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A methodology for the preliminary assessment of existing railway bridges for high-speed traffic

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ABSTRACT

The Swedish government is considering upgrading the train speed along three railway lines in the Southern part of Sweden from 200 km/h to 250 km/h. According to the current design code, this requires that the bridges be examined with dynamic simulations to avoid excessive vibrations. This paper employs a method that can be used at an early stage to estimate the expected cost of upgrading a bridge network. The results revealed that 70% of the plate/beam bridges, 64% of the closed slab-frame bridges, and 41% of the open slab-frame bridges are expected to not fulfill the requirement on the maximum bridge deck acceleration for ballasted tracks.

1. Introduction

After the Swedish election in 2010, it was decided that there will not be any further investment in new high-speed lines. As there still is a need to increase capacity, the government commissioned the Swedish Transport Administration to investigate the requirements of increased railway capacity up until 2050. In this extensive project, several disciplines were consulted to study various problems, eg. logistic, geotechnic, maintenance, track and bridges. With a view to the bridges, the divisions of structural engineering and bridges at the KTH Royal Institute of Technology and ELU Konsult AB were asked to conduct a preliminary assessment of the dynamic response of the bridges to facilitate a cost estimation of upgrading the maximum allowed speed to 250 km/h from the existing 70–200 km/h.

In total, there are more than 1000 bridges that should be analysed, see Fig. 1, located along the West main line (Stockholm to Gothenburg), South main line (Stockholm to Malmö) and West coast line (Gothenburg to Malmö). The verification is carried out according to EN1991-2 [1], which at the time of publication is the accepted design code in Sweden. It should be pointed out, however, that EN1991-2 is a design code for new bridges and might, therefore, be too conservative when existing structures are evaluated. Unfortunately, there are no guidelines for the assessment of existing railway bridges for high-speed trains.

One of the main issues with increasing the speed above 200 km/h is the risk of resonance, which occurs when the frequency of excitation of the train coincides with one of the natural frequencies f_n of a bridge. According to the Eurocode, the maximum bridge deck acceleration, deck twist, deflections, and angular rotation should not exceed their specific design values. This is to avoid excessive vibration. However, several authors [2–4] have shown that in most cases it is the maximum bridge deck acceleration $a_{\max}$ which is the governing factor. The reason for limiting $a_{\max}$ is related to the phenomenon of ballast instability, observed on European high-speed lines, with increased maintenance costs and potential safety risks to the passengers [2,5].

Several authors have studied the dynamic response of existing railway bridges. For example, Kwark et al. [6] investigated the dynamical behavior of a two-span continuous concrete bridge. The bridge was modeled using 3D beam element to represent the frame and the train was modeled as a suspended rigid beam. The results showed good correlation between model and measurement. In 2010 Martínez-Rodrigo et al. [7] evaluated the dynamic performance of three single-track short-to-medium-span simply-supported railway bridges. All three of the bridges are located in double-track branches, but constructed with structurally independent decks. In the study, it was found that none of the bridges satisfied the serviceability limit state of vertical acceleration. In order to limit the acceleration without replacing the bridges, the authors suggest that the two decks are cast as a single, continuous unit. As a result of the modification acceleration level is lowered with up to 50%. More recently, Rocha et al. [8] performed a safety assessment

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Fig. 1. Geographical overview. ○ Bridges along three railway lines in the Southern part of Sweden.

of a short span railway bridge for high-speed traffic using a probabilistic approach. That study found that the speed limit could be increased by 40 km/h compared with a deterministic approach. Furthermore, [9–13] should also be mentioned, since their work also investigated existing railway bridges for high-speed traffic.

The paper addresses the problem of a dynamic assessment of over 1000 bridges on a railway network in Sweden. The method essentially follows the procedure presented by Nualláin et al. [14]. The paper is organized as follows. Section 2 describes the methodology that is employed. This section also addresses the issue of dividing the bridges into blocks of similar properties. Furthermore, a closed–form solution to determine the maximum bridge deck acceleration is also presented. Unlike other analytical models, a wide variety of structures may be analysed, while the model remains fast and robust. Section 3 presents the results from the Monte Carlo simulations, while the conclusions are presented in Section 4. As far as the authors are aware, this is the first time the dynamic behavior of bridges has been assessed for an entire railway network. Previous studies have rather considered a specific object. In this context, the paper aims at providing a general framework for the preliminary evaluation of railway lines.

2. Methodology

The authors have applied a method previously presented by Nualláin et al. [14]. This method is also summarized in a flowchart in Fig. 2, to give an overview.

As the figure shows, the bridges are first divided into groups with similar properties, see Section 2.1, this could for example be slab-frame bridges, simply supported slabs, and so on. In Section 2.3 some random variables, e.g., fundamental frequency f_0, mass per unit length m, and foundation stiffness k, are retrieved manually for a sample of bridges to construct prediction intervals. With the proposed method, the span length, number of spans, and bridge width are considered to be deterministic variables, and must be determined for each bridge. The model and the simulation techniques are described in detail in Sections 2.2 and 2.4.

2.1. Blocking/grouping

There are in total 1019 bridges that need to be analysed. Out of these bridges, 48% are frame bridges, 43% beam bridges, and the remaining 9% mainly consist of arches, trusses, and culverts (see also Fig. 3). The survey also found that 90% of the bridges consist of concrete, while only 5% are steel bridges. Thus the remaining 5% consist essentially of stone. The distribution of the Swedish railway bridges is in accordance with a study conducted within the Sixth Framework Programme of the European Commission [15]. However it is remarkable how the distribution differs from the rest of Europe, where only 22.7% are concrete bridges. Instead, there are as many as 40.7% arches, 21.5% steel bridges and 13.9% steel/concrete composite bridges. For the span length, it was found that 70% of the bridge stock is shorter than 12 m. The corresponding value for spans longer than 30 m is only 3%. In between, the distribution is concentrated in the shorter span lengths, see Fig. 4. From these numbers it seems reasonable to only consider concrete bridges, as stone and steel bridges only represent 10% of the bridge stock. As an approximation, the concrete bridges are assumed to behave as either plate/beam bridges (see Section 2.2.1) or slab-frame bridges (see Section 2.2.2), depending on bridge type.