A study on the use of Short-Time Fourier Transform (STFT) analysis for track geometry evaluations concerning cyclic irregularities

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Sweden

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Workgroup: A systematic approach to improve passenger ride comfort

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Vehicle vibrations at the Hallandsås tunnel: collaborative investigation and results

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The Hallandsås tunnel

Hallandsåsen is a long ridge located in southern Sweden on the main railway line between Gothenburg and Malmö, Figure 1. It has long been a bottleneck for train traffic, due to low capacity and high longitudinal gradient of the track. Construction of the Hallandsås tunnel began in 1992, but was troubled from the start by the very difficult geological conditions with brittle rock and large amounts of water seeping in from surrounding rock. The construction of the tunnel has been a very large challenge for the Swedish Transport Administration, Trafikverket, as well as for the contractors. The extent of the difficulties was not anticipated from the start, causing the major delay and increase in costs.

Figure 1. Hallandsåsen and the location of the Hallandsås tunnel in southern Sweden.

In December 2015 the 8.7 km long twin-tube single-track tunnel was finally opened for traffic.

events close to the tunnel were measured, Figure 2b.

Measurements of track irregularities and rail profiles were made, as well as wheel profiles, although not of the vehicle with the measured vibrations. The profile measurements were used for a calculation of in-service mean values of equivalent conicity over 100 meters, Figure 2a.

The incident reports, equivalent conicity calculation and measured vehicle vibrations are all consistent with bogie hunting being the cause of the experienced vibrations by the tunnel. The investigation show that the rail profile was about 0.4 mm higher than the target profile, and a few short sections of less than 50 meters had track gauge below 1435 mm. Together with worn wheel profiles this caused high conicity, and the problems with vehicle vibrations.

An improved wheel reprofiling programme, together with corrective rail grinding has eliminated the vibration problem by the tunnel, and the temporary speed restriction was lifted shortly afterwards.

Collaboration Trafikverket and SJ

The project group formed to handle the Hallandsås incidents demonstrated the effectiveness of the infrastructure manager and operator of rolling stock working together. A joint project between SJ and Trafikver-

Origin of the collaboration:

Vibrations at the Hallandsås tunnel, as reported at IAVSD 2017.

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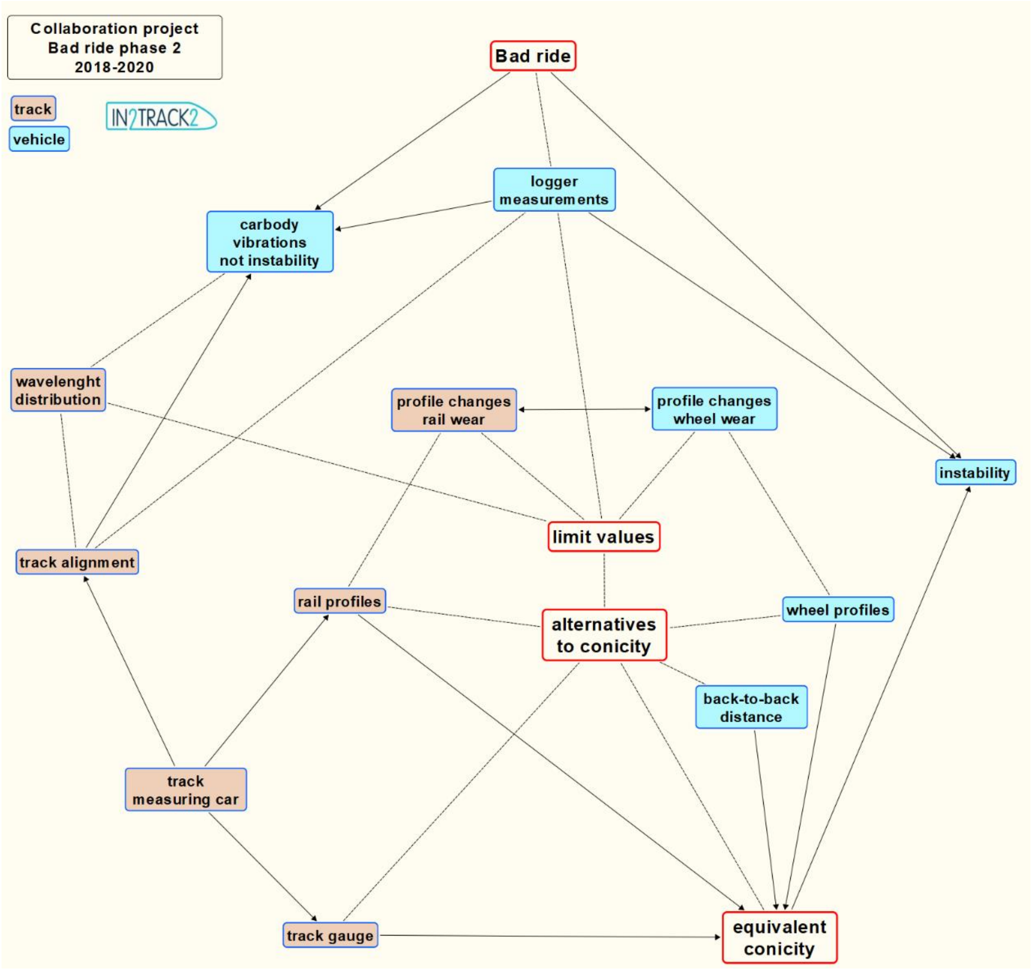
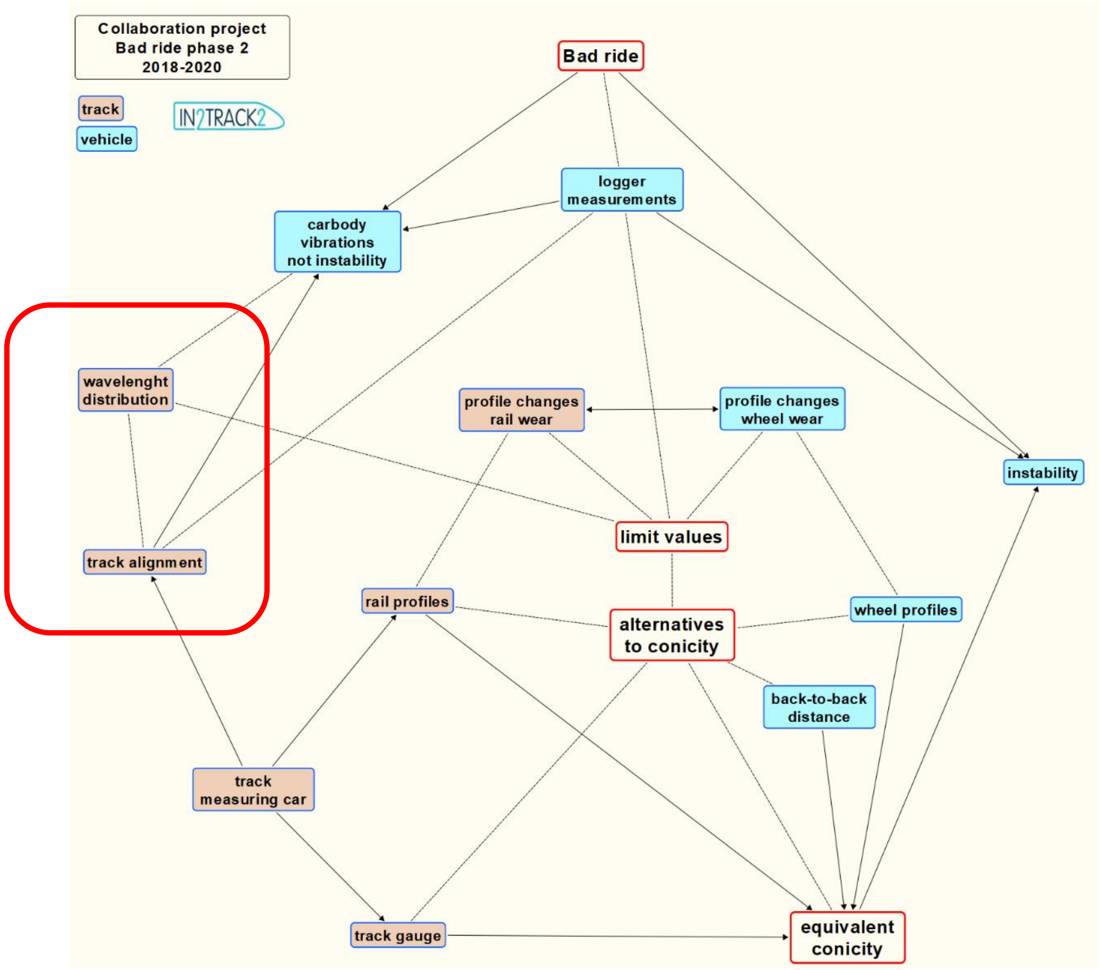


A number of topics has been covered by the workgroup.

Brown – track related

Blue – vehicle related



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Brown – track related

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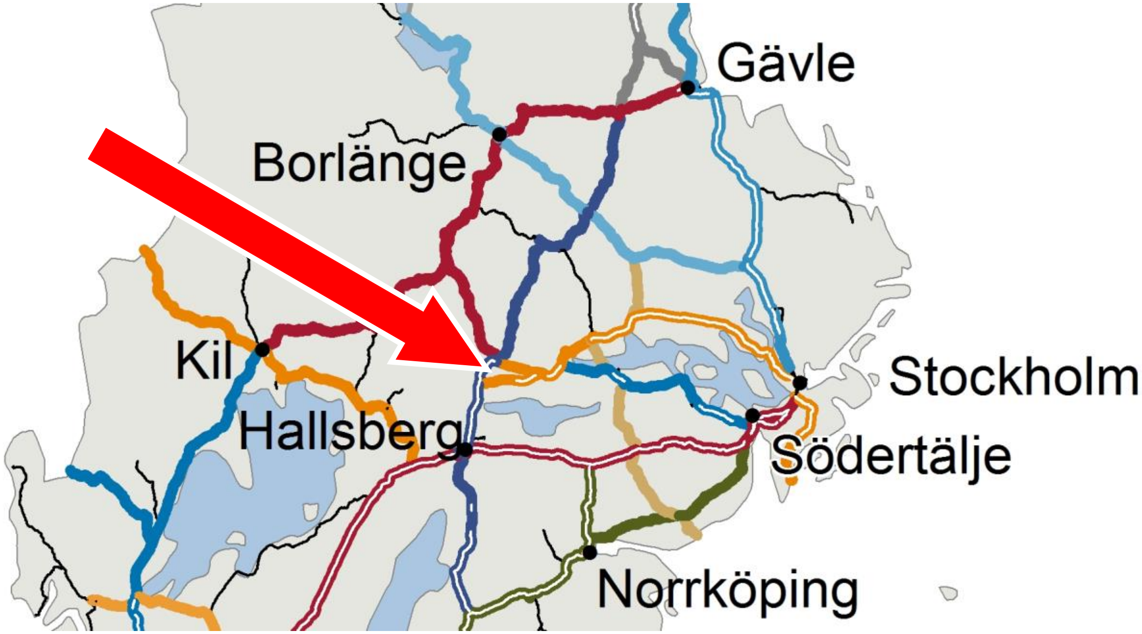
Today: track alignment and wavelength distribution.

The track: Bandel 354



- **Bdl (Bandel = part of line) 354:**
  - 35 km long, mostly passenger traffic, 200 km/h
  - Upgraded track: 60 E1 rail, concrete sleepers, Pandrol fastening systems
  - Track geometry qualities have been quite good before 2017

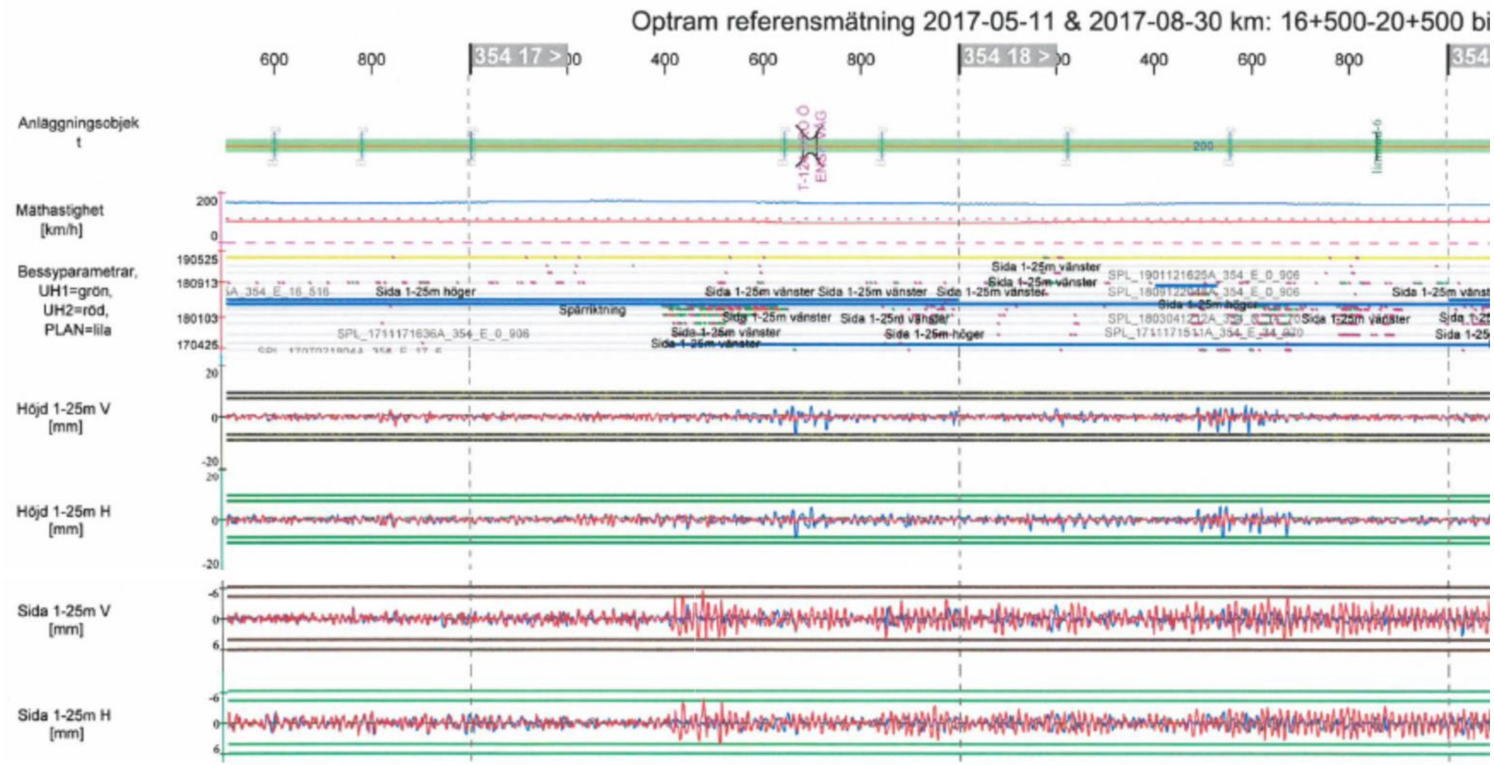
Reports of problems with vehicle vibrations and damaged track components

- **Bdl (Bandel = part of line) 354:**
  - During 2017 and 2018, problems with track geometry and damaged track components were reported repeatedly
  - Problems with vehicle vibrations and damaged suspension systems were also reported
  - Operational speed was reduced from 200 km/h, to 130 km/h and then to 70 km/h.

Two consequtive track measurements: 2017-05-11 and 2017-08-30

Longitudinal level
(LL; vertical; Z)

Alignment
(AL; lateral; Y)



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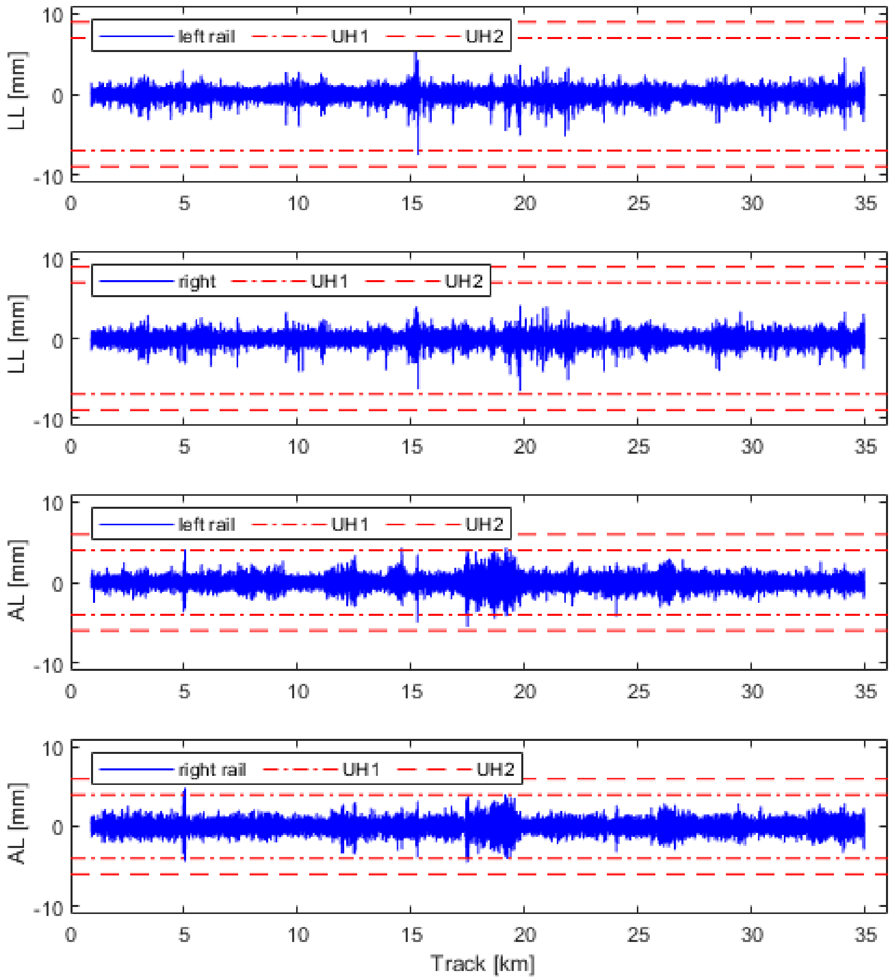
Bdl 354: track irregularities of LL D1 and AL D1 measured 2017-08-30



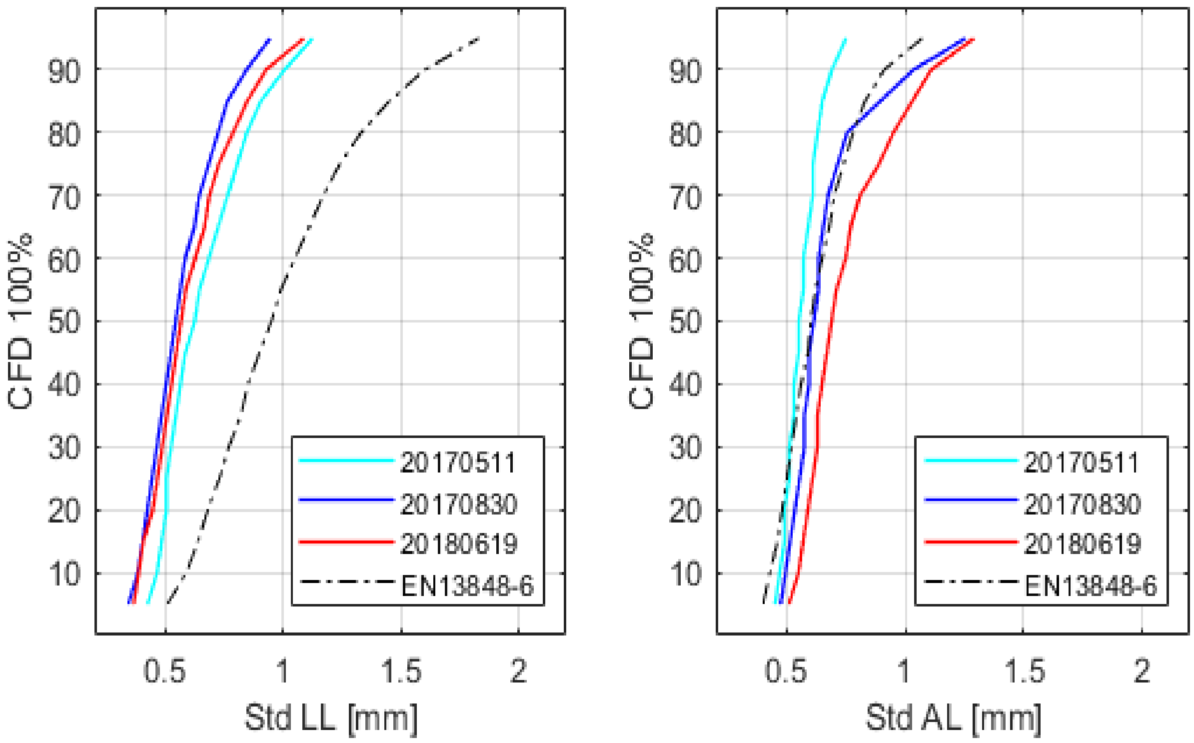
UH1/UH2: according to TRVINFRA00013

- UH1 = Intervention Limit “low”
- UH2 = Intervention Limit “high”

Most isolated defects are still below the intervention limits (IL) UH1 and UH2

AL D1	EN13848-5	TRVINFRA
UH1/IL low	7	4
UH2/IL high	9	6

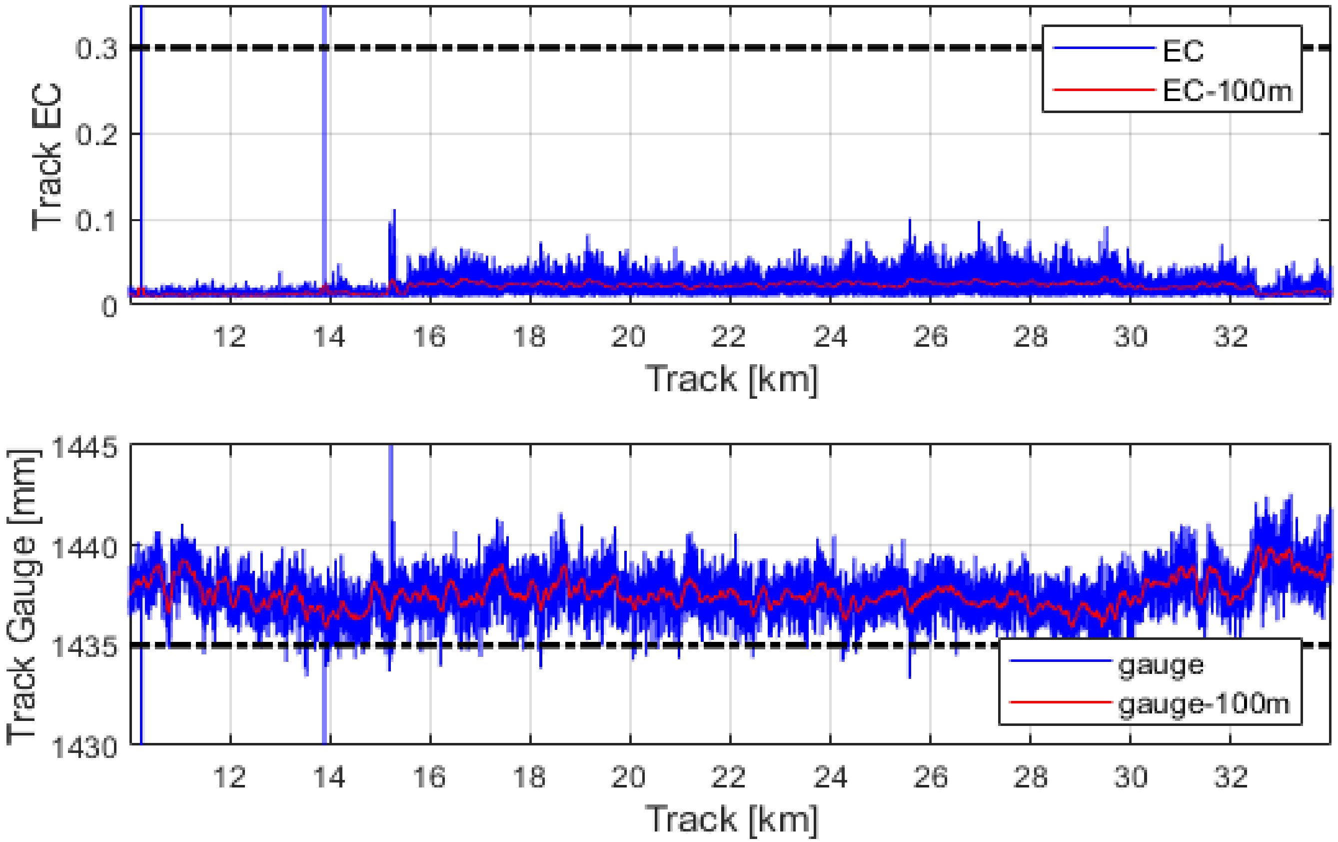
Bdl 354: Cumulative Frequency Distributions (CFD) of standard deviation



- 2017-05-11: the CFD curve for AL was still mostly lower than reference curve
- 2018-06-19: the CFD curve for AL was completely higher than reference curve

Checking if vibration problem is due to wheel/rail contact issues:

Track Equivalent conicity and track gauge 2017-08-30 -> OK!



STFT analysis

- The Short-Time Fourier Transform (STFT) is a Fourier-related transform used to determine the frequency content of local segments of a signal as it changes over time.
- The STFT analysis divides a longer time signal into shorter segments of equal length, and then computes the Fourier transform separately on each segment.

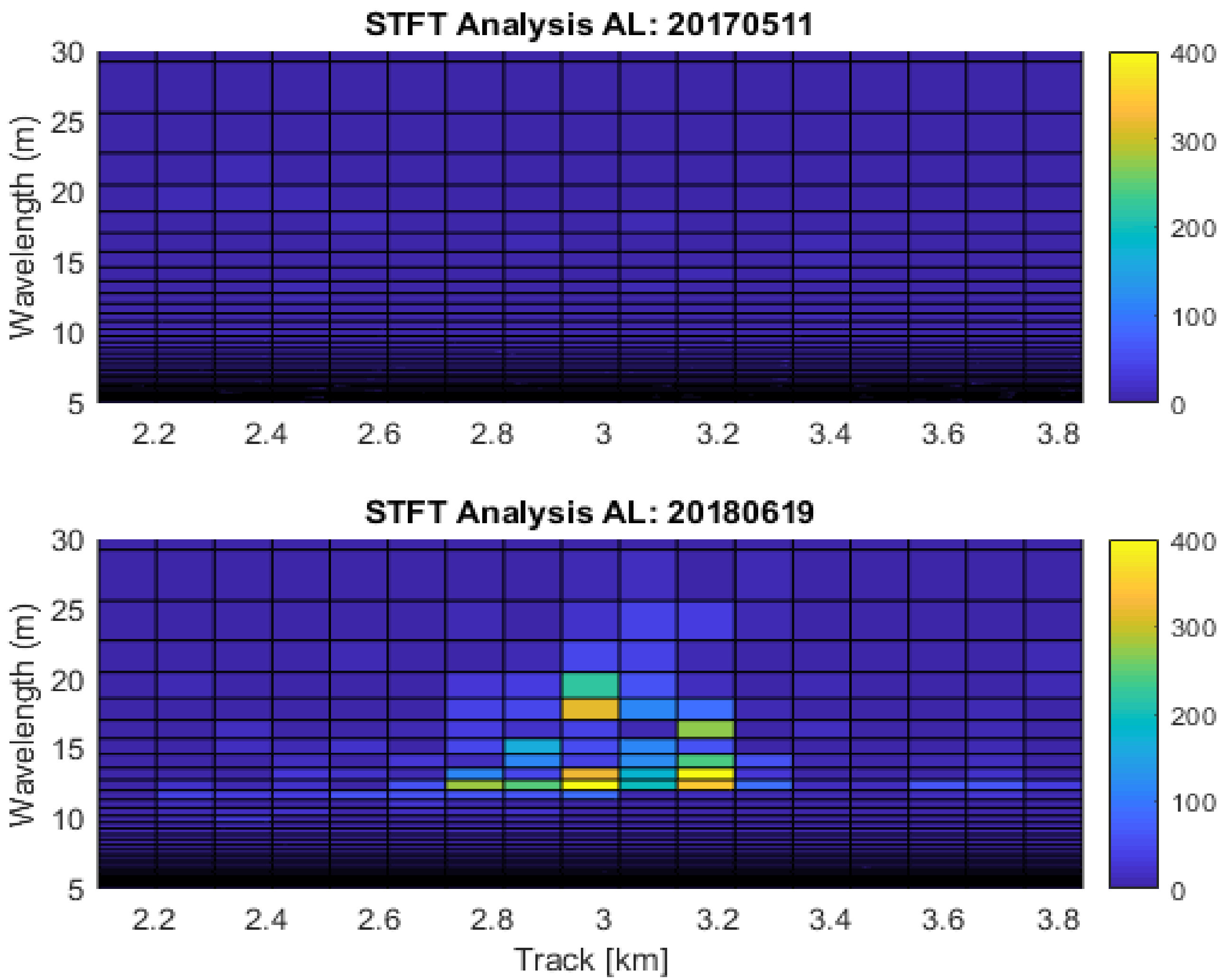
$$STFT\{x[n]\}(m,\omega) \equiv X(m,\omega) = \sum_{n=-\infty}^{\infty} x[n]\, w[n-m] e^{-j\omega n}$$

- The magnitude squared of the STFT yields the spectrogram representation of the Power Spectral Density of as

$$Spectrogram\{x[n]\}(m,\omega) \equiv |X(m,\omega)|^2$$

- The STFT analysis can be implemented very easily just by calling the Matlab function ***spectrogram***

STFT analysis km 2-4



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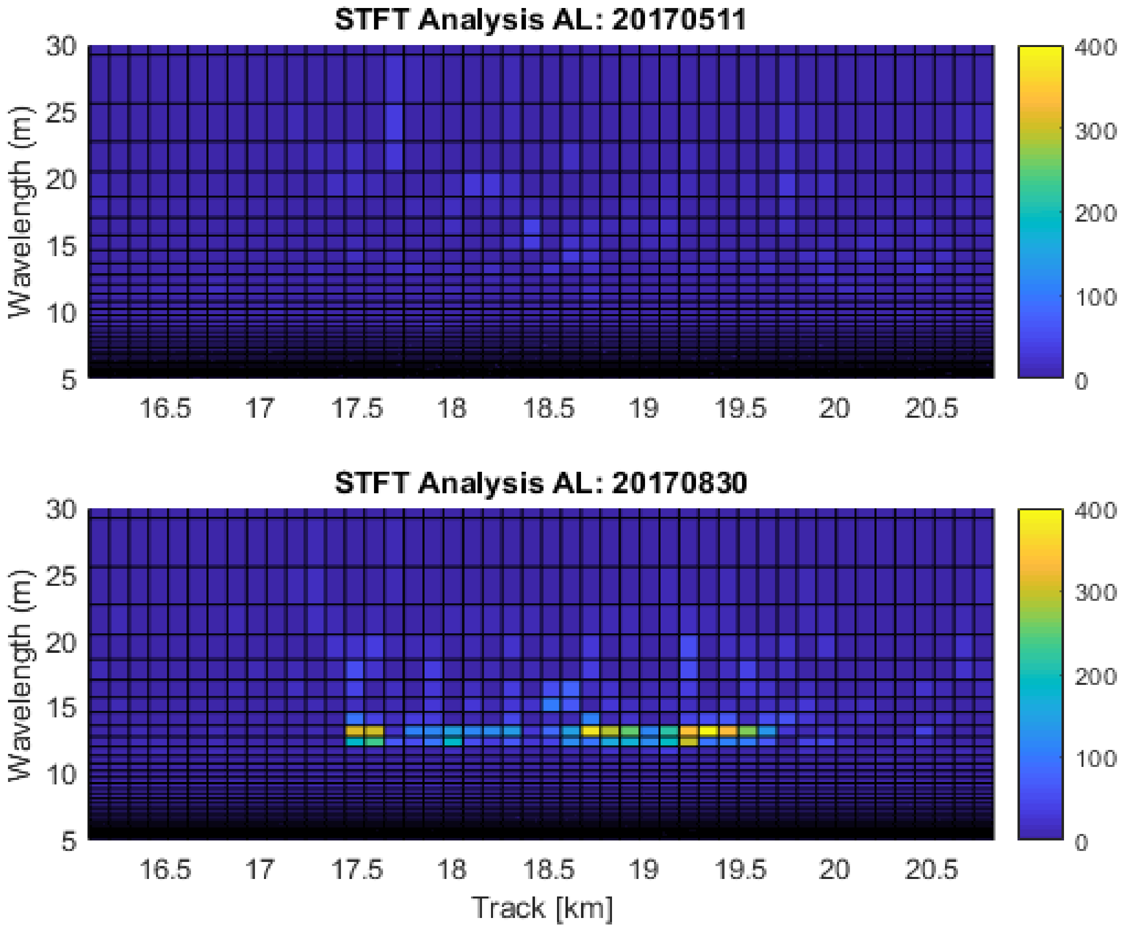
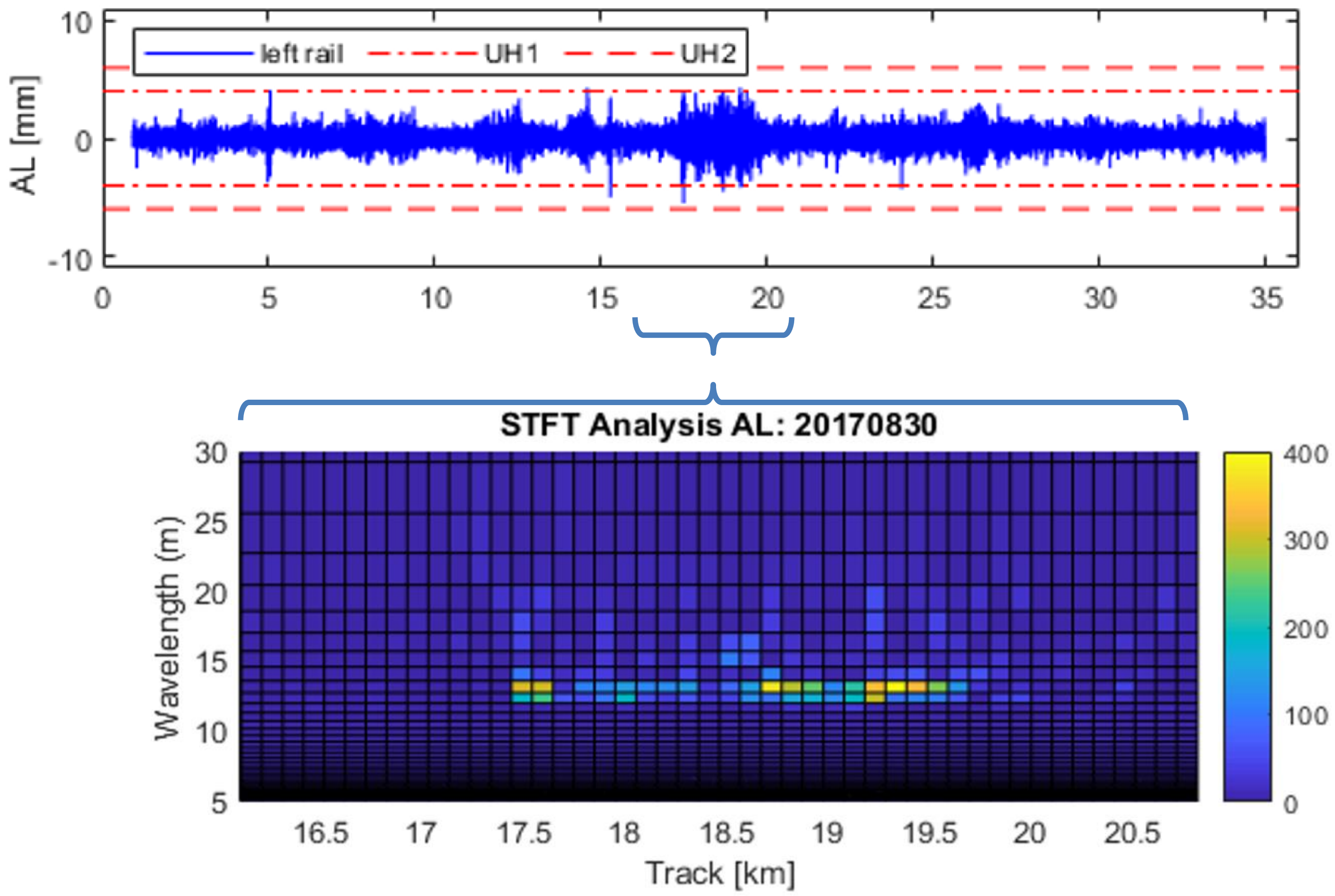
STFT analysis km 16-21



STFT analysis km 16-21



Cyclic irregularities:

how are they dealt with in Trafikverket's regulation?

- BVF587.02: " ......Vid viss kombination av våglängd och hastighet, som motsvarar fordonens egenfrekvens, kan **periodiska ojämnheter** orsaka kraftiga vaggrörelser och leda till lastförskjutning och urspåring….."

"With a certain combination of wavelength and speed, which corresponds to the natural frequency of the vehicles, periodic irregularities can cause strong vehicle vibrations and lead to load redistribution and even derailment. Errors of this type, which can be serious, do not have to be large and are therefore not so easy to be detected. They appear more clearly in the evaluation diagram of Track Recording Vehicle, showing with large values of standard deviations σ_s (alignment+twist). When such faults are detected, it is important that preventive maintenance is implemented before the isolated defects become too big. "

(*English Translation*)

- *Currently, in TRVINFRA00013 there are only UH1-limits for standard deviations, but not UH2. Standard Deviations are considered only comfort related and UH1-limits are often being ignored.*

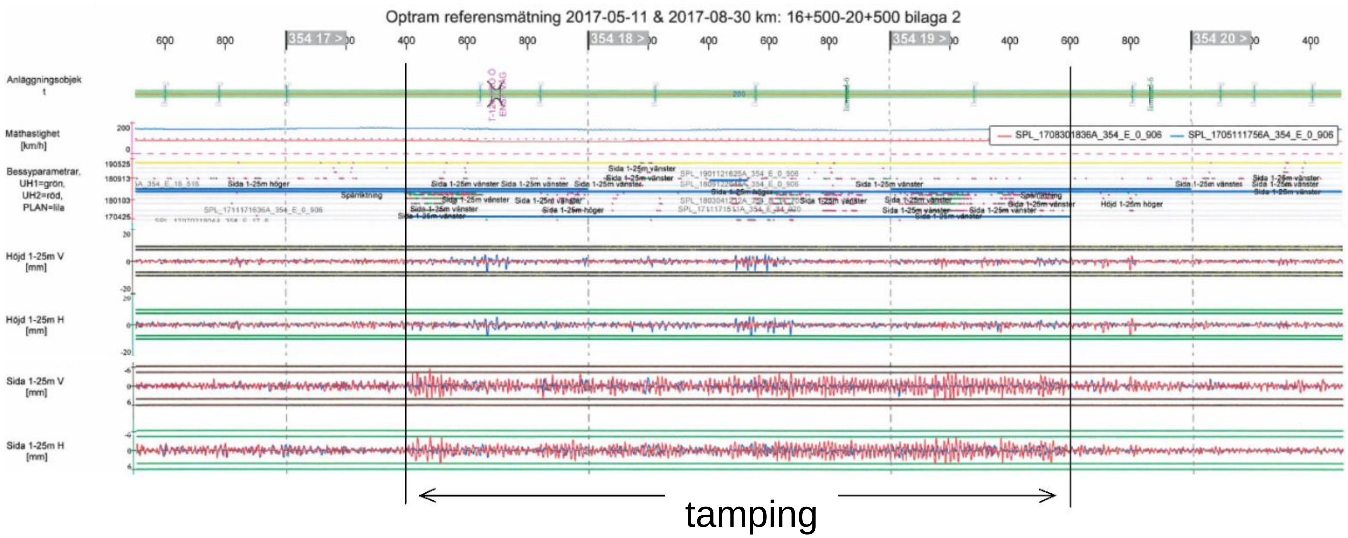
Summary

- The standard track geometry evaluation by comparing the peak values of isolated defects with predefined intervention limits is not sufficient for ensuring well-performing vehicle running characteristics. There are a number of pitfalls such as cyclic track irregularities that may lead to erroneous conclusions and results.

- Standard deviations of longitudinal level D1 and alignment D1 are fundamental for assessing track geometry quality and should not be treated as parameters that are comfort related only.

- STFT analysis presents track irregularities in a combined distance-wavelength domain and can be used to determine where and at which wavelength cyclic irregularities occur.

What caused the problems?



A combination of track and vehicle issues:

- Track tamping without sufficient stabilisation
- Unrelated: hunting instability due to maintenance issues

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IN2TRACK2 TRAFIKVERKET SJ Analytical Dynamics KTH GENSYS

Collaboration Project: A Systematic Approach to Improve Passenger Ride Comfort

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164707300-003	TRV 2020/113830	2020-11-21	1

Track Geometry Evaluations at Bdl 354

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Abstract

Knowing track geometry quality is essential for understanding vehicle-track dynamic interaction and ride stability. Principal track geometric parameters, known as longitudinal level, alignment, track gauge, cross level and twist, are routinely evaluated and used by infrastructure managers for safety control, maintenance planning and train speed setting.

This report presents a detailed investigation on track geometry quality at Bdl 354. Bdl is the abbreviation of Swedish word Bandel, meaning 'part of line'. Bdl 354 is about 35 km long and carries mostly passenger traffic with an operational speed of 200 km/h. During 2017 and 2018, severe problems with track geometry, damaged track components and ride instability of vehicle were reported.

The findings are presented in a report.

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…Thank you!