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MOVING DYNAMIC TEST LOADS FOR ROAD BRIDGES - A CASE STUDY

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Abstract: *Two types of dynamic testing load for bridges - driving sprung mass and driving impulse load - are examined from the drive-by identification point of view. Numerical studies in ANSYS using contact elements and in MATLAB using a modal solution together with coupling force were performed. Equations for the estimation of the impulse load caused by a rolling cogwheel were suggested. The experiments confirmed that a driving impulse load is more efficient in exciting bridge vibrations. This, together with the fact that impulse loading is not sensitive to surface roughness, leads to the conclusion that, as a method for bridge health monitoring, impulse loading is more promising than using a driving sprung mass.*

Keywords: Drive-by Identification, Bridge Testing, Moving Sprung Mass, Impulse Loading, Vibration Measurements, Laboratory Experiments

1. Introduction

The vibration response of a vehicle driving along a bridge contains also the information about the modal characteristic of a bridge which has been studied in recent years for the purposes of bridge health monitoring (e.g. Yang, 1997, 2004, 2005, O´Brien, 2017). Collecting information about the condition of a bridge comfortably and economically, from a passing vehicle, is a challenging idea, but there are still some problems that need to be clarified before standard practical use.

The idea of indirectly measuring bridge frequency from a passing vehicle emerged in Yang (2004) and since that time has been a subject of research. With increasing vehicle speed the response of the vehicle naturally increases, and there can be observed an increasing double-shift of the bridge frequency in the vehicle's spectrum.

According to a numerical study on viscous damping (Yang, 2004), damping doesn´t influence the vehicle's response in a decisive way.

On the other hand, the permanently changing surface roughness may have a substantial effect on the response of the passing vehicle (Lin, 2005, Yang, 2012, O´Brien, 2015, 2017). To overcome this problem chains of vehicles for measurement of the actual road profile seem to be the most promising approach (Kim, 2016). What has also proved helpful is tuning of the vehicle frequency distinctly higher than the bridge frequency.

The application of the Hilbert-Huang Transform to the measured response of the sprung mass can also identify higher bridge frequencies (Yang, 2009), or can even be applied for the purposes of damage detection (O´Brien, 2017).

Indirect identification of mode shapes is extensively discussed in O´Brien (2017-II), and an instrumented truck-trailer system with an exciter was suggested. A similar topic is also dealt with by Yang (2014).

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The feasibility of drive-by identification was first experimentally verified by Lin (2005), though the experiment used the response of a moving tractor-trailer system. Two bridge frequencies were identified from indirect measurements in Yang (2009).

Zhang (2012) suggests a moving dynamic load in the form of a “tapping vehicle” (a vehicle equipped with an exciter) to estimate the power mode shapes.

The idea of a moving impulse load is derived from the application of standard obstacle (Cantieni,1984 and ČSN736209, 1996), but the authors are not aware of any application of it in the form of an impulse chain for the purposes of bridge health monitoring, except in Bayer (2018).

The goal of the running project is the investigation of the perspectives of moving loads for testing of bridges. The present article reports on the results from the first series of numerical studies using ANSYS, and from experiments on a 4m long steel beam.

2. The model

The 4m long simply supported model is made from Jäckel steel 210x50x4 mm and has a mass of 33.3 kg. The measured and analytical natural frequencies of the model are presented in Table 1.

Tab. 1: Comparison of computed and measured natural frequencies

Mode No.	Analytical frequencies [Hz]	Experimental frequencies [Hz]	Estimated damping ratio [%]
1	6,98	7,01	0,16 - 0,50
2	13,41	11,84	0,18 - 0,56
3	27,74	27,66	0,11 - 0,34
4	36,10	34,78	0,22 - 0,69
6	60,89	59,94	0,33 - 1,03

3. Analysis

The nonlinear transient analysis offered by the program ANSYS was applied. A macro in APDL language was written using the shell181, mass21, targe170, conta175 and combin14 finite elements with a time step of 0.001 sec.

This type of analysis was used with the proportional damping model of the material, which does not entirely truncate the higher modes. The time-space discretization has to be managed carefully because any sudden move (or jump) by the vehicle from one place to another causes unrealistic effects in the response, mainly due to the contact elements. This, together with the fact that the solution is performed on the displacement level, results in obviously unrealistic phenomena, especially when considering the acceleration response and its frequency domain image.

The finite element analysis inevitably suffers from the discretisation, because the discrete movement from one node to another adds some non-existent discretisation frequency to the response and, in an adverse case, can be a source of numerical instabilities and unrealistic transient phenomena (like in the case of the applied contact elements in ANSYS).

This is the reason that another approach was chosen. The normal modes were imported from ANSYS into MATLAB and a solution using coupling force with the sprung mass was applied with the help of numerical integration. This approach is much faster than the transient solution by ANSYS and does not suffer from the phenomena caused by the contact elements. On the other hand, the normal–modes model and its condensing into the driving path is a rather severe simplification, and the reliable domain of this type of analysis will be studied as the next step.

Y.B-Young´s theory (Yang, 2004) provides another possibility for the estimation of the sprung mass response, though it neglects the damping.

The finite element analysis of the traveling impulse load is less problematic as it is discrete as well. On the other hand, the magnitude and form of the impulse caused by the edges of the cogwheel is difficult to estimate theoretically without experimental verification, because of a singularity in the vertical movement of the travelling mass and unknown deformation characteristics of the cogwheel tips.

Two working hypotheses for the evaluation of the impulse force were adopted. The first one is derived from the maximum vertical acceleration:

$$F_{y,max} = m * \frac{v_h^2}{r * cos^3(\frac{\pi}{n})} \tag{1}$$

and the second one from the maximum vertical velocity under the assumption of a quadratic impulse function:

$$F_{y,max} = m * \frac{4 * v_h^2}{3 * r * cos(\frac{\pi}{n})}, \tag{2}$$

Where m is the mass of the cogwheel, n is the number of teeth/tips on the cogwheel, v_h is the passing velocity and r is the diameter of the cogwheel. The applicability of equations (1) and (2) is currently under investigation using ANSYS together with the experimental results.

4. Experiments

The first series of experiments dealt with the passage of a sprung mass of 803g with a sprung mass frequency of 6.22, 7.99 and 9.78 Hz using two velocities, 0.1 and 0.2 m/s.

The traveling impulse load was imposed by a polygonal tire with a mass of 502g, having 7, 8 and 10 teeth, running along the same steel beam at velocities of 0.1 and 0.2 m/s.

The response of the beam was also measured for a mass of 501g rolling smoothly along the beam at velocities of 0.1 and 0.2 m/s. The average PSDs for the response of the steel beam in selected experiments are given in the Figure 1.

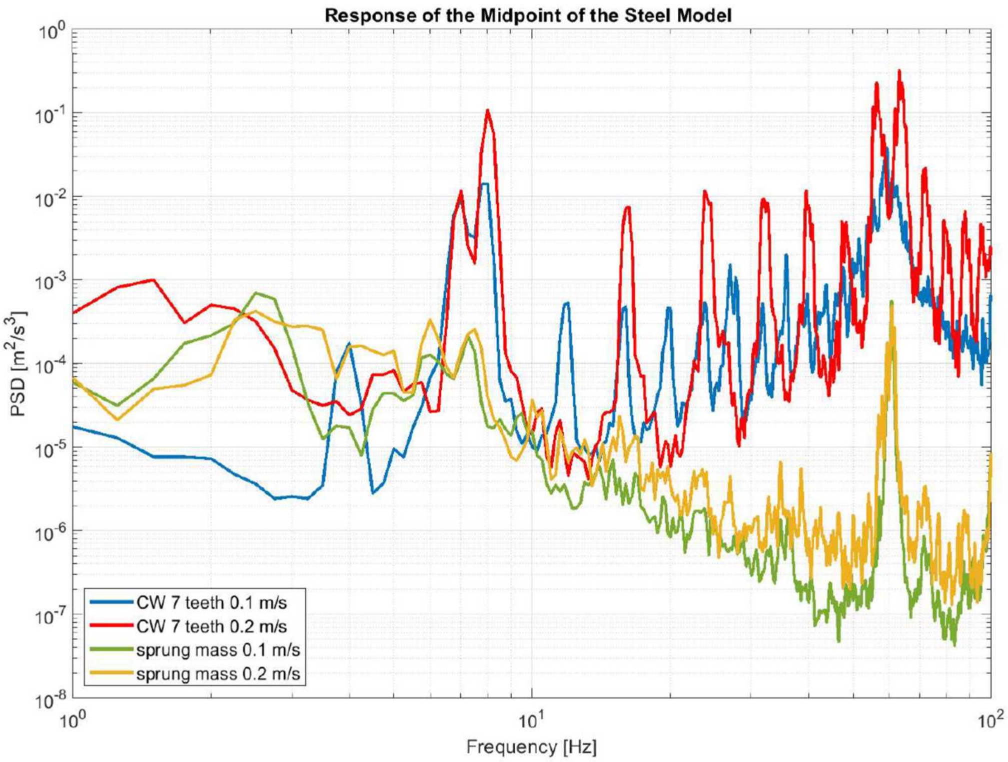

Fig. 1: Average PSD of the response of the midpoint of the steel beam to different excitations

5. Conclusions

Equations for the estimation of the impulse force caused by the rolling cogwheel were suggested. According to initial experimental results, it seems that the uncertainty of the analysis for the passage of the sprung mass will probably be higher than of the analysis of the traveling impulse load using ANSYS.

The experiments confirmed that the proposed impulse loading is more efficient in exciting the structure than the moving sprung mass. This, together with other reasons like construction aspects and insensitivity to surface roughness, implies that impulse loading is more promising for the purposes of drive-by identification than using a sprung mass.

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