the subsequent evaluation of the condition state of historical masonry bridge arches by means of numerical analysis. The arch geometry in the model was obtained from each individual voussoir or ashlar with its own contour geometry, which was obtained by close range photogrammetry. From this precise geometrical model, mechanical modelling tools and finite elements analysis were applied to accomplish two main goals: to estimate the failure load considering the arch stability using a discontinuous model of voussoirs assembled without tension at the interfaces, and to obtain the distribution of stresses into each voussoir. The obtained results by means of this procedure are compared with those obtained by rigid blocks limit analysis with regular geometry.

1. Introduction

Masonry arches are one of the most common and extended structural shapes in the worldwide architectural heritage, given that they are present in domed buildings, vaulted tunnels, or historic bridges. Arch bridges are the greatest examples of the use of masonry arches. They are especially abundant in the Northwest of Spain because the irregular landscape topography and dispersion of settlements pushed the construction of infrastructures that allowed passing and communication. Hundreds of bridges dating from the Roman and Medieval periods are still in service and constitute a meaningful part of the road network as well as an important part of the heritage of engineering works, so they ought to be preserved and assessed.

Either because of their heritage value or their structural function in built up structures, the analysis of masonry arches is still the subject of numerous investigations [1–3]. However, their analysis is not a simple task. As pointed by Lourenço et al. [4], the geometric data are typically not available anymore; further, the workmanship and natural materials involve high variability of mechanical properties whose characterisation is usually difficult and expensive. Thus, there is no general analysis method for these structural elements. Two main approaches coexist: one focuses on structural behaviour analysis with finite element methods (FEM) [4]; the other is based on limit analysis theory or equilibrium analysis [5,6].

Masonry-bridge arches have two main characteristics that should be of interest to the scientific community. Firstly, their design has followed no standardised but empirical rules, and secondly, they have been subject to an increase in service loads through the years. In order to prevent the disappearance or degradation of these arches, the scientific community has to face, at least two questions: (i) development of reliable and affordable methods to document historical infrastructures, and (ii) improvement of the procedures of structural analysis and evaluation of the current structural condition of the bridges. The first question concerns the cultural value of each structure, and includes storing its metrical and graphical data. The second matter refers to the role the bridge plays on society, which makes the verification of its safety conditions a serious issue.

The bridge documentation and modelling can greatly benefit from high 3D digital imaging and processing techniques given the advances in surveying techniques, computer graphics hardware, three-dimensional modelling software tools, and 3D display capabilities. Virtual reconstruction of real world objects and scenes for further analysis is getting increasing interest in several fields as heritage [7], construction technology [8], medicine [9], and computer vision [10].To obtain the geometry used for computations, photogrammetry and laser scanning techniques are of interest to several researchers in the fields of structure inspection and computation [11,12], especially photogrammetric techniques because they are more balanced in terms of cost and accuracy.

Structural computations might also incorporate geometric models obtained using digital modelling. While these models are derived from the external configuration of the structure (as ones obtained with traditional contact methods of measurement) with respect to

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