INTEGRATED NUMERICAL AND EXPERIMENTAL RESEARCH OF RAILWAY TRACK STRUCTURES

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SUMMARY

For the analysis of rail track structures a procedure is proposed where experimental data are processed directly by numerical models of real sized rail track structures. For the design of new rail track structures and the evaluation of existing track structures a simplified model of beam structures is proposed. The properties are linear and time dependent. To perform a dynamic analysis stiffness, mass and damping properties are required. These data are obtained from a small test specimen in a laboratory, using the instrumented hammer test. These results are compared with the results of numerical simulations of the experiments and applied for the numerical simulation of full-scale track structures. The results are very promising for more applications.

1. INTRODUCTION

With the development of high-speed train (HST) structures new research tools and design tools are developed and applied. New railway structure types are proposed and have to be evaluated. For the HST several alternative structures are investigated. Most promising is the so-called embedded rail structure -see fig. 1-. A sand bed or a pile foundation supports the concrete slab.

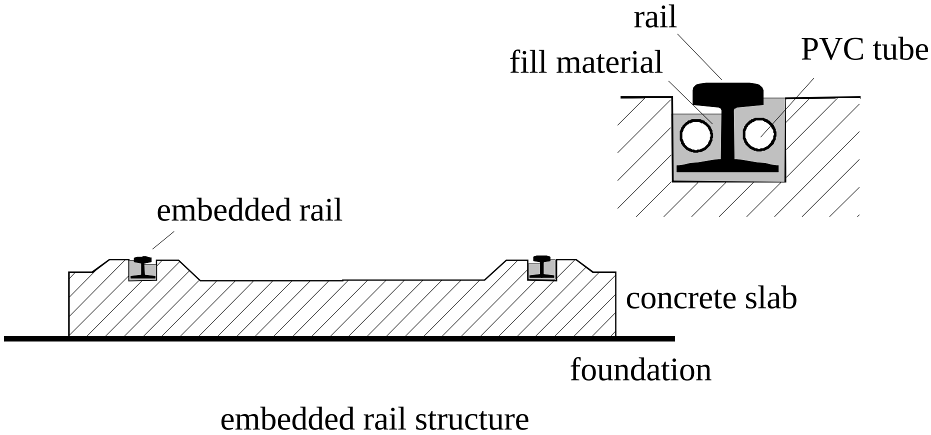


figure 1

This structure has to be compared with a classic track structure -see fig. 2-.
The most interesting aspects are

- Travellers comfort
- Noise hinder
- Maintenance track
- Strength of the structure

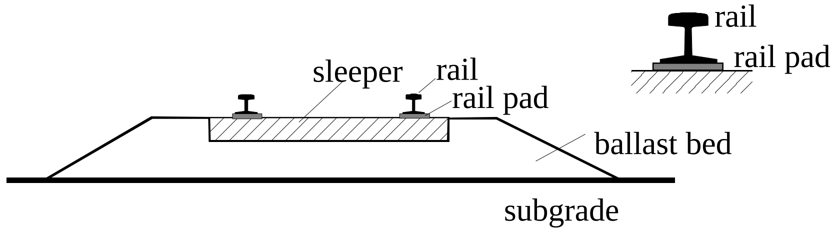


figure 2 classic rail track

The user’s comfort is measured by the accelerations of the coach; the interaction between rail and the vehicle is very important.

Strength is dependent on the contact stresses between rail and wheel; these forces may very strongly with respect to time and place.
Maintenance of the track is also dependent on the track forces. Settlement of the ballast bed and wear of the rail surface are regular maintenance problems
Noise hinder is very dependent on the damping properties of the high frequency modes of the structure.

To examine the structural properties by means of a structural analysis we need sufficient information about stiffness, damping and mass parameters. Because these parameters are applied in a macro way the values are also dependent on the structure shape and surroundings. Certainly the damping parameter, but also the stiffness and mass parameters, is difficult to estimate.
Our approach will be to get these parameters from a small-scale laboratory experiment and to apply these parameters in full-scale numerical simulations.

2. THE MECHANICAL MODEL

To perform a structural analysis for design and maintenance purposes it is most desirable to apply simple models. Nevertheless we may not oversimplify the models. For railway structures many problems can be modelled by linear elastic beam structures. Time dependency, however, has to be taken into account. Thus, in addition to the stiffness properties, we have to model also the damping and inertia properties.
For our applications it is sufficient to consider the vertical motions only; we do not consider horizontal forces and deformations in our models.

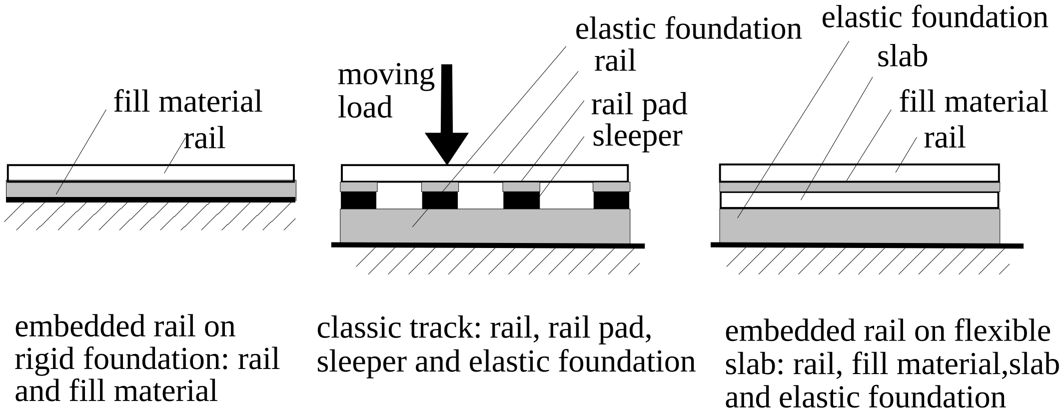
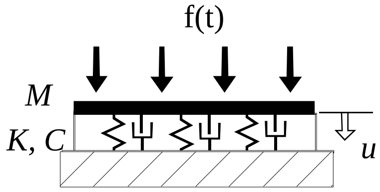


figure 3

To model the track we have to specify the properties of the composing structural components. The rail is modelled by a Timoshenko beam, taking into account bending and shear deformation properties. The material damping of steel is very little and ignored in these analyses. The mass of steel contributes to the translational and rotational inertia of the rail. In the same way we model the concrete slab of an embedded rail structure.
Underneath the concrete slab of an embedded rail structure or underneath the sleepers of a classic track we model the elastic foundation by means of an elastic bed following the Winkler model, sometimes enhanced by the Pasternak shear deformation stiffness. For a dynamic analysis we have to add damping and mass properties of the foundation.

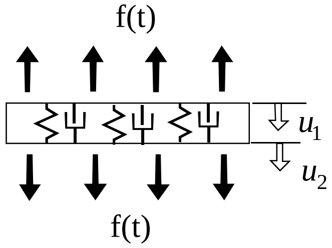


Stiffness, damping and mass properties of the elastic bed

$$f(t) = Ku + C\dot{u} + M\ddot{u}$$

figure 4

Between rail and concrete slab of an embedded rail structure we apply a fill material to smooth the load transfer between rail and slab. The same role plays the rail pad between rail and sleeper in a classic track. To model the layer of fill material we consider only the transfer of direct stresses (‘Winkler’ model); shear stresses are ignored. Damping and stiffness properties are very important for our analyses, but they are not very well known.



Stiffness and damping properties of the fill material

$$\Delta u = u_2 - u_1$$
$$f(t) = K\Delta u + C\Delta \dot{u}$$

figure 5

Mass contributions of the fill material are added to the rail mass.
We do not discuss the vehicle properties; usually these properties are well known (from the manufacturer).

3. THE LABORATORY EXPERIMENT

Most important, but also most unknown, are the stiffness and damping properties of the fill material (or rail pads). The other parameters are either well known or of minor importance. Our approach is to determine these parameters experimentally using the so-called ‘instrumented hammer test’.

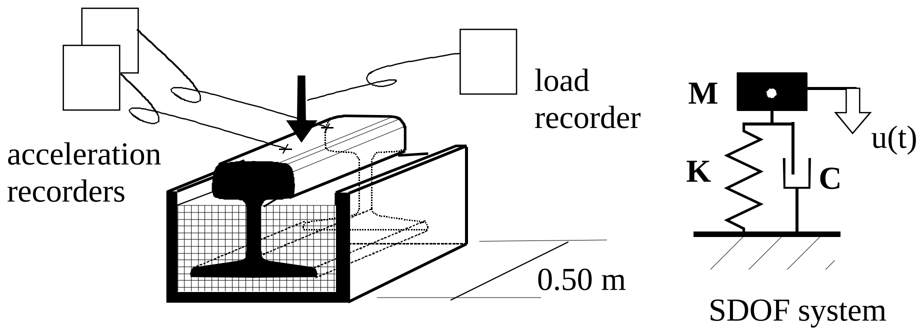


figure 6 instrumented hammer test

For this experiment we take a small (50 cm) specimen of the rail. This specimen is put into a stiff steel gutter, which will be filled up with the fill material. This structure is subjected to an impulse load applied by the instrumented hammer. At two places accelerator meters record the accelerations. The load, applied by the hammer, is recorded too. A Fast Fourier Transformation processes the recorded accelerations from the time into the frequency domain. Because of the small size of the specimen the structure can be modelled by a single degree of freedom (SDOF) system where K and C represent the stiffness and damping properties of the fill material. The mass M represents the mass of rail and fill material together. Assuming a SDOF system we can recalculate the K,C and M from the recorded data.

The correspondence between experiment and the SDOF system means that the SDOF system is a reliable model of the analysed structure.

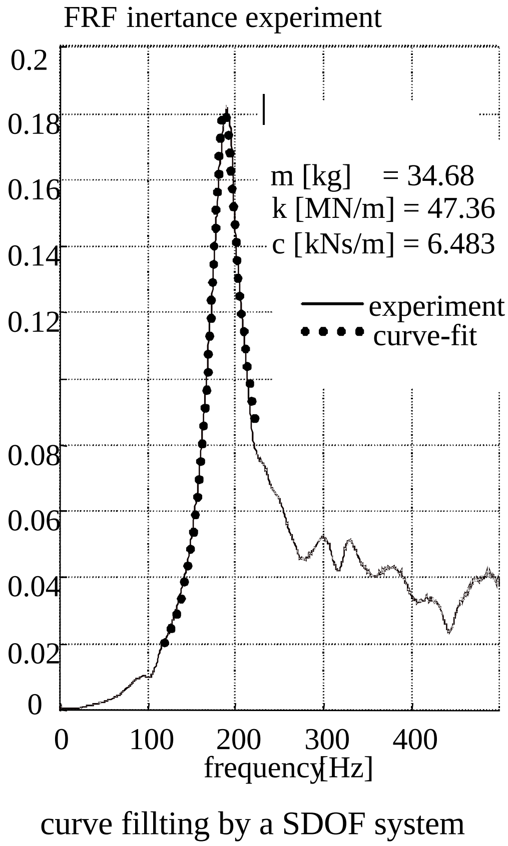


figure 7

4. EXPERIMENTAL VERIFICATION NUMERICAL MODEL

The experiment of figure 6 has been extended to a rail and gutter of 4 m length. This time the test has been carried out beyond the laboratory. The test specimen has been put onto a stiff dense sand foundation. The properties of the sand foundation are guessed, the properties of the fill material are taken from the laboratory experiment.
Again we applied the instrumented hammer test and we measured the accelerations. By means of a FFT the measured time dependent acceleration files are transformed into frequency dependent acceleration files.

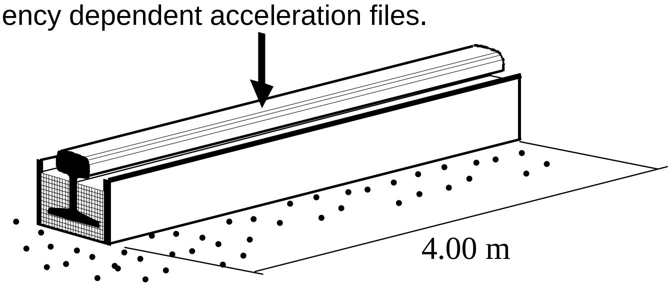


figure 8

Numerically we simulated the experiment by a finite element model, which has been based upon the properties of the mechanical model. For our analysis we applied 200 elements, for the numerical integration we applied 1000 time steps of 0.0001 second each. The time dependent acceleration file .$\ddot{u}(t)$ of the load application point has been transformed by a FFT to a frequency dependent acceleration file $\ddot{U}(w)$.

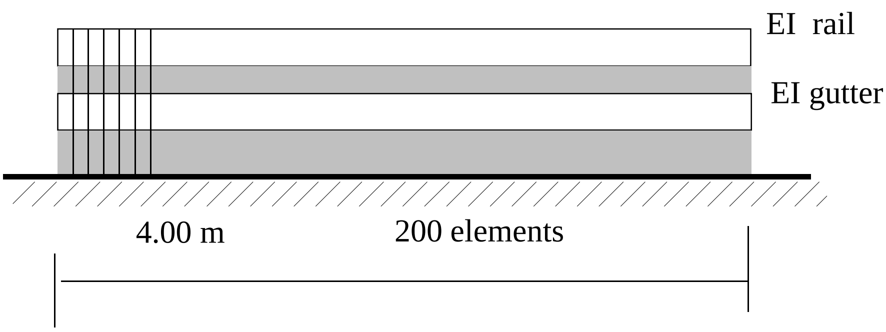


figure 9

In figure 10 both the experimental and the numerical accelerations $\ddot{U}(w)$ are shown. The striking correspondence between experimental and numerical results means that the mechanical model -and the numerical model- is very satisfactory for the analysis of (long) rail track structures.

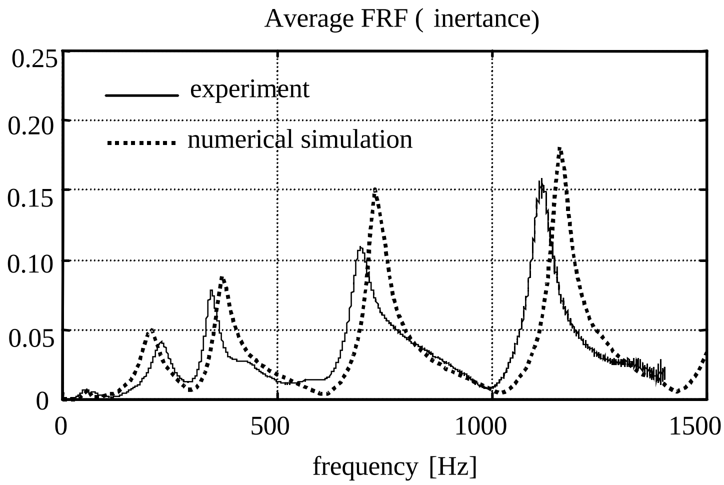


figure 10 FRF of a 4.00 m specimen

5. FULL SCALE NUMERICAL SIMULATION

An application of a full scale numerical simulation is the investigation of noise hinder. To investigate noise hinder we have to get insight in the structure damping properties of the applied load frequencies. For our analysis we modelled 80 m of an embedded rail structure into 800 elements of 0.1m each. The structure has been subjected to an impulse load, the numerical integration about time has been carried out with 1000 time steps of 0.0001 second each. At several points the displacements are output into time dependent displacement files *u(t)* which are transformed into frequency dependent displacement files $U(w)$ -see figure 11a-. The logarithmic representation $\hat{U}(w)$ of the file is given in decibels where

$$\hat{U}(w) = 10^{10} log(U(w))$$

These files $\hat{U}(w)$ are normalised with respect to the frequency dependent displacement file of the load application point. -see figure 11b-. The specific damping (per meter) is found by division of the normalised frequency file by the distance of the registration point to the load application point -see figure 11c-. The results of the graphs are averaged, the resulting graph is called the distance damping of the rail track.

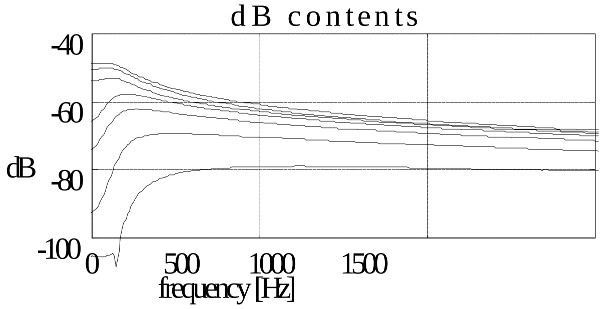


figure 11.a

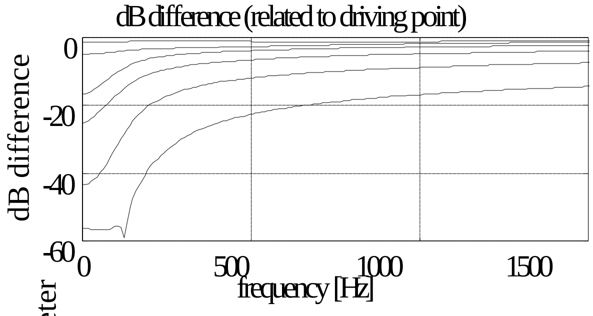


figure 11b

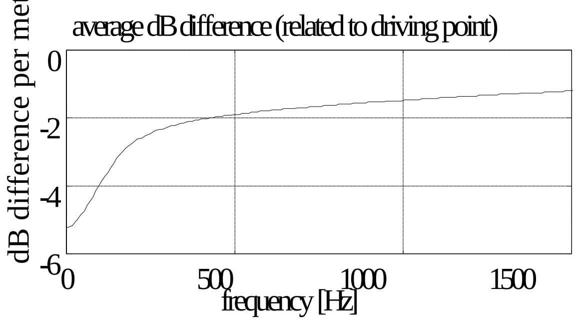


figure 11c

The distance damping shows us much damping of the low frequencies and a much smaller damping of the high frequencies. Because of the limitations of the model the shape of this result could be expected.

6. CONCLUSIONS

The integration of experimental research and numerical simulations has shown to be very successful for the design of new rail track structures and the evaluation of existing track structures. With limited means the experiments are easy to carry out in a laboratory, the numerical simulations are performed on a normal PC. The procedure optimises the most powerful aspects of both experimental and numerical research.

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