Hybrid method for measurement and predictions of vibrations in Railwaytunnels in the Netherlands

Peter Roelands and Wim Soede

Summary

Exact prediction of vibrations from new tunnels based on scientific knowledge and computer models is still a challenge due to the complexity of the subsurface and the different types of vibration possible in the subsurface. Therefore, the use of field-measurements is felt to be important as input for the prediction model and for verification of the prediction itself. Because those field-measurements cannot fill the whole picture from train to the floor of each house, it is important to use a modular prediction model and to plan measurements in such a way that they can be incorporated in a hybrid prediction model. This paper discusses how measurements are incorporated in two projects: the Betuweroute from Rotterdam to Germany and the North/Southline Amsterdam.

1. Introduction

Prognosis of vibrations in the Netherlands from tunnels and railwaytracks is a challenge due to the soft and rapidly changing layers and soils. Next to this, along any tunnel or railwaytrack a wide variety of houses can be found with different numbers of floors and different types of foundation. Until now, no official computational model or standard is available as a tool for prediction of vibrations.

Figure 1 gives the total transmission path from a tunnel to a house with the sub-divisions. The tunnel will vibrate due to the vibrations of the passing train. The ballasted track will transmit the vibration of the train. Next, the transmission path for each local situation is determined by (nearly) unknown parameters: transmission from tunnel to the soil; transmission through the soil and the transmission from the soil to the piles of the foundation. The vibrations of the foundation is transmitted to floors and walls of the house giving vibrations which can be felt and, in most cases, will be audible as low frequency noise.

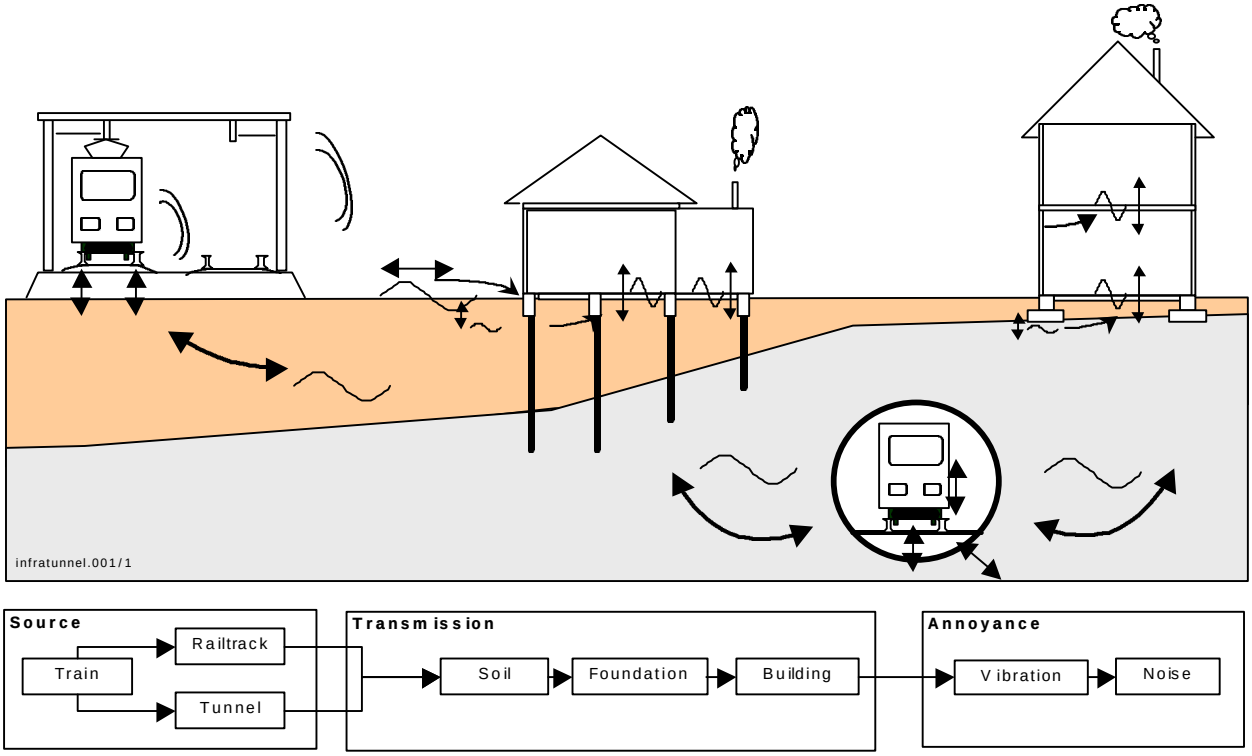

Figure 1 Transmission from Railtrack or tunnel to houses results in chance on annoyance by vibrations and noise (noise through air for standard track or low frequency noise induced by vibrations).

This means that the prediction model must account for all transmission paths and parameters, including measures to reduce the vibration. The measures can consist of adaptation of the dynamic behavior of the train (hard to influence), ballasted track (special connection of rail, embedded rail, special bed or isolated floor) or transmission (special materials on sides of tunnel or an extra deep concrete wall in soil to provide extra insulation). It will be clear that it is of help to break this model into modules, which describes sections of the whole transmissionpath. Each module can than be based on scientific knowledge and verified/exchanged with real-world vibration measurements. The combination of modules based on scientific knowledge and the real-world measurements result in a so-called hybrid model.

Within the projects Betuweroute and North/Southline it is decided to improve the models with the aid of measurements. These measurements are felt to be very important to improve the reliability of the predictions by the model. Those measurements must be carrried out in such a way that they can generate input for the prediction model or even can be used instead of one of the modules. The next two sections describe the efforts and plans to generate measurements for improvement of the hybrid model.

2. BETUWEROUTE

During the planning the “Betuweroute” project organisation was convinced that the vibration levels in all houses were in accordance with the relevant standards (DIN4150, among other things).
In conclusion of the deliberation with the people living in the neighborhood, they were promised that – after the Betuwe route had come into operation – active monitoring (thus at the initiative of the project organisation) shall be implemented in order to be able to assess the levels of vibration in all houses up to a distance of 50 meters from the track.
The choice of this distance is based upon the results of measurements in houses along the “Haven” railway track in Rotterdam. From this we were able to conclude that the levels of vibration will be lower – at a distance of over 50 meters – than the levels employed in the standards. These conclusions were verified by means of calculations based upon the most recent calculation models of that time.
Following complaints, “passive monitoring” will take place for houses at a distance of 50 to 100 meters.

Until now the approach of the monitoring preparation is aimed at:

1. Determining the monitoring extent (number of houses and number of measurements required).
2. Supporting and participating in developments in such a manner that the monitoring itself, the data storage, and the interpretation can be carried out as efficiently as possible. In this framework we strive for
    - Universal set up for a measurement campaign in order for measurement results
        - of various projects to be interchangeable
        - to be workable for the validation of the modular prognosis model
        - to be suitable for project monitoring.
    - A set-up for the storage of vibration measurements and calculations results in a consistent manner.
    - Implementation of mitigating measures in the modular prognosis model for the purpose of creating a possibility to estimate the influence of certain measures.
3. Developing a hybrid method as an alternative for measurements in all houses.

In this case, monitoring will take place in the representative house, per group of houses. For the remaining houses the level will be demonstrated by means of a calculation. This is possible when the measurement in the representative house meets the protocol. These measurements have been set up in such a manner that the transference from the source to the recipient is portrayed in as much detail as possible. The emphasis is on the transmission medium. In that manner insight in ground transmission as well as transference between the source – ground, ground – foundation, foundation – floors, is obtained, Subsequently more insight is gained regarding the base criterion. Part of the knowledge regarding vibration transmission can already be obtained during vibration measurements that are carried out in case of complaints (during the realization). After all, the transmission parameters for the vibrations during manufacturing are comparable with the vibration transmission during use. The set up of these measurements must be so that the measurements to the houses concerned can be put on a par level with a measurement of the representative house of the group of houses concerned.

3. NORTH/SOUTHLINE

The North/southline will be constructed with the Tunnel Bore Method. The problem to be solved is that little is known about the transmission of vibrations passing a light, segmented and round tunnel in soft soils. The target approach is to get enough information on the possible vibration levels before the tunnel is constructed. Based on this prediction several possible measures can be taken into study.

The practical solutions to these questions appeared to be an experiment in the recently bored 2nd Heinenoordtunnel near Rotterdam and a plan to measure vibrations based on a method which was successfully used for prediction near houses of the High-Speed-Line South from Amsterdam to Paris (executed by TNO building and construction).

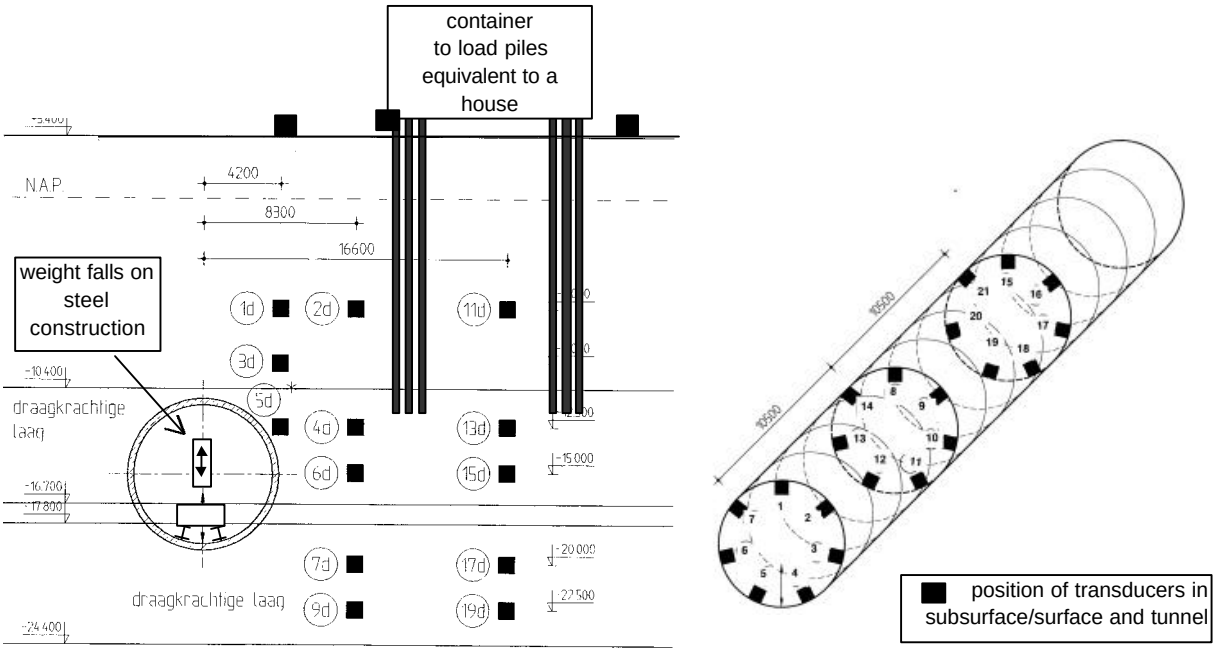

Figure 2 Vibration experiment Heinenoord tunnel with position of transducers in ground and on piles (left) and in the tunnel itself (right).

Vibration experiment 2nd Heinenoordtunnel

The 2nd Heinenoordtunnel is the first bored tunnel in soft soil in the Netherlands. The tunnel is built south of Rotterdam just below the river 'Oude Maas'. The tunnel itself has a diameter of 8 m and is segmented. Each segment has a width of 1.5 m and consists of 7 pieces that form the circle. Basically, the segments are placed freely next to each other with small ridges for exact placement during the building process. On behalf of the North/South Metro Line an experimental field of piles (loaded with seacontainers) was made for determination of groundmovements due to the boreprocess itself (Teunissen and Hutteman, 1998). The main goal of the vibration experiment is the determination of the transmission from the tunnel to the piles. The source used in the experiment was a concrete weight of approx. 800 kg. In order to prevent damage of the concrete lining of the tunnel a steel construction was designed to spread the impulse-force over 3 or 4 segments (size comparable with a pair of wheels of a train).
The experiment was designed to measure the dynamic behavior of the tunnel and the several transmission paths through the soil to the surface and the piles (wood, concrete). The vibration-transducers were placed on the inside surface of the tunnel, in boreholes, on the surface itself and on the experimental piles (see figure 2). The data were obtained as detailed as possible to provide 3-dimensional vibration information at all points. The data is now under study to extract information for the prediction model.

Local vibration measurement and check before finishing

To get a further insight in the transmission a measurement plan is in development to measure the transmission path from the subsurface to the houses with a special borehole measurement. A borehole is made and a pile is put in the hole. The pile is excited with a vibrator on top. The vibration-transducers are now placed on the surface and houses in the direct surrounding (foundation and floors). This experiment will give more information on the local situation.
The final check before finishing of the North/Southline will be the in-situ measurements of the transmission of vibrations direct after construction of the bare tunnel. This can easily be done with a shaker or weight in the newly built tunnel. Based on this final transmission measurement measures can be tuned to the local situation.

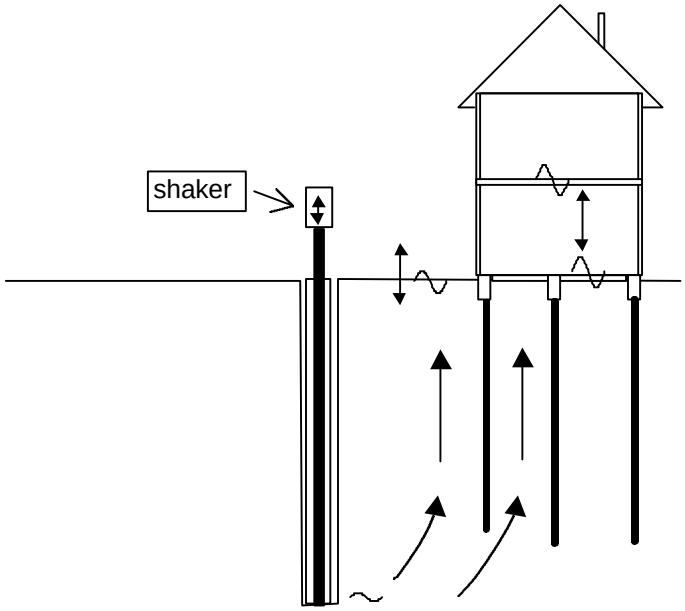

Figure 3 Set-up for local measurement of transmission with a shaker that drives a pile.

4. Conclusion

A hybrid model based on scientific knowledge and real measurements can be a successful tool for prediction of vibration levels, when measurements are defined in such a way that they can provide direct information to discrete modules within the full model. Those measurements can be done in an early stage on an experimental base (e.g. 2nd Heinenoordtunnel, North/Southline) or a practical base after construction (e.g. Betuweroute). Within the Betuweroute project special emphasis is given to use those predictions for a wide variety of situations.