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Background

Railway track stiffness is an important property closely related to track condition and maintenance. Track stiffness variations occur over time and space due to dynamic train loading and aging of track components. Track stiffness variations may further lead to geometry deteriorations and vibration problems. It is therefore essential to continuously monitor track stiffness variations, as well as related track component degradations, over time and space, so that preventive and targeted maintenance can be performed to reduce the life-cycle cost of rail infrastructures.

Various techniques exist for evaluating track stiffness from dynamic responses of the train–track system, including track-side and train-borne measurements. The track-side measurement uses sensors mounted on sleepers to measure the track stiffness at each sleeper support. Nonetheless, because of the cost of sensor deployment, the track-side measurement is more suited for discrete locations in the rail network of special interest, such as transition zones. To scan for track stiffness over a long distance, specialised measurement vehicles were developed. However, they can only measure at low speeds and require track occupation, thus not suitable for frequent measurements.

In comparison, train-borne measurements using in-service vehicles are more cost-effective and allow for more frequent surveys of the entire rail network. However, existing techniques are not able to measure the respective stiffness of different track layers, such as the ballast and railpad stiffness. In addition, existing train-borne techniques using in-service vehicles have seldom been validated by field measurement data.

Increased knowledge and implementable results

In project In2Track2, a method was developed that can simultaneously assess the stiffness of railpad and ballast from axle box accelerations (ABA) measured on in-service trains. The technique was validated in the lab. The objective of this study is to validate the method in an industrially relevant environment. To this end, the method is adapted and applied to real-world vehicle–track systems and validated through field measurements.

The test site was chosen at a railway bridge between Murjek and Boden on the Iron Ore line in Sweden, as shown in figure 26-1. Track stiffness variations from the transition zone to the bridge covering 10 sleepers (i.e., sp1 – sp10) were evaluated.

A vehicle-track interaction (VTI) model was developed and calibrated/validated by hammer tests and ABA measurements at the test site. Simulations were conducted with different combinations of railpad and ballast stiffness using the validated VTI model. As a result, quantitative relationships between track stiffness and measured ABA features were established, see figure 26-2 for an example.

Based on these relationships, the stiffness of each track layer is related to distinct ABA features, which enables multi-layer track stiffness evaluations. In particular, ABA exhibits higher sensitivity to the ballast stiffness in the low-frequency range (below 150 Hz), while the railpad stiffness has a greater impact on frequencies ranging from 150 to 1200 Hz.

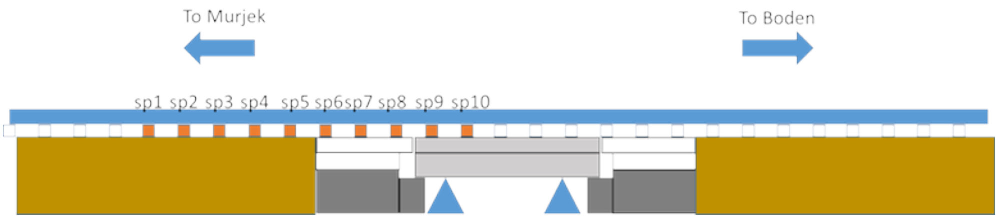

Figure 26-1 Schematic of the field measurement site

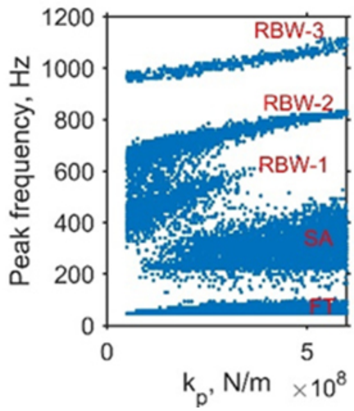

Figure 26-1 Relationships between railpad stiffness (kp) and peak frequencies of ABA.

Subsequently, data-driven models were trained based on the simulations to establish the inverse relationships, i.e., between ABA features and track stiffness. These data-driven models were used to evaluate the railpad and ballast stiffness across the 10 sleepers (figure 26-1) based on measured ABA features.

The results were compared with those evaluated by hammer tests. The stiffness variations evaluated by the ABA and hammer test exhibited a similar trend, indicating the change in supporting conditions in the transition zone. In addition, the stiffness values obtained from the ABA measurements are higher than those by the hammer tests due to the difference in loading conditions. It was also verified that the unloaded and loaded stiffness values identified in the study align with those reported in the literature.

Implementation and open questions

In future studies and practical applications, a more comprehensive understanding of the rate at which track stiffness changes can be gained by integrating frequent ABA measurements with in-track validations, utilising the techniques demonstrated in this study.

The technology can be used to monitor changes in track stiffness over time due to track maintenance activities (e.g., tamping) or seasonal effects (e.g., groundwater level and temperature). The technology could also be developed to detect spatial stiffness variations due to, e.g., different fastening systems and property changes in embankments or subsoil.

The technology can be further developed and demonstrated under different and more complex operational conditions, such as with the existence of rail discontinuities, at varying vehicle speeds and different levels of track irregularities.

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