

Vibration Monitoring and Noise Improvement of an old Railway Bridge

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Summary

Concern for the environmental and the quality of life of citizens forces policy-maker to transfer the transportation of goods from the traditional heavy trucks to railways. However, railway companies are subjected to tremendous resistance and objections to build new railway lines until the problem of vibration exposure to citizens is solved. In general high intensity traffic, wind and other dynamic action generate high noise levels and vibrations on systems and structures. An innovative method is required to notably reduce noise and vibration, at the same time minimizing energy and material use. For these ambitious goals it was necessary to perform some studies on an existing old steel structure in Austria. Numerous field tests have been performed including the measurements of structural vibration on the one hand and noise radiation on the other hand. Tests with an experimental train have also been performed, gathering signals under well-known boundary conditions (load level and acceleration). Testing existing as well as new developed noise reducing technologies at the Joint Research Centre will be the main outcome of this project.

Keywords: Natural frequency; mode shape; damping behaviour; noise emission; vibration behaviour; system identification.

1. Introduction

The concept of structural control originated in the early 1970s. Passive methods utilise the system response to dissipate energy without requiring an external power source. Active control, on the other hand, refers to methods that require a large power supply to operate large size actuators. Between passive and active control a very promising area is developing based on semi-active control laws. A very promising class of semi-active control devices uses advanced materials as for example rheological fluids [9].

Starting point for this extensive research is the CaSCo project (Consistent Semi-active System Control) supported by the European Commission in the frame of their current research programme FP 5. The basic project idea is to develop advanced damping technologies in order to reduce noise and vibration of railway lines. A rather simple, compact and very robust technology is required which can be used for upgrading existing systems as well as achieving better vibration attenuation for future projects. An interesting and powerful method is the application of semi-active damping devices. Some research has been performed in the past concerning active control in civil engineering, which was not really applicable for practical solutions due to extensive space and energy requirements. The semi-active approach is based upon miniaturised equipment that is designed to work as stand alone unit with only less power consumption and less maintenance required.

The innovative aspects are to apply magneto-rheological fluid technology for the real-time control of forces and increase energy dissipation, while at the same time minimise geometric dimensions of individual devices.

2. Problem Statement

Due to their high transport capacity and effective use of energy with lowest damage to the environment, railways are one of the most important means of transportation for the future. In spite

of the advantages of railways in comparison with other transport systems as for example motorcars, the acceptance of new railway lines is very low especially by potential neighbours. One of the most important reasons for that is the fear of irritations from noise and vibrations induced by modern high-speed trains. These problems especially occur in densely populated areas as in towns, where railway routes are in tunnels with low overburden and very close to residential buildings [3]. Due to maintenance reasons ballast less permanent ways become more and more important, especially for such tunnel lines. With regard to load carrying capability and to long-time stability of the track these solid roadways show a lot of advantages. Nevertheless the most important disadvantages of most kinds of permanent ways are the additional increasing noise and vibration emissions caused by such superstructures.

The source of noise and vibration emissions of railway lines is the rough contact area of the wheel-rail-system. The roughness causes vibrations that are induced into the superstructure and propagate through the soil to buildings in the neighbourhood. For the further remarks vibrations are defined as perceptible low frequency oscillations between 1 Hz and 80 Hz, whereas structure or ground borne noise are mechanical vibrations in an audible frequency range between 16 Hz and 20 kHz. Both kinds of emissions are propagated through the soil by mechanical wave propagation. Noise and vibration caused by rail traffic can be transmitted through the air (railway lines at ground level) and through the soil (railway lines at ground level and underground). In adjacent structures the induced vibrations in the frequency range of around 8 to 20 Hz mainly affect timber-ceiling structures or steel girder construction. Excitation frequencies of railway induced vibrations between 40 Hz and 80 Hz may cause significant acoustic phenomena that are called structure born sound.

For the reduction of vibration, sufficient results have been obtained so far by application of Mass-Spring-Systems [10]. The audible noise emission mainly from old steel bridges is a problem that has to be solved in future. This paper focuses on reduction measures of audible noise that is emitted during train passage. Generally speaking there is only little knowledge about the noise emission from railway bridges up to now.

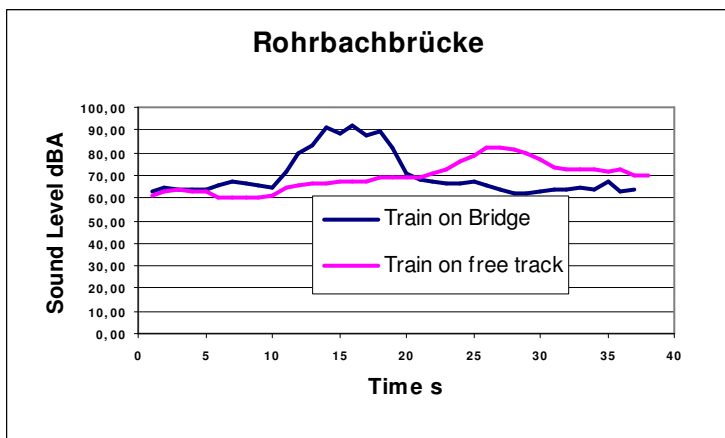


Fig. 1 Noise emission on free track and on a bridge

The main target for the development is shown in figure 1, where the results of a sound level measurement is presented during train passage on a steel bridge and on the free track. The noise emission difference was in the range of $\Delta L \approx 10 \text{ dB(A)}$ which corresponds to a doubling of the noise emitted on free track. This ambitious goal should be achieved in the development in order to upgrade extensive steel bridges successfully.

3. State of the Art

The concept of control for engineering applications originated in the early 1970. In the three decades, much progress has been made toward exploiting the potential benefits offered for protection of structures when subjected to high level of noise, earthquakes, high wind, blast and other internal or external dynamic excitations. Recently, the use of so-called "Smart Materials" allows an improvement in vibration control techniques [5].

Passive control refers to methods that utilize the system response to dissipate energy without requiring an external power source for their operation. Examples are metallic dampers, friction dampers, viscoelastic dampers, viscous fluid dampers, tuned mass dampers and tuned liquid dampers. Their effectiveness has clearly proven by laboratory and in field experiments and observations, but their performance has intrinsic limitations due to the fact that they must be tuned once for all before encountering the vibration phenomenon.

Active Control, on the other hand, refers to systems that require a large power source to operate large actuators that dissipate energy and supply control forces. Such systems are used to control the response of system components to internal or external excitation, where the safety or comfort level of the occupants is of concern. Active control makes use of a wide variety of actuators, including active mass dampers, hybrid mass dampers, tendon controls, which may employ hydraulic, pneumatic, electro-magnetic actuation. The need for an external power supply makes this system vulnerable to power failure, especially for earthquakes.

Semi-active control combines the best features of active and passive systems. According to presently accepted definitions, a semi-active control device is one that has properties that can be adjusted in real time but cannot input energy into the system being controlled. These methods require a small power source (a battery, for example) to operate and utilize the system response to dissipate energy. Preliminary studies have shown that semi-active control laws can potentially achieve the performance of fully active systems. Two systems are generally included in this category: 1) variable stiffness and 2) variable dampers. In the first category, the stiffness of the system components is adjusted to establish a non-resonant condition. In the second category, supplemental energy dissipation devices, such as fluid, friction, and rheological dampers are used. Modifications are made to allow adjustments in their mechanical properties to achieve significant reductions in the response.

A comparison among these methods from an experimental point of view is furnished for example in [4]. It must be noticed that no control technique is - a priori - better than another, because the final choice depends on several design constraints and requirements as for example:

- Performance
- Maintenance
- Robustness
- Manufacturing
- Energy consumption
- Reliability
- Installation
- Cost

and other technical constraints related to maximum stroke of actuating devices, needed electronics and sensors, computational time, implementation aspects.

For these reasons, semi-active devices based on magnetorheological fluids seem to be more appropriated for mechanical vibration at relatively low frequency (up to 20 Hz), for example and high amplitude (up to some millimetres). On the contrary, passive devices similar to Tuned Mass Dampers can be successfully used for acoustic noise reduction on the web plates of the main beams.

However, as mentioned above, it is very difficult to give an answer before considering a wide spectrum of possible devices. For this reason in the CaSCo Project different solutions will be tested in order to properly compare them experimentally on a real bridge.

Further details about the state of the art in the field of control of structures can be found in the proceedings of the Third World Conference on Structural Control [6].

4. AMBIENT VIBRATION TESTS

Ambient Vibration Testing does not require a controlled excitation of the structure. The structure's response to ambient excitation is recorded in a large number of points. By the application of system identification (SI) technologies the frequency response functions are determined and analysed. For large and flexible structures, such as suspension bridges, cable-stayed bridges and high-rise buildings it becomes too difficult and costly to provide controlled excitation (forced testing) at levels that are significantly higher than the excitation provided by ambient sources. The method only requires the measurement of the response to ambient excitation that might be caused by wind, traffic, waves or micro-seismic activity. It is assumed that the excitation is relatively smoothly distributed in the frequency band of interest (white noise). Then the natural frequencies and mode shapes of the structures as well as the other remaining modal parameters can be identified.

The main advantage of this method is that normal operation, such as traffic, does not have to be influenced or interrupted during testing. Traffic is a welcome source of excitation that usually provides good wide-band excitation but also deserves attention on additional effects. The bases for the assessment of structures by the ambient vibration method are the so-called modal parameters, i.e. natural frequencies, mode shapes, damping values and vibration intensities. In addition a new

development, the trend cards, are a very good indicator for assessment because interesting information about damage locations can be obtained and eventually on the severity of this damage.



Fig. 2 Rohrbachbrücke in Austria built 1903

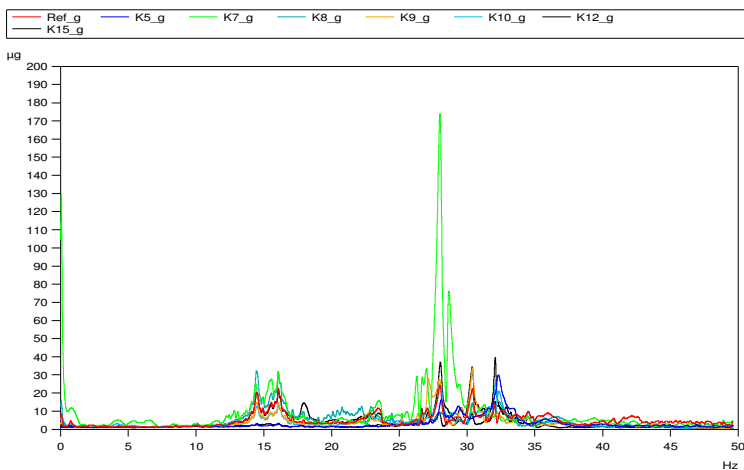


Fig. 3 Frequency spectrum vertical direction of the acceleration signal measured on the deck

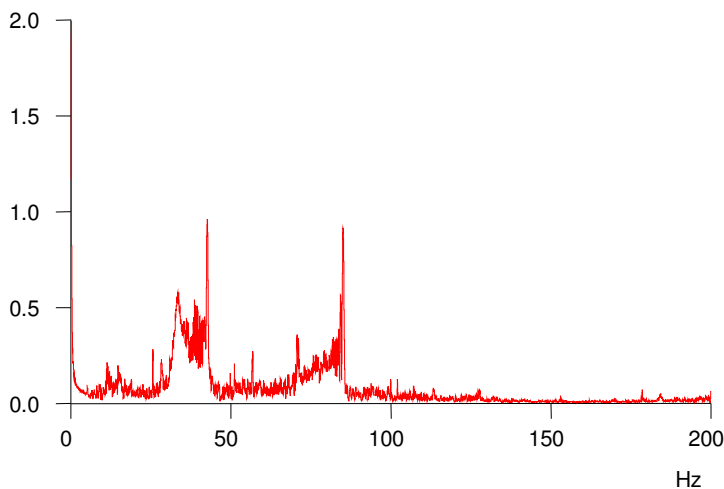


Fig. 4 Frequency spectrum obtained from the sound measurement

These ambient tests have been performed on the bridge in order to identify the basic modal parameters of the whole structure as well as the frequencies of some single elements. Therefore an extensive measurement campaign was performed and the structural elements such as rails, sleepers, transversal and longitudinal girders have been instrumented. In addition some sensors have been applied to the web of the main girder to quantify the vibration intensity.

The data from the sound measurements have also been treated by a Fast Fourier Transformation (FFT) in order to obtain a signal in the frequency domain. The emitted noise (air transmitted noise) from the train has been eliminated before detailed assessment took place in order to show the structural response only. This step is important to carry out the comparison between disturbing noise emission of the train and natural frequencies of the structural elements.

Matching frequencies point to the element which is main responsible for the noise origination. From the data shown in figure 4 the bandwidth of interest is between 40 Hz and 100 Hz.

Main outcome of this tests was, that the web-plate of the main girder have shown a matching of frequencies in the range of 75 Hz (second dominant frequency in figure 4) that is already the audible frequency range. Thus, the web-plate is working as a huge loudspeaker-membrane. Changes of the dynamic parameters of this element will also lead to a change in the audible noise emission.

Currently some state of the art techniques are existing, which will be accessed for the laboratory tests in Ispra in order to quantify their efficiency.

5. Laboratory Tests

After the bridge was dismantled in Austria and moved to the Joint Research Centre JRC by truck, a detailed investigation programme took place. The first step was system identification according to the field tests to carry out a comparison between the dynamic behaviour in the laboratory and in the field. This test is necessary to calibrate the results obtained by the extensive tests. A permanent monitoring equipment was installed to the bridge to enable an accurate determination of the noise attenuating effects obtained by the different damping devices. Several very accurate accelerometers are applied to the structure.

The testing procedure follows up to basic lines, which are (i) integration of additional elements especially to vibrating parts (web-plate of main beam) and (ii) changes of the structure itself.



Fig. 5 Rohrbachbridge in the Laboratory

Until now extensive tests have been performed using a Laser Doppler Vibrometer (LDV) from the University of Ancona in order to determine accurate values for the frequencies as well as for identification of mode shapes of the web plate. This investigation serves as base for application of counter measures to reduce the vibration intensity and the audible noise emission. Figure 6 shows the preliminary results obtained by these measurements, based upon an input-output identification. The first “bending” mode of the web-plate was identified at 73 Hz, which corresponds to the measured values during the field tests very well.

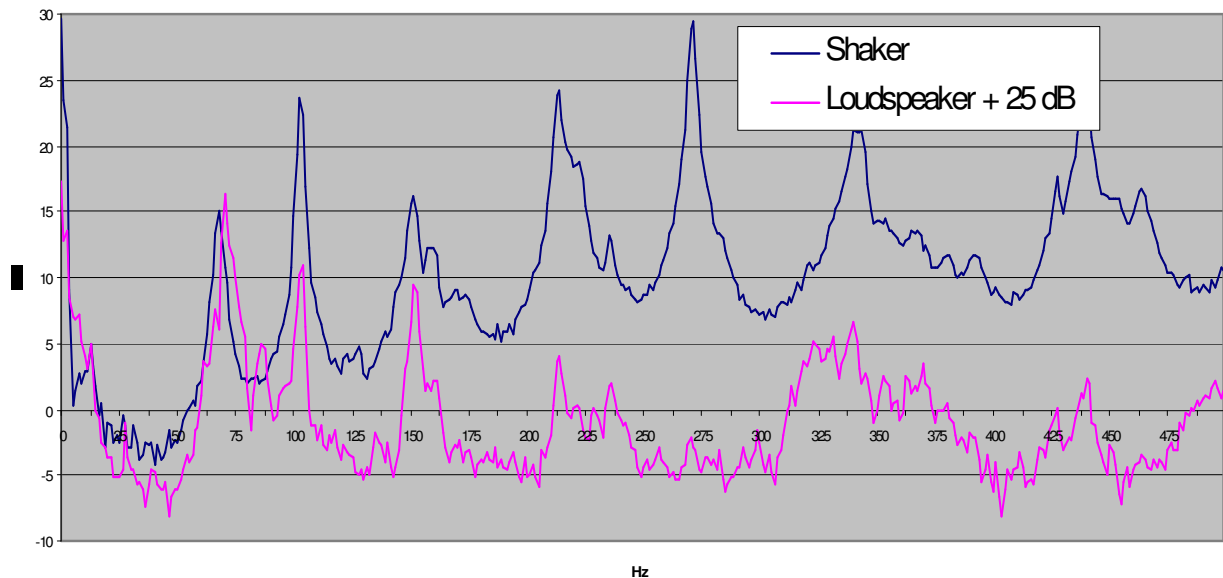


Fig. 6 – Preliminary results obtained by the Laser measurement

The basic idea to meet the targets defined is to introduce additional elements to the vibrating web-plate to reduce the vibration intensity of the element at the same time changing the structural response drastically. For example forced vibration nodes or counter waves introduced by a well

tuned Mass-Spring-System lead to good results. This can be achieved by replacing the wood sleepers by a thin concrete slab on semi-active or rubber bearings. One of the main restraints for this operation is the fact that the final level of rails must be the same after the substitutions and this implies that the bearings must be very flat to be arranged in such a small gap.

In addition very simple solutions such like stiffening of the web were tried in order to study the effect to the audible noise. Preliminary calculations performed on a finite element model have showed very good results for the proposed techniques.

6. Conclusions

The Main outcome until now was the identification of the main noise-radiating element, which is the web-plate of the main girder. This has been assumed earlier, a sound proof of this effect was not done until now. The frequency connected to this effect has been obtained both with ambient vibrations techniques on the field and laser Doppler vibrometer techniques in laboratory, the results matching very well.

The current work focuses on the change of vibration behaviour of the web-plate, which will be investigated for state of the art solutions (additional masses which are correctly applied) as well as semi-active devices developed during this project. Moreover an uncoupling of the rail (vibration source) from the structure by semi-active devices will achieve very good results, as the finite element calculations have already shown.

The research project is still under progress and currently in the very busy testing phase. Moreover due to the strict regulations of this project the main technical details are strictly confidential and cannot be presented in this paper extensively.

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