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Ambient vibration testing and condition assessment of the Paderno iron arch bridge (1889)

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ABSTRACT

The Paderno iron arch bridge, erected in 1889 and still used as a combined road and rail bridge, is the most important monument of XIX century iron architecture in Italy. The bridge, with an arch span of 150 m, has a total length of 266 m between the abutments and about 2600 tons of wrought iron were used in its construction.

After a description of the historic structure, the paper presents the results of the experimental modal analysis of the bridge. The dynamic tests, performed in operational conditions (i.e. under traffic and wind-induced excitation) between June and October 2009, represented the first experimental survey carried out on the global characteristics of the bridge since the load reception tests (1889 and 1892) and suggested the opportunity of installing a permanent dynamic monitoring system on the bridge with Structural Health Monitoring purposes.

1. Introduction

The San Michele bridge (Figs. 1 and 2) is an iron arch bridge that crosses the Adda river, linking the small towns of Paderno and Calusco d'Adda, about 50 km far from Milan. The bridge was built between 1887 and 1889 by the Società Nazionale delle Officine di Savigliano (SNOS) to complete one of the first Italian railway lines [1,2]. The historic structure, better known as Paderno bridge, is protected by the Italian Ministry of Cultural Heritage since 1980 and is a symbol of Italian industrial archaeology heritage. The Paderno bridge shares its structural architecture with similar iron arch bridges built in Europe at the time, such as the Garabit viaduct in France (Eiffel and Boyer, 1884), the Maria Pia bridge (Eiffel and Seyrig, 1877) and the Luiz I bridge (Seyrig, 1885) in Porto.

The main structural elements of the bridge (Fig. 2) are a parabolic iron arch, with a span of 150 m, and a truss-box metal girder, 266 m long, resting on nine equally spaced bearings. Four of these bearings are supported by the arch, directly or through metallic piers, while the remaining ones are supported by three iron piers and by the abutments. Hence, the girder behaves as a beam bridge defined between abutments and with equally spaced elastic supports.

Notwithstanding the lack of maintenance and the poor state of preservation of the structure, significantly damaged by corrosion, the bridge is still used as a combined road and rail bridge, with the top deck of the truss-box girder carrying one lane of alternate road traffic and the bottom deck housing the tracks of a single-line railway. Although the weight and speed of vehicles are limited (180 kN/axis and 15 km/h for the trains, 35 kN and 20 km/h for the road vehicles), the bridge has not been saved from the progressive increase in road and rail traffic, generally experienced by the infrastructures during the past years. For example, the daily train passages (at present 53) were triplicate from the '80s and the one-way road traffic loads the bridge almost continuously during the day.

Within a systematic surveillance program of the main infrastructures owned by the Province of Lecco – such as the Victory Bridge [3] and the new cable-stayed bridge on the Adda river [4,5] – three different ambient vibration tests were recently carried out on the roadway deck of the Paderno bridge by the VibLab (Laboratory of Vibrations and Dynamic Monitoring of Structures) of Politecnico di Milano. The first test, performed at the end of June 2009, was aimed at investigating the vertical dynamic characteristics of the bridge; subsequently, two other tests were carried out to check the variation over time of the previously identified resonant frequencies (September 2009) and to investigate the transverse dynamic behaviour (October 2009).

Furthermore, an innovative interferometric radar [5,6] was used to measure the dynamic deflections induced by the train passages in one selected point of the railway deck, with the main objective of evaluating the dynamic effects [7,8] of railway traffic.

The paper first describes the historic infrastructure, emphasizing the erection procedures and the main steps of structural

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Fig. 1. View of the Paderno iron arch bridge (1889).

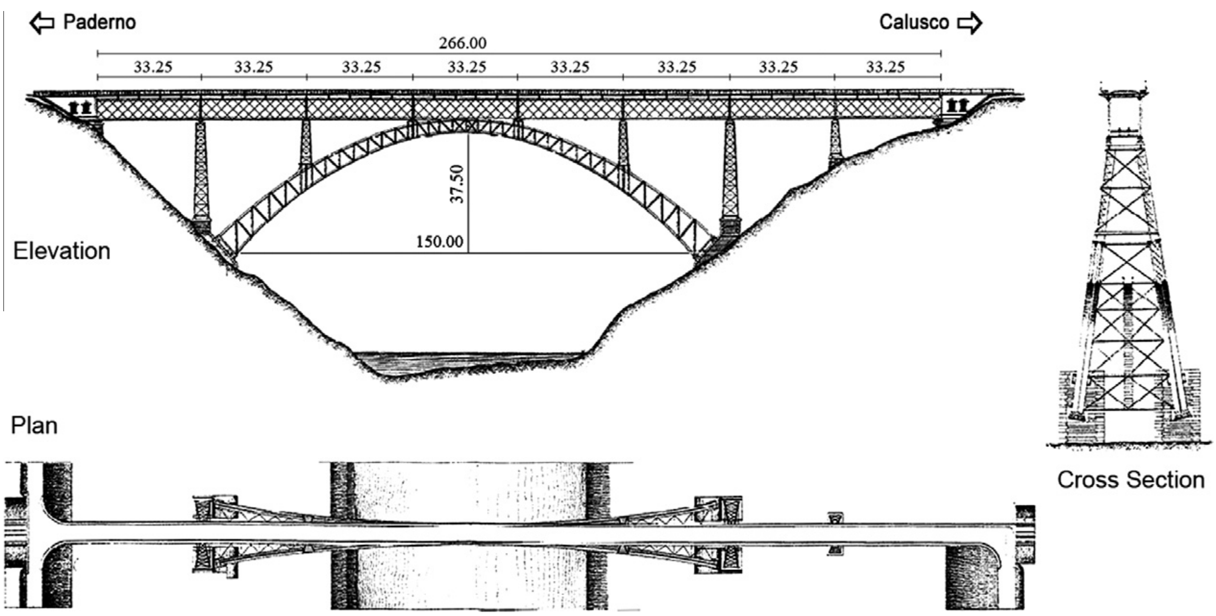

Fig. 2. Elevation, plan and cross-section [1] of the Paderno bridge (dimensions in m).

modification made during the history of the bridge. Subsequently, the paper focuses on the dynamic tests, the experimental procedures, the data analysis techniques and the identified dynamic characteristics (i.e. natural frequencies, mode shapes and damping ratios) of the bridge. In order to assess the accuracy of the identified modal parameters in view of future studies, the most significant mode shapes and associated natural frequencies were determined by using two different identification techniques, with different theoretical background: the Frequency Domain Decomposition [9] and the data-driven Stochastic Subspace Identification [10,11]. The two methods provided clear identification of the vibration modes in the investigated frequency range, with most of these modes being clearly detected also by automated procedures [12].

The identified dynamic characteristics provided significant information about the structural condition of the historic infrastructure and suggested the opportunity of setting up a Structural Health Monitoring (SHM) program, based on the continuous dynamic monitoring of the bridge.

2. Description of the bridge and historic background

The Paderno bridge (Figs. 1 and 2) was designed in 1886 by the head of SNOS technical division, the Swiss engineer Julius Röthlisberger (1851–1911). Rothlisberger's design was preferred to other entries into a competition held by the Italian government due to the scheduled erection time of only 18 months: the construction officially began on September 1887 and was completed on March 1889.

The bridge consists of a single span parabolic arch (Fig. 3), an upper trussed box girder and a series of piers. Three piers are erected from masonry basements while the others are supported by the parabolic arch; all the piers are battered in both directions (Fig. 4) according to the European practice of the late XIX century.

The arch consists of two ribs, with a span of 150.0 m and rise of 37.5 m; as shown in Fig. 3, each of the two ribs is composed of double members 1.0 m apart and has a variable height, between 8.0 m near the supports and 4.0 m at the crown. Since the two parabolic arch ribs are canted inward, the distance between the ribs is vari-