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Experiences from Analysis and Experiment Considering the Vehicle Scanning Method

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Abstract

Application of the Vehicle Scanning Method (VSM) on real bridges requires more precise analysis that can be provided by the closed form solution. Analytical solutions applied the previously proposed hybrid time effective method using ANSYS and MATLAB that makes possible to account for a vehicle mass, initial condition of the spring mass and damping. The effect of initial conditions and vehicle mass was studied in the following case study. The computed results were compared to experiments. The relation between the exciting forces caused by the scanning vehicle and vibration noise from other sources affecting the sprung mass seems to be decisive for a successful application of the VSM. A higher vehicle damping can reduce the adverse effects of initial vibration state of the vehicle when entering a bridge.

Keywords: VSM, moving loads, bridges, finite element method, modal analysis, initial conditions

1 Introduction

The idea that the natural frequency of a bridge can be determined by means of a passing vehicle has been pursued since the closed-form solution for a sprung mass on a beam was published [1]. A recent review of the achievements in the field of VSM, formerly called "drive-by identification", can be read in [2]. However, the idealization considered in the closed-form solution, which is the base of the VSM, is nearly impossible to achieve under practical circumstances. The sprung mass cannot roll directly on a roadway or rail, it has to be pulled by another vehicle or have its own drive, most bridges cannot be modelled as a simply-supported beam, damping cannot always be neglected and the vibrations of the vehicle as well as of the bridge cannot be zero when the scanning vehicle enters the bridge.

These shortcomings of idealization led to FE solutions that applied the Vehicle-Bridge Interaction (VBI) element [3] or later on the MINE element [4] or to applications of finite elements (FE) programs with implemented kinematic formulations like e.g. LS-Dyna.

To the FE family belongs also a promising alternative approach suggested recently [5] which allows for the use of standard FE packages when modeling a bridge of interest, but the moving vehicle problem is formulated in MATLAB. This approach was applied to carry out a preliminary theoretical case study concerning the influence of crossing the expansion joint of a bridge model by a test vehicle. The effect of the relation vehicle mass / spring mass was also examined. Finally, the theoretical results were confronted with a laboratory experiment. The most interesting features of the comparison are discussed in the last paragraph – Conclusions.

2 Analysis

The applied approach [5] was designed to enable a time efficient analysis of complex bridge structures. The main advantage is that pre-processing and modelling makes use of the whole comfort of the programme package ANSYS that solves also the Modal Analysis. The computed eigenvalues and mode shapes are exported into MATLAB where moving vehicle problem is solved using a numerical integration by the help of coupling equations for the contact force between wheels and the bridge. The formulation of vehicle equations has to be done for each type of vehicle separately. At present there is available formulation for a sprung mass with two masses (vehicle with the contact and a spring mass – see Fig.1). It can also easily account for initial conditions of the vehicle, that can be set as initial vertical velocity of the sprung mass.

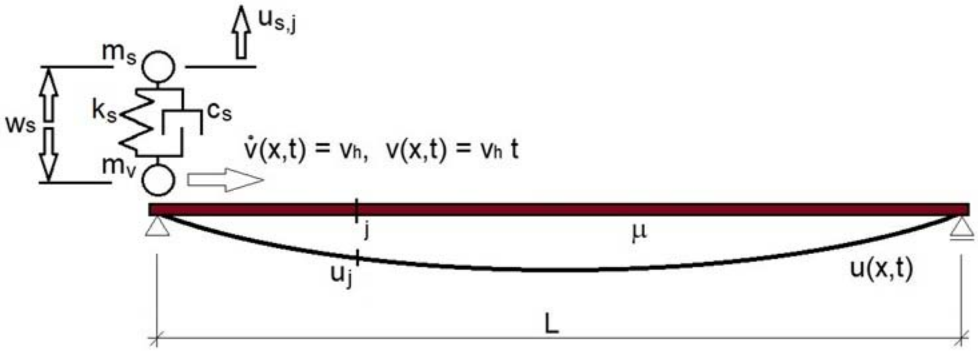

Figure 1: Schema of the test beam with a moving sprung mass

The experimental bridge model corresponds, except of small details, to the Figure 1. It is made of a steel U-profile 0.21 × 0.05 × 0.004 m with L = 3.98 and a total mass of 33.3 kg. Analytical model was tuned to the parameters of the experimental facility. First five bending modes (6.99, 27.63, 60.17, 99.81, 138.1264 Hz) were exported into MATLAB using the APDL macro language. The modes were further processed as described in [5] and the HHT-α algorithm [6] was applied for numerical integration. Viscous proportional damping (α=0.2, β=2.5e-5) was applied for the bridge and damping ratio of c_s=0.01 for the spring dash pot. The spring mass m_s=245g and the vehicle mass m_v=631g.

Concerning the experimental facility, the initial conditions of the moving spring mass were of interest, because the dynamic effect of the gap between the bridge model and the runway before it could not be eliminated mechanically. Further on also the differences between the applied method and the closed form solution were of interest. The initial spring mass velocity adjusted according to experiments was equal to 0.21 m/s. Figure 2 shows computed acceleration Power Spectral Density (PSD) of the spring mass with the initial conditions, without them and the results of the closed form solution (one DOF) for a moving spring mass 245 g and a total mass of 876 g. The horizontal moving velocity of the vehicle was 0.1 m/s.

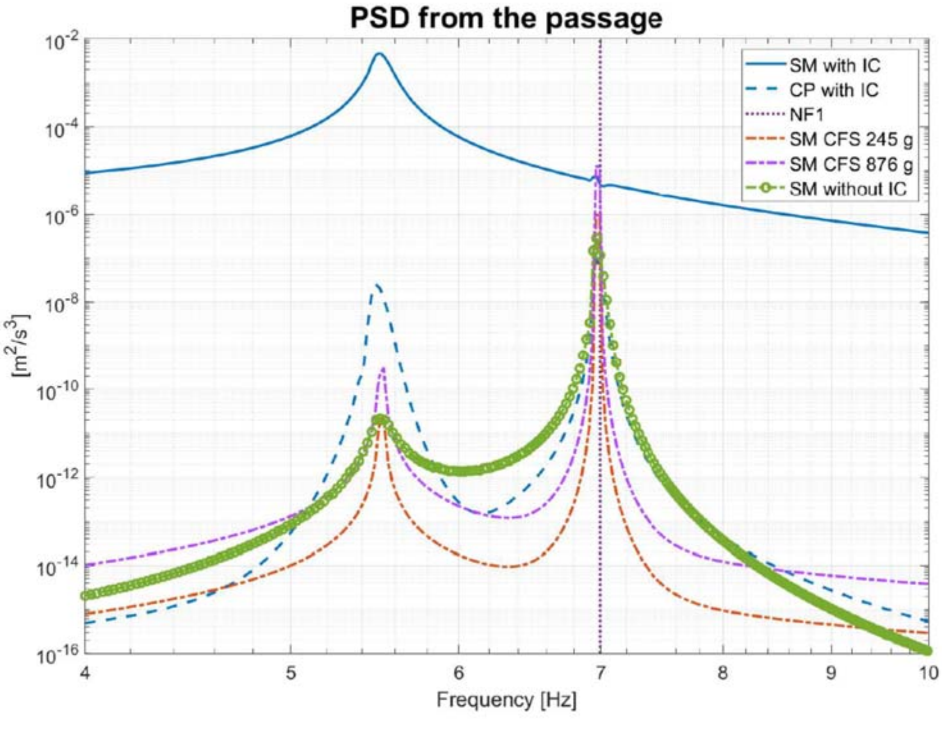

Figure 2: Computed PSD (SM with IC – sprung mass with initial conditions; CP with IC – contact point with initial conditions; NF1 - 1st natural frequency; SM CFS 245 g – closed form solution considering the mass of 245g; SM CFS 876g - closed form solution considering the mass of 245g; (SM with IC – sprung mass without initial conditions)

The peaks are distinct on the position corresponding to the 1st natural frequency except of the sprung mass curve with initial conditions considered. It confirms that the one-DOF closed form solution can provide us with a good initial estimates in spite of its relative simplicity. It implies that in case of an initial impulse (or in case of other noise affecting the sprung mass), the backward calculation of the contact point response from the sprung mass accelerations may be easily covered by a noise disabling a successful identification of bridge frequencies. The mode shapes may be also biased by the initial conditions of the sprung mass in a decisive way.

3 Experiments

Brüel & Kjær accelerometers type 4374 connected to a four-channel Nexus Conditioning amplifier were used for the vibration measurement, and a DEWE 43V measuring rack provided 24 bit resolution for the final data acquisition with 1kHz sampling rate. The data was further processed in MATLAB.
Time records from analysis and experiments are compared in Figure 3.

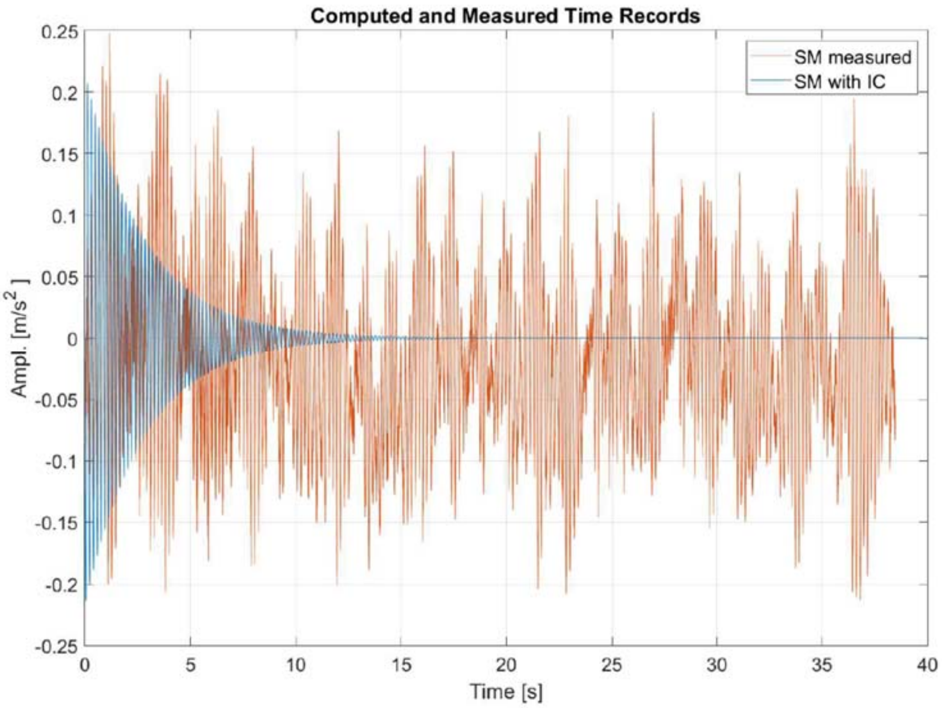

Figure 3: Measured (red) and calculated (blue) response of the sprung mass

The effect of initial conditions was attenuated approximately after 1/3rd of the passage time. The comparison with analysis pointed out the fact that there must be another substantial source of the vibrational noise which is probably due to a combination of pulling device effects, surface of the rolled steel and imperfections of wheels. Without the analysis, the vibrations could be attributed to vehicle-bridge interactions which is obviously not true. By the way, the vibrations computed by the closed form solution would appear only as a line in the scale of Figure 3. This comparison has also drawn the attention to the fact that the relation between the exciting forces caused by the scanning vehicle and vibration noise from other sources affecting the sprung mass seems to be decisive for a successful application of the VSM.

It can be further inferred that the adverse effect of initial conditions can be reduced by larger damping of the sprung mass which may supplement the conclusions stated in [7] after a more detailed study.
Figure 4 offers the corresponding comparison in the frequency domain. In spite of the enormous noise, the peak of the bridge frequency can be distinguished (see the black arrow). The contact point response was backward calculated from the sprung mass accelerations while neglecting the damping because of its low value, which would not improve the frequency identification in a decisive way in this case [8]. All peaks of higher frequencies were drowned in noise.

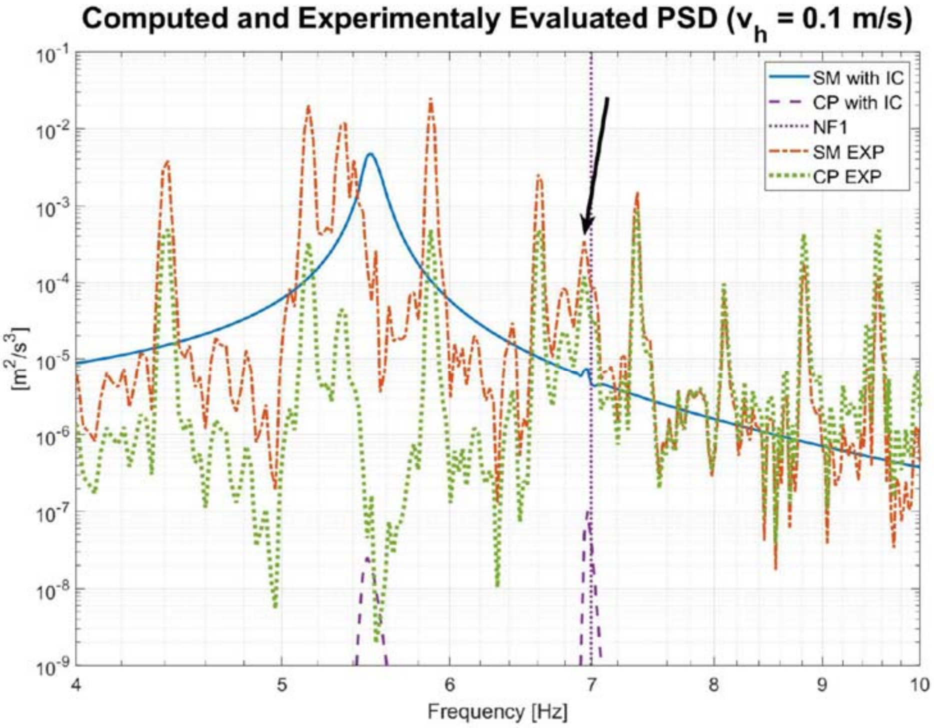

Figure 4: Analytical and experimental PSDs (SM with IC – sprung mass with initial conditions; CP with IC – contact point with initial conditions; NF1 - 1st natural frequency; SM EXP – sprung mass response from measurements; CP EXP – contact point response derived from SM EXP)

In spite of the fact that the agreement between analysis and experiment was rather poor it provided us with useful information.

4 Conclusions

A recently developed method for vehicle bridge interaction suited for large finite element models was applied to account for initial vibrations of vehicle´s sprung mass when entering the bridge. The analysis helped to reveal insufficiencies in the experimental setup.

A higher damping of the sprung mass can reduce the unwanted effects of its initial vibrations. The relation of vehicle mass / sprung mass did not have a substantial effect on the evaluation of frequencies by the VSM in this case.

The conducted study has also drawn the attention to the fact that the relation between the exciting forces caused by the scanning vehicle and vibration noise from other sources affecting the sprung mass seems to be decisive for a successful application of the VSM.

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