

# Vehicle vibrations at the Hallandsås tunnel: collaborative investigation and results

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**ABSTRACT:** Vehicle vibrations at the newly opened Hallandsås tunnel in southern Sweden caused a temporary speed restriction and a massive media attention. The problem was solved efficiently by Trafikverket, the infrastructure manager, and SJ, the rolling stock operator, working together. The cause of the vibrations was bogie hunting, caused by high equivalent conicity. 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. The successful project has triggered a collaboration between Trafikverket and SJ to improve the detection and mitigation of poor ride comfort.

## 1 BACKGROUND

Hallandsåsen is a long ridge located in southern Sweden on the main railway line between Gothenburg and Malmö, Sweden's second and third largest cities, Figure 1. It has long been a bottleneck for train traffic, due to a low capacity and a high longitudinal gradient of the track. Problems with heavy freight trains have been recurrent, especially in autumn due to low friction caused by leaves on the track. There has long been a demand for a tunnel through the ridge, with an expected increase in transport capacity of five to six times, and a shortening of the time of travel by 10-15 minutes.



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

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.

In December 2015 the Hallandsås tunnel was finally opened for traffic. It is 8.7 km long, consisting of two single-track tunnels with ballasted track, elastic fastening and 60E1 rail. The rail inclination is 1:30, which is the Swedish standard.

Soon after the opening of the tunnel there were reports of vehicle vibrations by the tunnel. This led to a preventive speed reduction while the cause of the vibrations were being investigated. The earlier controversies surrounding the tunnel led to a massive media attention, with lots of speculations in the press regarding the integrity of the tunnel and the cause of the vibrations.

Trafikverket, the infrastructure manager, and SJ, the train operator, rapidly formed a collaboration group to investigate and eliminate the cause of the vibration. This paper describes the collaboration and the findings of the group. The successful teamwork has led to a continued collaboration between Trafikverket and SJ with the goal to improve overall ride quality, especially when there is no clear root cause, but it is shared between train and track.

## 2 VIBRATIONS

The first indications of a vibration problem by the tunnel came in January 2016, shortly after the tunnel was opened for traffic. It was not only one operator or type of vehicle that experienced problems. It happened at high speeds, and was reported to start either inside or close to the tunnel entrances.

### 3 VEHICLE MEASUREMENTS

On ongoing study with ride comfort monitoring of SJ's X55 trains proved helpful in the investigation. Ride comfort loggers by Analytical Dynamics measure carbody accelerations and GPS signals continuously, with automatic upload and evaluation in the cloud. The loggers are powered from the train and can be used continuously without interaction.

Two short vibrations events close to the tunnel were measured during this period, Figure 2, where the longitudinal (X) and lateral (Y) accelerations are shown. The frequency is about 5 Hz.

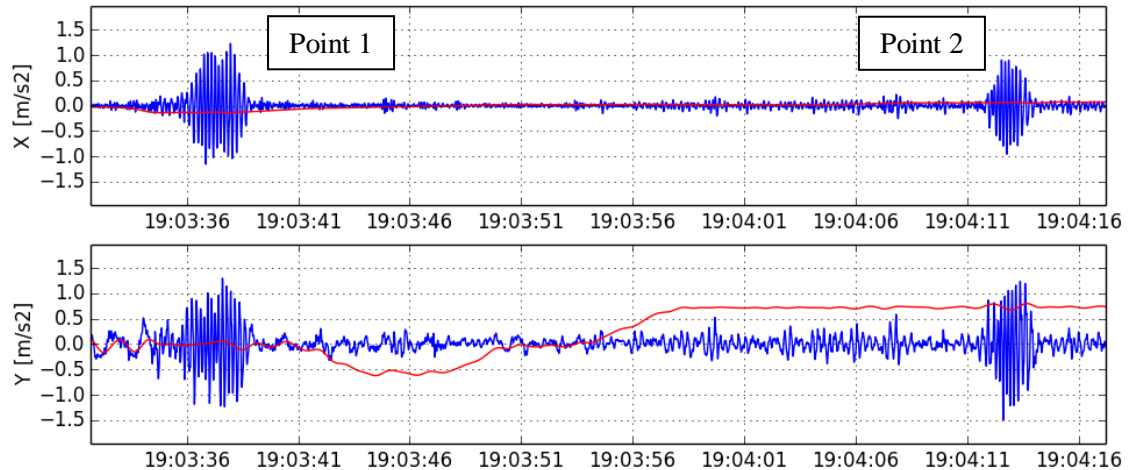


Figure 2. Two short vibration events by the Hallandsås tunnel measured on a SJ X55 train, i.e. Regina by Bombardier Transportation. Longitudinal (X) and lateral (Y) accelerations.

The location of the events could be pinpointed by the GPS measurement. They were initiated close to track switches south of the tunnel, Figure 3, with the train going northward towards Gothenburg. The location was consistent with reports of other incidents, although vibrations were known to have continued into the tunnel.

#### Locations of vibrations

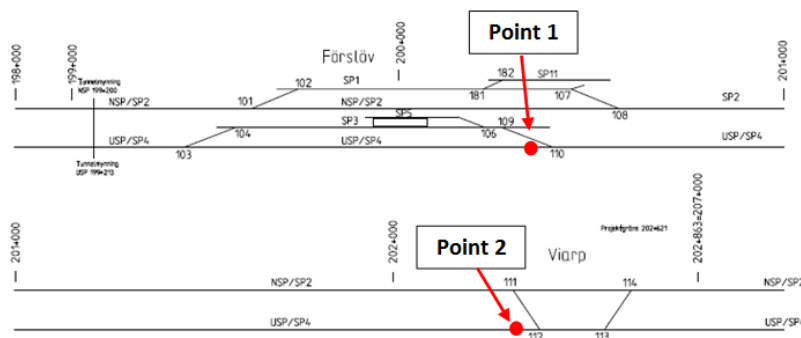


Figure 3. A track map showing the locations of the vibrations in Figure 2, point 1 and 2, measured by GPS. Both events were initiated close to switches.

### 4 EQUIVALENT CONICITY

Measurements of track irregularities and rail profiles were made, as well as the wheel profiles on one of the reported vehicles, although not of the vehicle with the vibrations in Figure 2. The rail and wheel profile measurements were used for a calculation of in-service mean values of equivalent conicity over 100 meters. The calculations followed exactly the method for determining the equivalent conicity given in (SS-EN 15302:2008) and the specifications given in (TSI INF, 2014)

and (TSI LOC&PAS, 2014). The calculations were carried out using a specifically developed software (Wrang, Li, Sundvall, Jahlenius, 2009). The result is shown in Figure 4, together with the lateral accelerations from the logger measurement. The conicity is calculated for three different wheelsets, with worn wheels, mildly worn wheels and a nominal wheel profile.

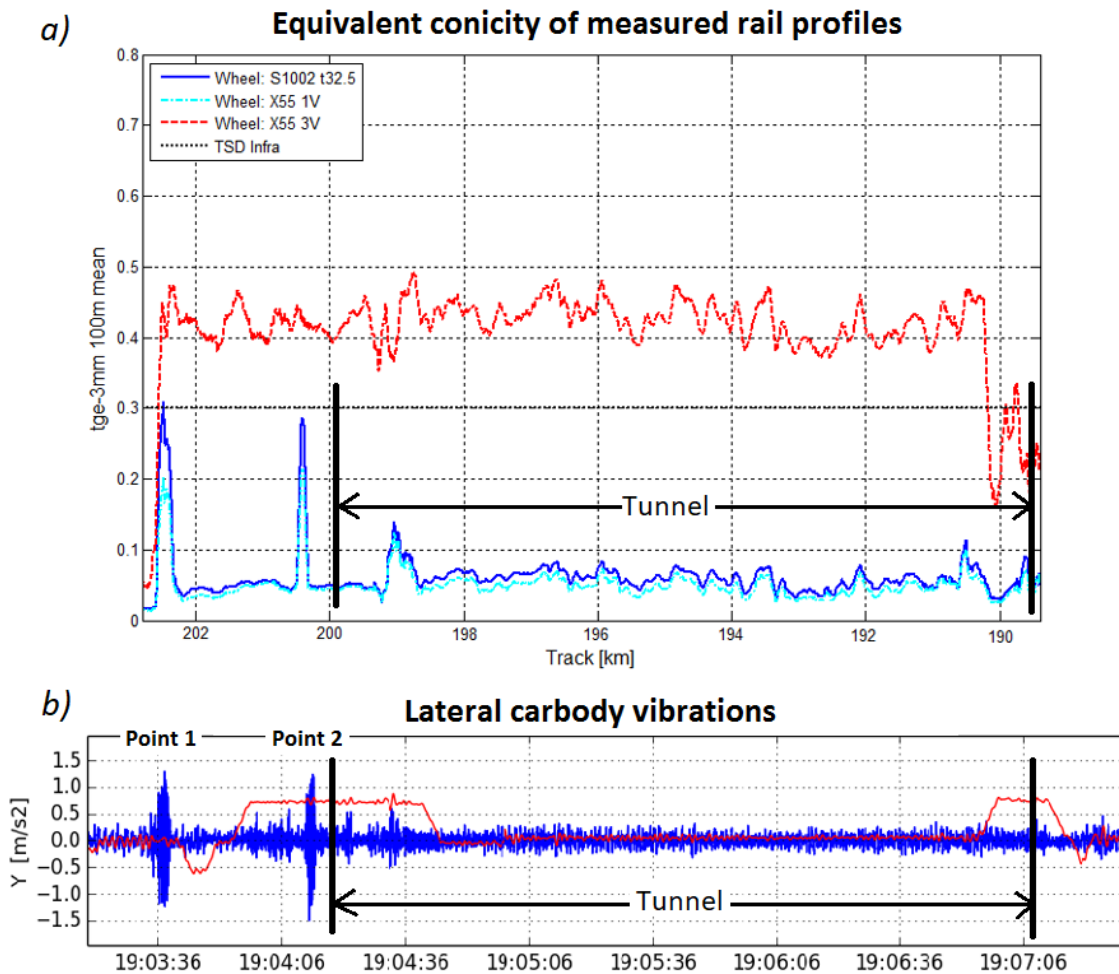


Figure 4. a) Equivalent conicity of measured rail profiles versus nominal and measured wheel profiles, although not from the vehicle with measured vibrations. b) Lateral acceleration in the carbody. The locations match the positions with high equivalent conicity of the mildly worn wheels and the nominal S1002 wheel profile.

The worn wheels show a consistent high equivalent conicity of 0.4 and above, whereas the mildly worn and the nominal S1002 wheel profile show a similar pattern, with low conicities except for a few hot spots. These coincide with the locations of the vehicle vibrations, shown in the bottom diagram.

## 5 FINDINGS AND CORRECTIVE MEASURES

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. The tunnel had no influence on the initiation of the vibrations, besides the possible

higher wheel-rail friction inside the tunnel. The vibrations have had no influence on the integrity of the tunnel.

## 6 COLLABORATION BETWEEN 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 Trafikverket is in progress to find new ways to improve ride comfort. Figure 5 shows the proposed work flow.

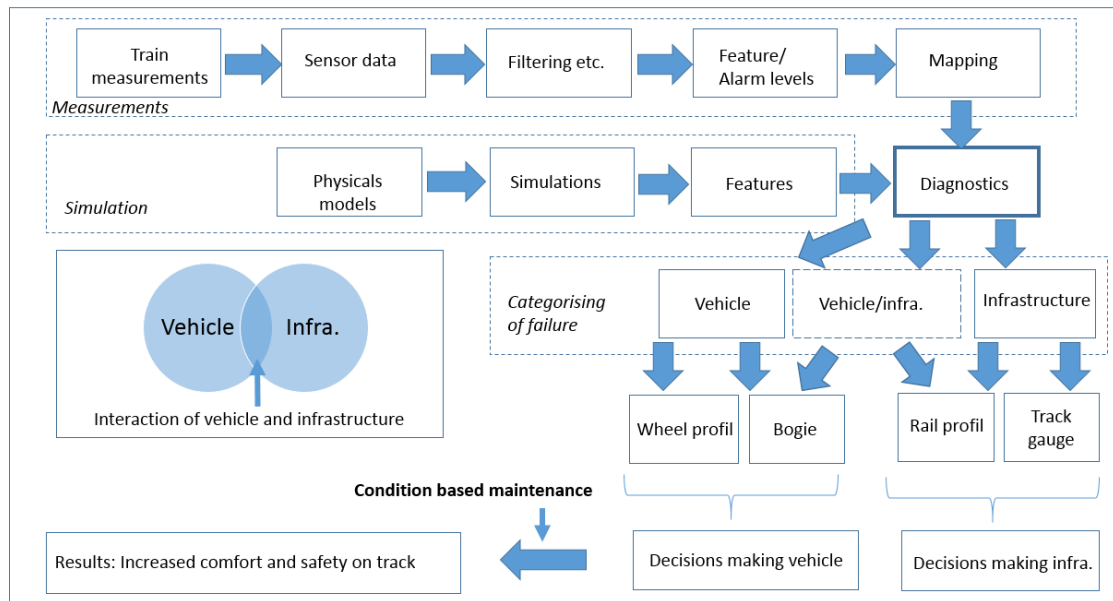


Figure 5. Condition based maintenance of the parameters that impact the riding comfort.

It is proposed to use both ride comfort measurements and multi-body simulations. The simulations identify signatures from different failure modes e.g. high conicity between wheel and rail, worn lateral or vertical damper etc. Data from online measurements are compared with the distinct signatures from the simulations, and by using pattern recognition faults can be diagnosed efficiently. The goal is to improve the efficiency of error correction, and to give the correct diagnosis whether the problem is related to the vehicle or the infrastructure, or both vehicle and infrastructure, as was the case in the Hallandsås vibrations.

## 7 SUMMARY

Vehicle vibrations at the newly opened Hallandsås tunnel in southern Sweden caused a temporary speed restriction and a massive media attention. The problem was solved efficiently by Trafikverket, the infrastructure manager, and SJ, the rolling stock operator, working together. The cause of the vibrations was bogie hunting, caused by high equivalent conicity. An improved wheel reprofiling programme, together with corrective rail milling and grinding has eliminated the vibration problem by the tunnel, and the temporary speed restriction was lifted shortly afterwards. The successful project has triggered a collaboration between Trafikverket and SJ to improve the detection and mitigation of poor ride comfort.

## REFERENCES

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