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Defect detection in the Netherlands and Romania

Nunez, Alfredo; Hendriks, Jurjen; Moraal, Jan; Ramirez Fonseca, Ivan; Dollevoet, Rolf; Li, Zili

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Rail Condition Monitoring using Axle Box Acceleration Measurements: defect detection in the Netherlands and Romania

Alfredo Núñez, Jurjen Hendriks, Jan Moraal, Ivan Ramirez, Rolf Dollevoet and Zili Li
Section of Railway Engineering, Delft University of Technology
Stevinweg 1, 2628CN, Delft, The Netherlands
A.A.NunezVicencio@tudelft.nl; J.M.Hendriks@tudelft.nl; J.Moraal@tudelft.nl; I.RamirezFonseca@tudelft.nl; R.P.B.J.Dollevoet@tudelft.nl; Z.Li@tudelft.nl

ABSTRACT

In this paper we discuss rail condition monitoring based on axle box acceleration (ABA) measurements. We present three case studies. The first one in The Netherlands, the detection of local defects with different severity levels (squat A, squat B and squat C) is analysed. The second case from the Faurei testing ring in Romania, the detection of rail defects over the whole testing ring is presented and examples of responses at a local defect (wheel-burn) is discussed with measurements at 80km/h (conventional speed measurement) and 200km/h (high speed measurement). In the third case, ABA measurements were obtained during operation in a train with passengers in the railway line near Brasov, Bartolomeu-Zărneşti. Examples of the defects and validations are discussed.

KEYWORDS: Railway infrastructure, axle box acceleration, rail condition monitoring, rail maintenance.

1 INTRODUCTION

In many countries, the demand for railway services for passengers and freight is increasing. Additionally, many large-scale railway projects are being constructed, to increase capacity and to accommodate the increase in demand. As a consequence, the railway infrastructure is less available for field activities such as monitoring, and the maintenance operations are becoming more complex, distributed all over the large railway network. One way to perform rail monitoring more efficiently is to do it "during revenue operation", by making use of trains in operation. Thus, while transporting people and goods, to collect information about the condition of the infrastructure. One technology that is ready for use under this setup is axle box acceleration measurement.

Axle box acceleration (ABA) measurement has been used in countries like Japan (Sunaga et al., 1997), Poland (Massel, 1999), Italy (Bocciolone et al., 2007), Korea (Lee et al., 2012), Spain (Salvador et al., 2016), among others. In the Dutch railways, ABA measurements have been used for detection of early and late stage squats (Molodova et al., 2011; Li et al., 2011; Molodova et al., 2014; Li et al., 2015). The ABA system has also been used to understand the degradation of insulated rail joints (Oregui et al., 2015; Molodova et al., 2016) and rail crossings (Wei et al., 2017; Wei et al., 2018). Other extensions include the detection of short pitch corrugation (Li et al., 2015), analysis of welds (Núñez et al., 2018), transition zones, railway bridges, among others. ABA system has also been tested to evaluate bolt tightness in joints, located in the tram network of Sheffield (Oregui et al., 2017). The ABA data has been employed to develop key performance indicators (KPIs) to facilitate rail maintenance (Jamshidi et al., 2017). With predictive KPIs designed based on ABA, the evolution of defects can be used for the identification of degradation models and to obtain optimal railway maintenance decisions (Su et al., 2017).

In this paper, we discuss examples of the ABA monitoring results in three cases: The Netherlands, the Faurei testing ring in Romania, and in the line Bartolomeu-Zărneşti located in the Transylvanian area of Romania. In Section 2, the ABA system is described. Detection of local defects with different severity levels are discussed in Section 3. In Section 4, detection of rail defects over a whole testing ring is presented and examples of responses at conventional and high speed measurements at a local irregularity are presented. In Section 5, the measurement results obtained during operation in a train with passenger in the Transylvanian railway line near Brasov are presented. Finally, conclusions and further research are presented.

2 AXLE BOX ACCELERATION MEASUREMENTS

ABA data is collected from accelerometers mounted at the axle boxes. For positioning, a GPS receiver and either a tacho or speed-sensor are used. The monitoring of the entire Dutch railway provides a data volume of several terabytes (Núñez et al., 2014). Multiple accelerometers are usually considered to reduce noise to increase the detection hit rate of small defects. Once installed, the measurement has a low cost in the sense that it is not needed to book expensive specialized measurement trains for the daily monitoring of defects. Accelerometers are also becoming cheaper in the market. The information acquired from the measurement provide an accurate indication of the effective severity of the defect. In Figure 1, the trains used for measurements in The Netherlands, Faurei Test Ring and are presented.

(a)

(b) (c)

Figure 1: ABA sensors installed on trains in (a) The Netherlands, (b) the test ring Faurei in Romania, and (c) the line Bartolomeu-Zărneşti, Romania.

Once the ABA system is mounted on the train, the data is collected. For processing of the acceleration signals we use the scale-averaged wavelet power (SAWP) for the automatic detection of defects. This function captures the variation of the wavelet spectrum in a signal, and thus, the system triggers the detection when the power spectrum of the frequencies related to the squats is higher than a given threshold.

$$\overline{W}_n^2 = \frac{\delta_j \delta_t}{C_\delta} \sum_{j=j_1}^{j_2} \frac{\left|W_n(s_j)\right|^2}{s_j} \tag{1}$$

where n is the time index, δ_j is a scale step, δ_t is the time step, and C_δ is an empirically derived constant for each wavelet function over the scales s_{j1} to s_{j2}. For detailed explanations, see (Molodova et al., 2014) and (Li et al., 2015).

3 MEASUREMENTS IN THE NETHERLANDS

In this section, three examples of typical squat defects in The Netherlands are discussed. In Figure 2, Figure 3 and Figure 4 the ABA response at light squat, moderate squat and severe squat are presented. Vertical and longitudinal ABA are given, with the scalogram showing the wavelet power spectrum. For the light squats, the variations on the power spectrum are more visible with the longitudinal signals. In the case of moderate and severe squats, their responses are evident after processing in both time and frequency domain with both vertical and longitudinal ABA. In the Netherlands, the detection of moderate and severe defects is performed with a 100% of hit rate detection.

With the information of where the defects are located, grinding operation can be focus on areas with high density of seed squats or squats A, while replacement operations can be planned for detected squats B and squats C. Additionally, a ranking of the defects can be performed based on both energy concentration and maximum peak in the time domain signal.

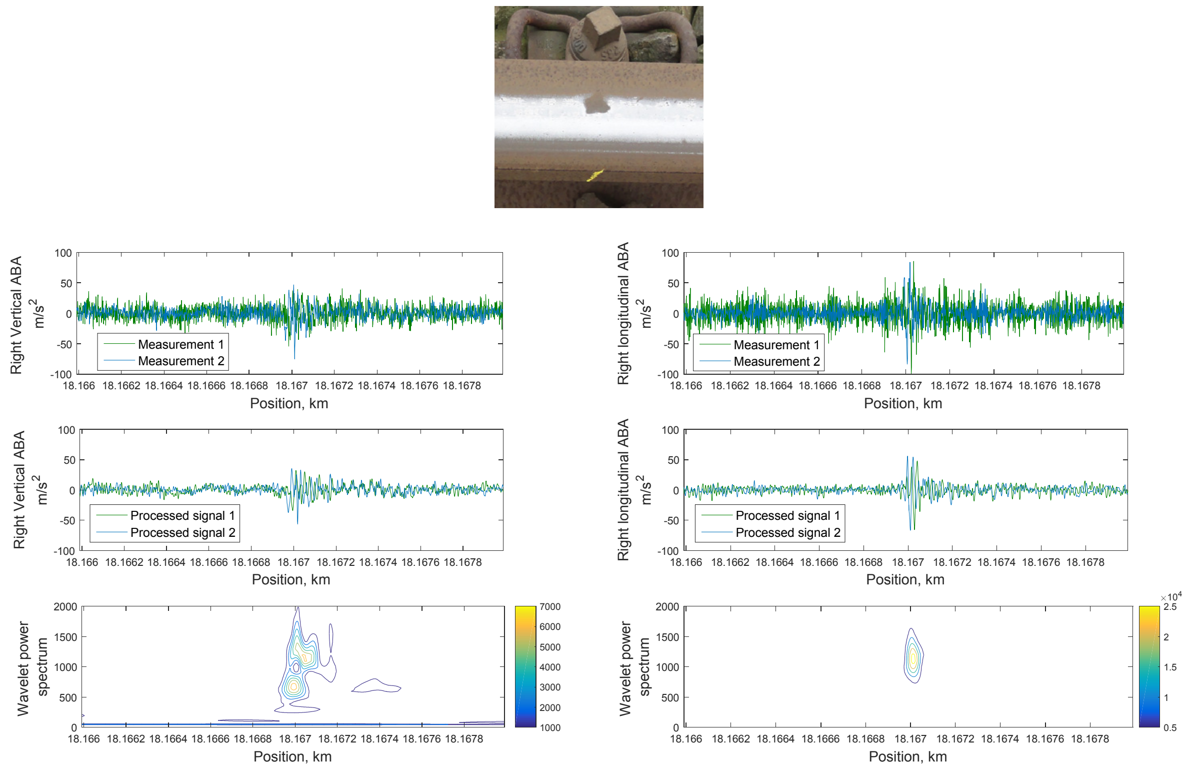

Figure 2: Light squat (squat A) in the Dutch railways. Vertical and longitudinal ABA are processed, and the time-frequency representation is used for assessment of the defect.

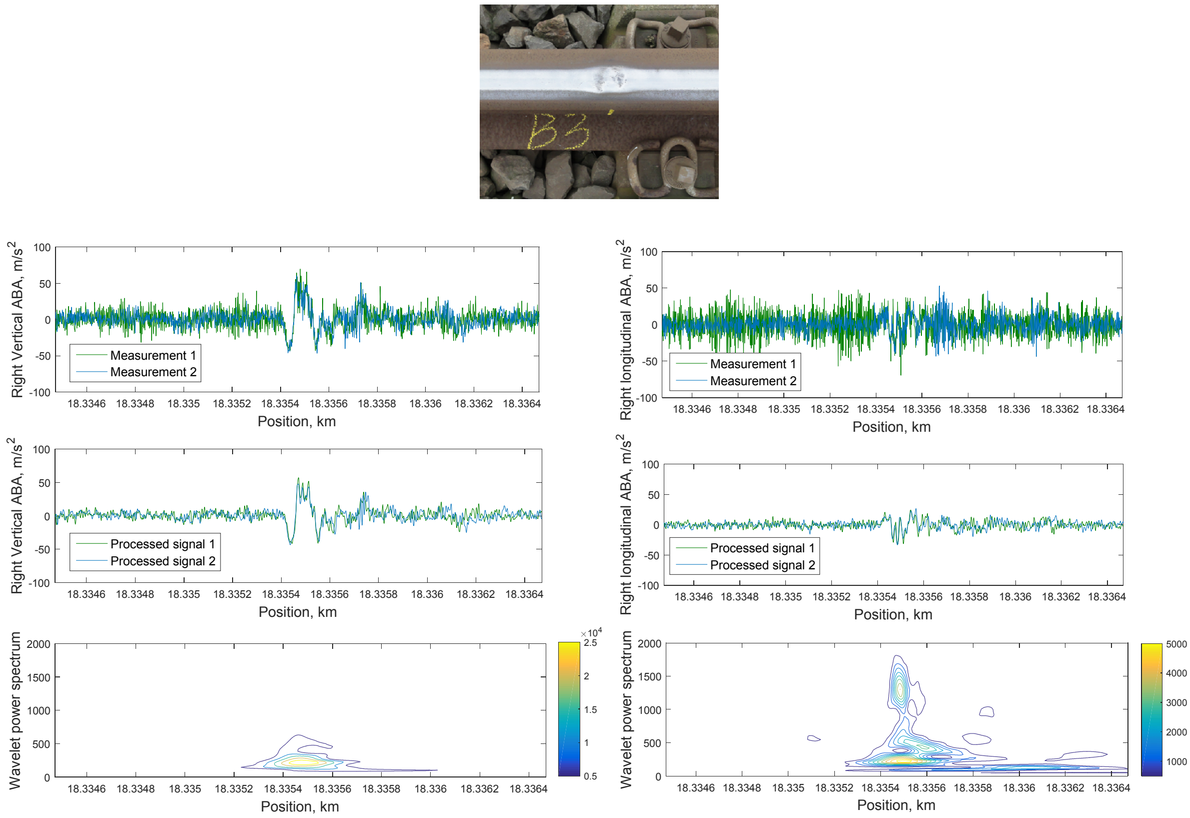

Figure 3: Moderate squat (squat B) in the Dutch railways. Vertical and longitudinal ABA are processed, and the time-frequency representation is used for assessment of the defect.

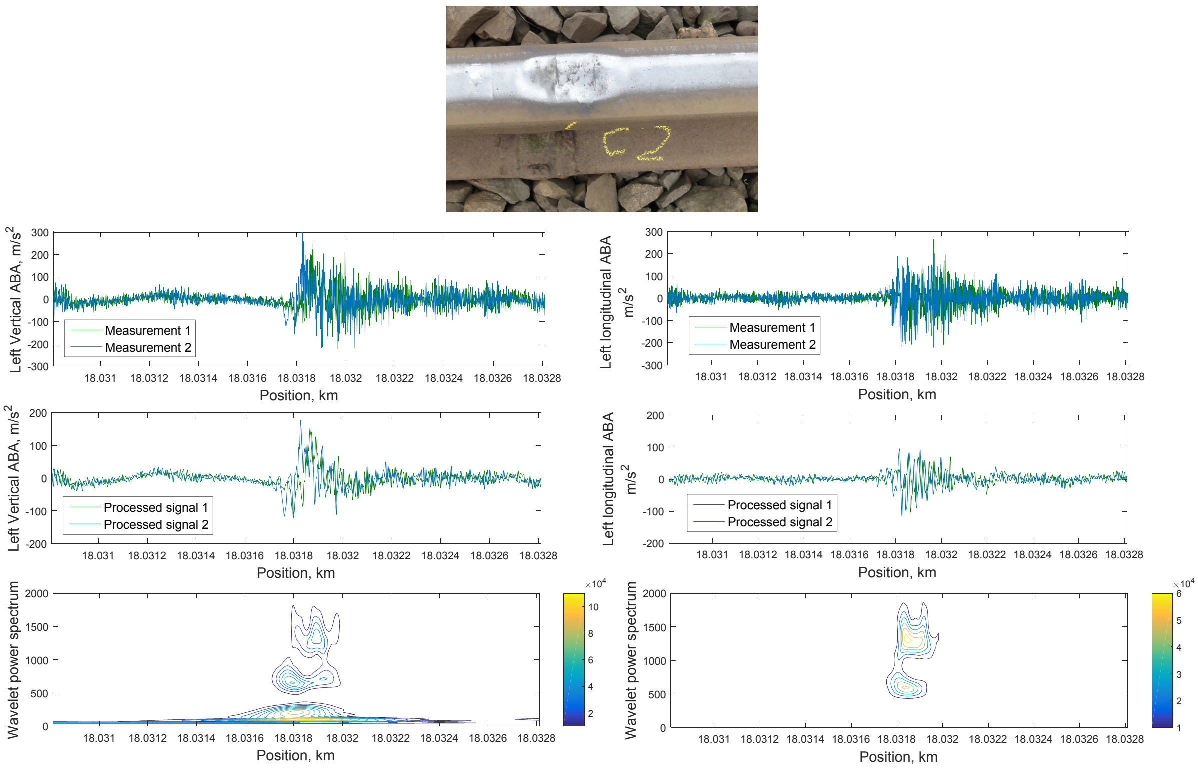

Figure 4: Severe squat (squat C) in the Dutch railways. Vertical and longitudinal ABA are processed, and the time-frequency representation is used for assessment of the defect.

4 MEASUREMENTS IN THE TEST RING FAREAU

Făurei railway testing centre belongs to the Romanian Railway Authority (AFER). Different dynamic measurements are performed in this ring. The trains in this test ring can run with speeds up to 220km/h. Thus, the track quality condition of the test ring should be kept with high standards, to ensure safety specially during the high-speed operations. ABA measurements were conducted in this ring with various speeds. Defects and condition of insulated joints and switches and crossings were measured. In Figure 5, a map of the test ring and a map with the location of defects (D), insulated joints (IJ), switches and crossings (S&C), welds (W) with low quality are presented. All those detected locations were inspected, and some few examples are shown in Figure 6.

ABA measurements were conducted at a whole range of speeds from 20 to 220 km/h. In Figure 7 and Figure 8 the ABA responses at a local defect are presented at 80km/h and 200km/h respectively. As can be observed, the ABA system is capable to detect defects in a high-speed operation. Actually, at a higher speed the energy and the time response of defects are much higher. Experimental results indicates that ABA measurements are actually useful at both lower and higher speed. Thus, it can be used for monitoring of metro systems, trams, conventional lines and also high speed lines.

(a) (b)

Figure 5: (a) Map of the test ring near the city Faurei, (b) detection results of the most interesting locations for inspection.

Figure 6: Examples of some of the defects detected.

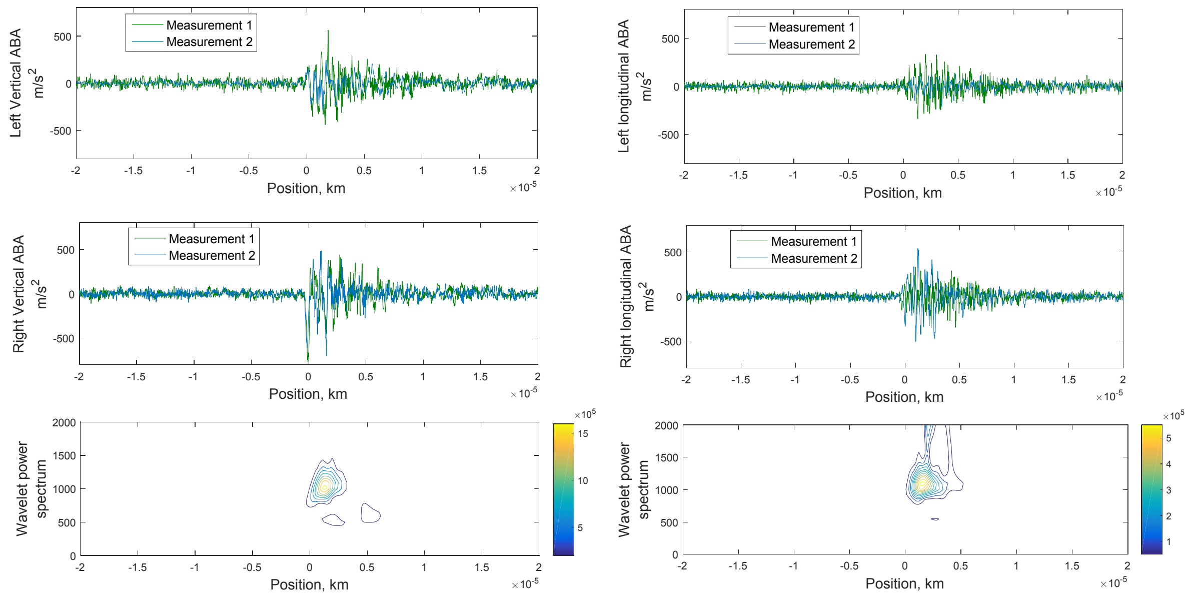

Figure 7: Vertical and longitudinal ABA and wavelet power spectrum at a defect, measured at 200 km/h.

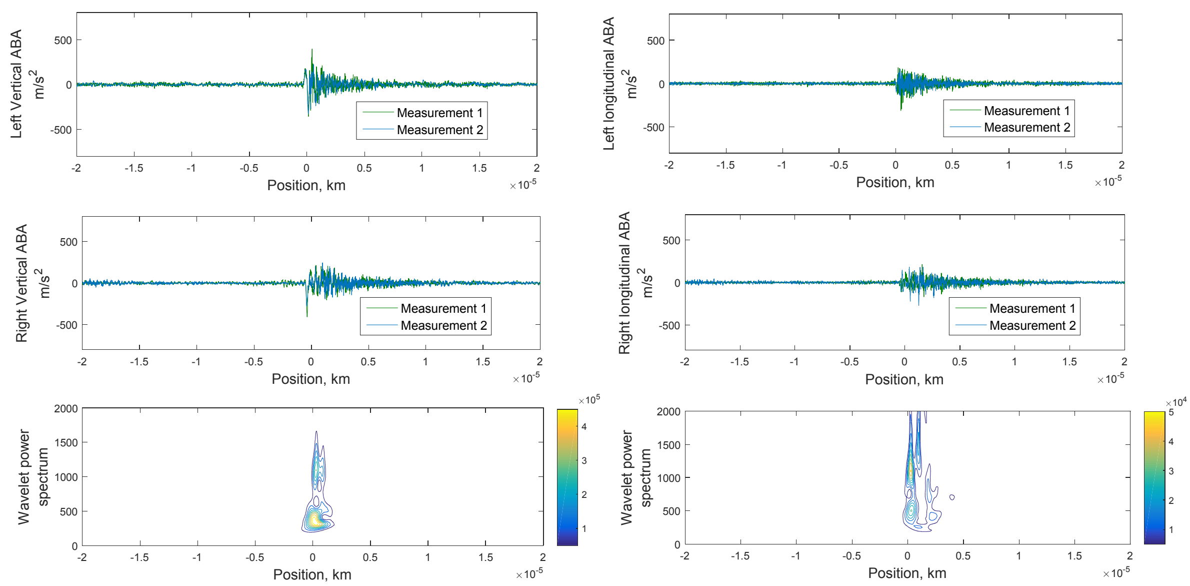

Figure 8: Vertical and longitudinal ABA and wavelet power spectrum at a defect, measured at 80 km/h.

5 MEASUREMENTS IN THE LINE BRAŞOV TO ZĂRNEŞTI IN ROMANIA

A measurement campaign was conducted in the track Bartolomeu-Zărneşti in Romania. The track is situated in the Transylvanian region and it connects Bartolomeu, a suburban area of the city Braşov, to the town Zărneşti. Over the track, there are small towns containing railway stations as well. After performing the measurement over the full track Bartolomeu-Zărneşti, the defect detection algorithm was run off-line. Based on ABA, the location of the places where the ABA signal show largest energy variations were highlighted as show in the Figure 9. These locations were ranked and send to the inframanager RCCF, as these are the places where the highest dynamic forces are occurring. RCCF conducted a field inspection and validation of the locations identified by the ABA detection. The results from the validation indicate locations where the rail joints were asymmetric, lack of support under sleeper, deformation of rail ends of joint, and exfoliated rail. Additional to the most interesting places for field inspection, detailed examples of ABA signals and wavelet scalogram at welds and corrugation were obtained (see Figure 10 and Figure 11). With the measurement a complete set of locations classified from high to low priority for field inspections were developed.

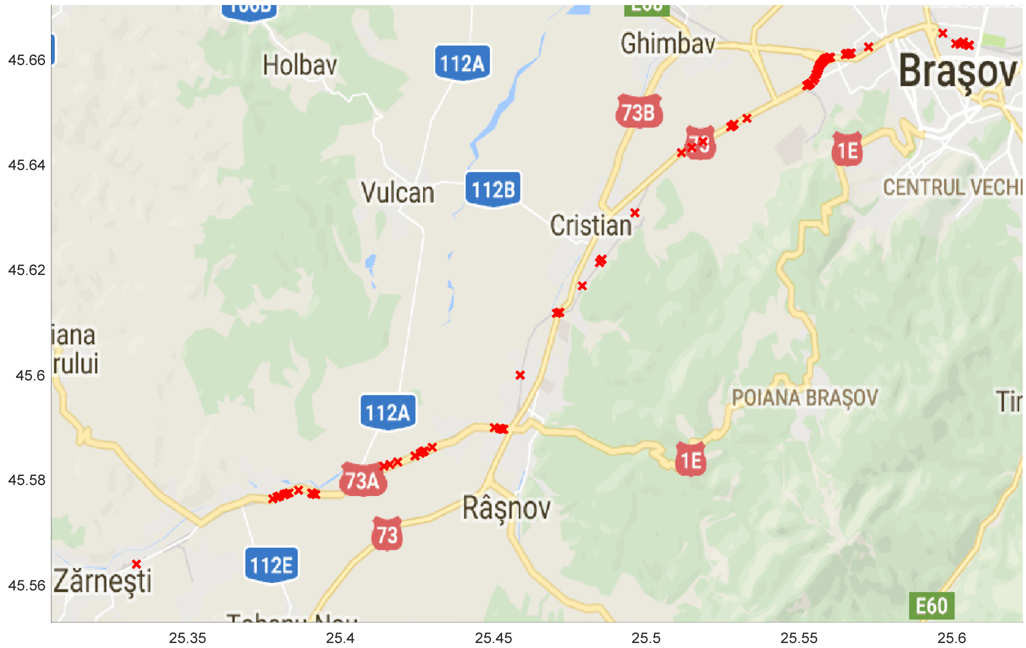

Figure 9: Locations of the top 75 places where the ABA signal show largest energy variations.

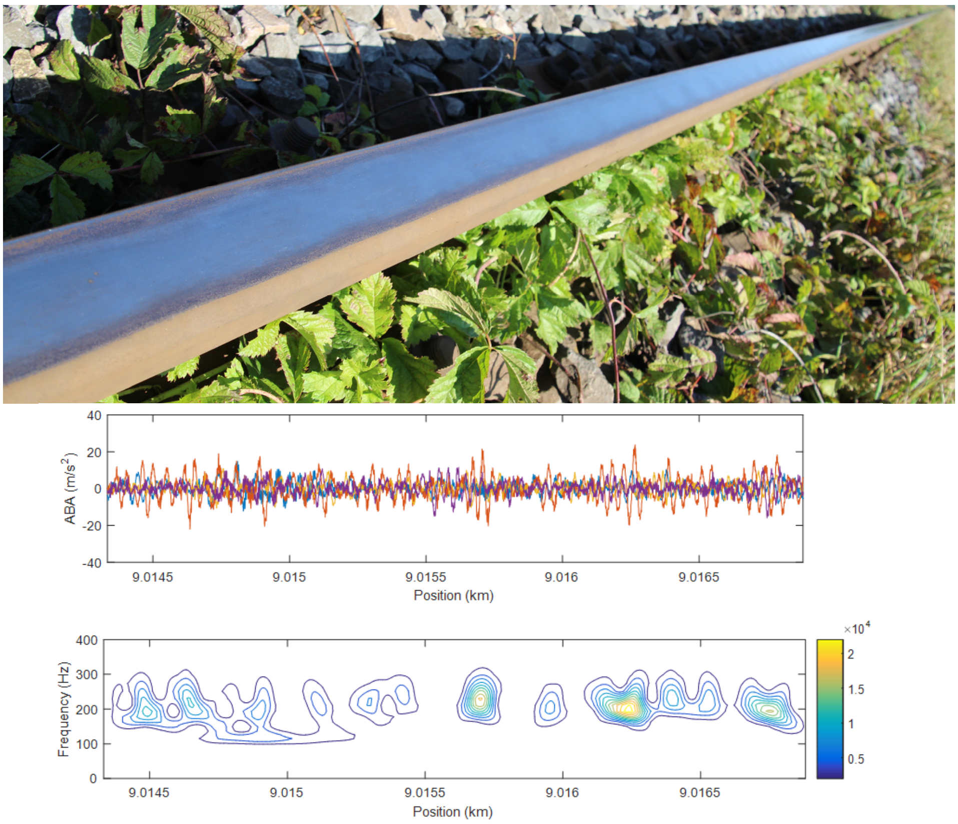

Figure 10: Corrugation, ABA signal and the corresponding wavelet scalogram.

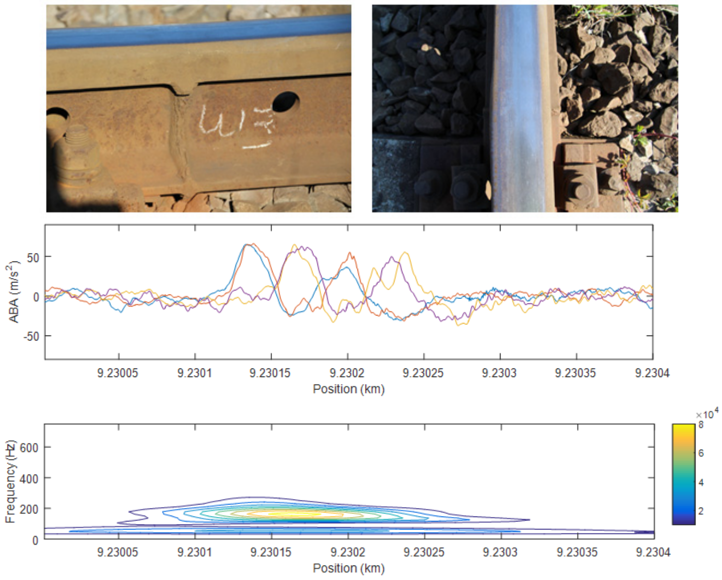

Figure 11: Weld, ABA signal and the corresponding wavelet scalogram.

6 CONCLUSIONS

In this paper, three examples from the rail condition monitoring based on ABA measurements are presented. In the Netherlands and Romania, the detection of local defects with different severity levels was possible. This supports to prove the generalization capabilities of the ABA system, with promising results for implementation in railway networks in other countries as well. The detailed information of the defects can be used to optimize grinding plans, so to aim at areas with seed squats and light squats, where grinding is still effective. In the case of moderate and severe squats, a ranking of these can be conducted based on the highest energy of the ABA signals, so that replacement operations are conducted first in the most severe locations. The second example presented was obtained in the Faurei testing ring in Romania. The ABA system can detect defects and responses at weld, S&C and insulated joints at both conventional and high speeds. ABA proved efficient at a wide speed range from low to high speed, making the system suitable for metro, conventional and high speed railway. Finally, in the third case, ABA measurements were obtained during operation in a train with passengers in the railway line near Brasov, Bartolomeu-Zărneşti. The information provided to the inframanager helped in defining the most relevant locations for field inspection. Further research is focus on the online detection of defects, self-learning algorithms to inspect infrastructures, and fusion of information with other sources such as image, ultrasonic and eddy current measurements.

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