Construction and Building Materials 153 (2017) 663–681

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Experimental characterization of the mechanical behaviour of components and materials of stone masonry railway bridges

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HIGHLIGHTS

- Experimental characterization of materials of stone masonry railway bridges.
- *In situ* tests: DPSH, georadar, Ménard pressuremeter (PMT) and flat-jacks.
- Lab tests on constituent materials' samples taken from the studied bridges.
- Test results allowed provided good characterization for numerical simulation models.
- Useful data, since this type of information is very scarce and improves knowledge.

ARTICLE INFO

Article history:
Received 24 October 2015
Received in revised form 20 June 2017
Accepted 4 July 2017

Keywords:
Stone masonry bridges
Experimental characterization
DPSH
Georadar
Ménard Pressuremeter (PMT)
Flat-jack
Stone joint testing

ABSTRACT

This article focuses on the experimental characterization of constituent materials of stone masonry railway bridges. The study refers to two railway bridges, an overpass in Durrães (near Barcelos, Portugal) and a culvert in São Pedro da Torre (next to the north border Portugal-Spain), both included in the Portuguese railway network. The experimental campaign comprised core sampling and *in situ* tests using several techniques, namely Dynamic Probing Super Heavy (DPSH), georadar, Ménard pressuremeter (PMT) and flat-jacks, as well as lab tests on constituent materials' samples taken from the studied bridges. The main objective of this work is therefore to use these experimental results for calibrating numerical models for structural behaviour simulation of the two bridge cases.

1. Introduction

The structural behaviour study of masonry arch bridges has shown that material characterization of structural components is a key issue for better understanding this type of construction [24]. Due to materials' heterogeneity (masonry and infill) and construction techniques used in this type of structures, laboratory tests on samples taken from the bridges and *in situ* tests for structural characterization are crucial for successful and realistic numerical simulation of such structures using duly calibrated models [8].

Several non-destructive and slightly-destructive testing techniques are generally accepted appropriate for estimating physical and mechanical parameters of constituent materials of stone masonry bridges, thus contributing for evaluating the conservation conditions of materials and to validate numerical simulation models of stone bridges. Flat-jack and pressuremeter tests are examples of such techniques, which are suitable for masonry and infill material, respectively.

Flat-jack tests allow estimating *in situ* stress and masonry deformability properties, without requiring any sample extraction [5]. The testing technique originates from rock mechanics, but its use became quite common to test masonry walls according to the single and double flat-jack testing variants. As usual, also in this work single flat-jack tests were carried out to estimate the

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http://dx.doi.org/10.1016/j.conbuildmat.2017.07.069

in situ vertical stress while double flat-jack tests were adopted to obtain deformability properties of stone masonry.

The pressuremeter test has wide application in soft or hard soils and rocks [18], allowing to determine deformability parameters of the tested material. This technique consists in introducing a probe inside a previously drilled borehole, which is pressurized to force the probe dilation that imposes radial compression in the surrounding material area. In this work, the pressuremeter test is applied to the bridges' infill material in order to estimate its deformability properties.

In masonry bridges, information related to the dimensions of the various structural elements has been investigated using *in situ* testing techniques such as georadar or GPR Ground Penetrating Radar). Since the mid-1980s, these tests became quite popular in the engineering field, with applications in ancient masonry structures [13,16]. Such tests consist on emitting and recording electromagnetic waves to detect the presence of voids, the contact conditions between materials and to identify the thickness of constituent layers and/or facing stones. Within the present work scope, GPR tests were used to understand the geometry of the bridge and to study the geometry of foundations. DPSH (Dynamic Probing Super Heavy) tests were also used for comparison with GPR results, thus further helping on estimating the bed rock depth.

This work also comprised laboratory tests carried out for characterizing material collected from the bridges by core sampling. These included current lab tests on stone samples, such as uniaxial and classical diametral compression tests, to obtain physical and mechanical characteristics of the granite stone. Stone-to-stone joint samples were also tested in shear and cyclic compression, in order to characterise the joints' behaviour and, therefore, to obtain behaviour curves with the evolution the shear/compressive stress with horizontal/vertical displacement.

In this context, the paper presents some results obtained in testing campaigns carried out in two railway bridges made of granite stone masonry arches in operational conditions in the Minho railway line. The work was part of the *StonArcRail* project activities recently developed at the Faculty of Engineering, University of Porto (FEUP) and the Polytechnic Institute of Tomar (IPT), with the institutional and logistic support of REFER, EPE, the former national body for the Portuguese railway network exploitation and management. The experimental campaign focused on the long span Durrães bridge, located near Barcelos (Portugal) and on a single arch bridge (actually an hydraulic passage, denominated PK124) in São Pedro da Torre, near Valença (close to the Portuguese-Spanish north border). It included *in situ* tests for the characterization of materials with experimental data obtained from georadar, DPSH tests, flat-jack and pressuremeter tests and laboratory tests on bridges' material samples.

Experiments also included global structure characterization through vibration tests on both bridges and response measurement under in-service loading. Details of vibration tests can be found in [10] and in [9], respectively, for the PK124 bridge and for the Durrães bridge.

The *in situ* and lab tests results allowed obtaining a detailed characterization of the constituent materials of both bridges, as well as of their whole structures, and thus the obtained mechanical parameters' values have been used in numerical simulation models of the bridges' structural behaviour. Another paper [11], prepared by some authors of the present one, provides a detailed description of the calibration methodology for the numerical model of Durrães bridge using the results of the experimental campaign herein addressed.

2. Case studies

2.1. Durrães bridge

The Durrães bridge was designed in 1876 [7,23] and built in 1878 by the Royal Company of Portuguese Railways. The bridge extends over 178 m, with 5.3 m width and 22 m maximum height from the ground to the bridge deck. It comprises 16 arches with 9 m span, supported by 15 piers and 2 abutments (Fig. 1a). The bridge deck supports a ballast layer about 0.5 m thick, over which bi-block concrete sleepers and rail profile UIC60 are laid on, and parapets made of granite blocks (Fig. 1b).

The arches have uniform thickness of 0.7 m and the piers' height, measured between the footings and the arch springing, range from 11 to 12 m, except for the shorter pier near the right abutment (Fig. 2). The two piers located at about 1/3 and 2/3 of the total bridge length (supporting arches 5 and 6 and arches 11 and 12) have about twice as the cross-sectional area of the other piers.

According to available design data, the foundation soil consists of a variable depth topsoil layer over the bed rock, onto which the piers footings sit (Fig. 3).

2.2. PK124 bridge

The PK124 bridge is a culvert hydraulic passage with masonry structure quite common in the Portuguese railway network (Fig. 4a). Its design [22]) and construction date back to January 1879, when the railway line portion between Caminha and Valença

Fig. 1. Durrães Bridge: a) general view (piers and arches) and b) railway deck.