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Investigating dynamic amplification factor of railway masonry arch bridges through dynamic load tests

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HIGHLIGHTS

- Dynamic load testing of 11 masonry arch bridges.
- Determining dynamic amplification factor of bridges based on displacement measurements.
- Studying the correlation of dynamic amplification factor with structural geometrical and mechanical characteristics.
- Comparing experimental dynamic amplification factor with proposed values of standards.

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ABSTRACT

Structural assessment of masonry bridges is of great importance due to long service-life and deterioration of masonry and a growing demand for increasing the axle load. An important factor in doing so is the dynamic amplification factor (DAF), which accounts for dynamic impact of moving trains on a bridge. Accurate evaluation of DAF leads to sustainable management of existing bridges. A total of 845 dynamic load tests are carried out on 11 masonry arch bridges in Iranian railway network and results are used to assess the effect of train formation, train speed, span length, rise/span ratio, first natural frequencies in vertical and lateral directions, and combined modulus of elasticity of masonry and mortar on DAF. The correlation coefficients between first vertical frequency and modulus of elasticity and DAF are 0.53 and 0.56, respectively, which are the highest amongst studied parameters. Moreover, root mean square deviation between experimental DAF values and those determined according to various standards are determined and compared.

1. Introduction

Masonry bridges comprise an important asset of many railway infrastructures. According to UIC (Union Internationale des Chemins, international union of railways), approximately 40% of the bridge stock of the railway organizations within UIC are masonry structures [1]. Many defects have developed in masonry bridges due to their old age, which range from material deterioration to crack propagation and material loss. Safety of masonry structures is therefore crucial to the safe operation of railway network. However, structural assessment of such structures is rather difficult due to complexity of details and deterioration of masonry. The combined application of dynamic load test results with advanced finite element modeling of masonry arch bridges have proven to be a reliable method for assessing such structures and has gained significant attention during recent decades [2–4].

One of the primary aspects in structural assessment of bridges is the response of the structure to dynamic loads. It is a well-known fact that moving vehicles exert a dynamic force on bridges as they cross the structure. To account for such effects, a common practice is to apply a dynamic amplification factor (DAF) as follows:

$$R_{Dynamic} = (1 + DAF) \times R_{Static} \quad (1)$$

In which $R_{Dynamic}$ is the dynamic response of the bridge, R_{Static} is the static response of the bridge, and DAF is the dynamic amplification factor. Although the bridge response may be determined based on deflection or strain measurement, this paper focuses on deflection measurements, since all tested bridges were instrumented with extensometers. The role of DAF is significant in condition appraisal of bridges. However, the evaluation of this

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parameter is rather complicated due to a plethora of factors affecting it. This actually explains the reason for varying values and affecting parameters of DAF in different design codes.

Most design codes consider span length as the main parameter for determining DAF, while some take first natural frequency [5–7]. In this regard, various researchers have tried to investigate the parameters affecting DAF. A summary of proposed equations of standards for Railway bridges is presented in Table 1. 'L' is the span length of the bridge, and 'L_Φ' is the determinant length, which for masonry arch bridges is twice the clear opening, 'V' is train's speed, and 'f' is first natural frequency of the bridge. [6].

Eurocode also proposes a detailed method for determining DAF, which is applicable for real train loading, which is as follows (Eurocode annex C) [6]:

$$\begin{aligned} &1+\varphi'+\varphi'' \quad \textit{for track with standard maintenance} \\ &1+\varphi'+0.5\varphi'' \quad \textit{for carefully maintained tracks} \end{aligned} \tag{5}$$

Table 1
A summary of equations proposed by various standards for DAF.

AREMA [5]	$\begin{cases} 40-\frac{3L^2}{148.6}; L \leqslant 24 \\ 16+\frac{182.9}{L-9.1}; L \geqslant 24 \end{cases}$	(2)
Eurocode (Simplified method) [6]	$\begin{cases} \frac{2.16}{\sqrt{L_\phi}-0.2}+0.73;\ \textit{Standard Maintenance} \\ \frac{1.44}{\sqrt{L_\phi}-0.2}+0.82;\ \textit{Carefully Maintained} \end{cases}$	(3)
ORE [7]	$0.65 \times \frac{K}{(1-K+K^2)},\ \textit{where}\ K = \frac{V}{2/L\times f}$	(4)

in which

$$\begin{aligned} &\varphi' = \frac{K}{1-K+K^4} \quad \textit{for}\ K < 0.76 \\ &\varphi' = 1.325 \quad \textit{for}\ K \geqslant 0.76 \end{aligned} \tag{6}$$

where

$$K = \frac{v}{2L_\phi \times n_0} \tag{7}$$

and

$$\varphi'' = \frac{\alpha}{100}\left[56e^{-\left(\frac{L_\phi}{10}\right)^2} + 50\left(\frac{L_\phi n_0}{80}-1\right)e^{-\left(\frac{L_\phi}{20}\right)^2}\right] \geqslant 0 \tag{8}$$

with

$$\begin{aligned} &\alpha = \frac{v}{22} \quad \textit{if}\ v \leqslant 22m/s \\ &\alpha = 1 \quad \textit{if}\ v > 22m/s \end{aligned} \tag{9}$$

in which 'v' is the maximum permitted speed (m/s), 'n_0'' is the first bending natural frequency of bridge loaded by permanent actions, 'α' is the coefficient for speed, and rest of parameters are as defined before.

ϕ' covers the rate of loading due to the speed of traffic crossing the structure and the inertial response of the structure. It also covers the effects of the passage of successive loads which may excite the structure and cause resonance. ϕ'' covers the effects of variations in wheel loads resulting from track or vehicle imperfections [4].

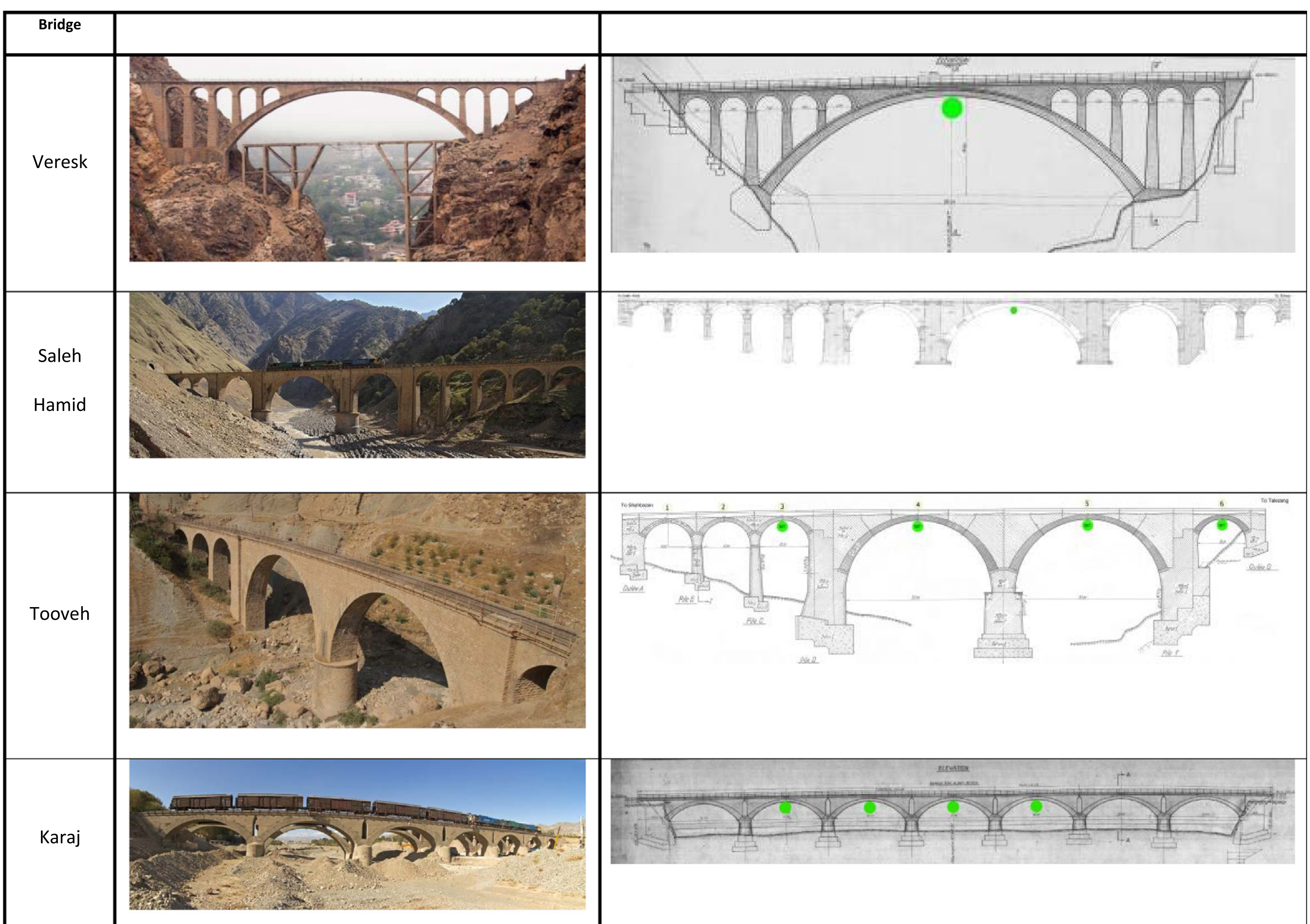

Fig. 1. A view of each bridge and its sensoring plan (green dots represent sensor locations). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)