On wayside detector measurement of wheel–rail impact loads induced by wheel flats – Data analysis, alarm levels and regulations

Citation for the original published paper (version of record):
Mattsson, K., Nielsen, J., Fehrlund, L. et al (2024). On wayside detector measurement of wheel–rail impact loads induced by wheel flats – Data
analysis, alarm levels and regulations. Proceedings of the Sixth International Conference on Railway Technology: Research, Development and Maintenance. http://dx.doi.org/10.4203/ccc.7.7.10

(article starts on next page)

Full bibliographic reference: K. Mattsson, J.C.O. Nielsen, L. Fehrlund, M. Maglio, T. Vernersson, "On Wayside Detector Measurement of Wheel-Rail Impact Loads Induced by Wheel Flats – Data Analysis, Alarm Levels and Regulations", in J. Pombo, (Editor), "Proceedings of the Sixth International Conference on Railway Technology: Research, Development and Maintenance", Civil-Comp Press, Edinburgh, UK, Online volume: CCC 7, Paper 7.10, 2024, doi:10.4203/ccc.7.7.10

On wayside detector measurement of wheel–rail impact loads induced by wheel flats – Data analysis, alarm levels and regulations

Klara Mattsson[1*], Jens C.O. Nielsen[2], Lars Fehrlund[3], Michele Maglio[1] and Tore Vernersson[2]

[1] Trafikverket, Gothenburg, Sweden

[2] Department of Mechanics and Maritime Sciences/CHARMEC, Chalmers University of Technology, Gothenburg, Sweden

[3] Green Cargo AB, Stockholm, Sweden

[*] klara.mattsson@trafikverket.se

Abstract

Wheel–rail impact loads induced by discrete wheel tread irregularities, such as wheel flats, may lead to severe damage of vehicles and tracks. In Sweden, wheel removal regulations are applied if the wheel flat is longer than 60 mm independent of axle load and train speed. Condition monitoring of wheels is carried out via measurement of peak loads in wheel impact load detectors. If measured loads exceed the alarm level 350 kN, a train speed reduction is imposed until the vehicle with the wheel damage has been decoupled from the train. In this study, measured peak loads from six detectors along a specific freight traffic route are compared for different wheel flat lengths, axle loads and train speeds. The alarm level was not exceeded for any of the wheel flats, including those significantly longer than 60 mm. To reduce costs due to unnecessary traffic disruptions while maintaining safety, it is suggested that wheel removal criteria should strictly be based on measured loads in detectors instead of by visual inspection of wheel flat length. The detectors should be subjected to regular monitoring of track geometry and should have a robust and transparent calibration procedure for measurement of dynamic wheel loads.

Keywords: wheel impact load detector, wheel flat, alarm level, regulations, track stiffness, track geometry.

1 Introduction

To increase passenger and freight traffic, railway transportation needs to be safe, reliable, environmentally friendly, cost-efficient, and on time. To achieve this, regulations and procedures to avoid traffic disruptions caused by infrastructure failures and unnecessary stopping of trains are needed. In this context, the consequences of different forms of wheel out-of-roundness can be a significant issue.

A discrete wheel tread irregularity is a deviation from the nominal wheel radius along a short section of the wheel circumference. It is a local surface damage that for example could be induced by rolling contact fatigue (RCF) or be a consequence of the wheel sliding without rolling (wheel flat). In traffic operation, such irregularities may lead to momentary losses of wheel–rail contact and severe impact loading. The consequences can be rail breaks and sleeper cracking, high-cycle fatigue of wheelsets and other vehicle components, impact noise and ground-borne vibration [1,2].

According to regulations by the Swedish Transport Administration, *Trafikverket*, wheel flats longer than 60 mm are not allowed in traffic. If a wheel flat longer than 60 mm is detected, the vehicle with the damaged wheel must be decoupled from the train and taken out of traffic [3]. This regulation holds irrespective of the current axle load of the vehicle, even though a given wheel flat on an unloaded vehicle would generally induce significantly lower wheel–rail impact loads (peak loads) than if the vehicle is loaded. Consequently, trains may have to stop during regular service to disconnect a wagon with a wheel flat and leave it at a station or passing siding where an extra track is available. This could cause major costs and delays in the overall traffic operation, especially on single-track lines and where the available tracks at stations are needed for oncoming trains. Incurred costs for the traffic operators are increased production costs (wheelset replacement on site, transportation to the nearest workshop at reduced train speed, etc.), fines, and reimbursements to passengers for delayed journeys.

Field tests of dynamic vehicle–track interaction involving trains with different types of wheel tread irregularities have been reported in several studies, see [4–10]. For a given wheel flat, these measurements have indicated a local maximum in vertical wheel–rail contact force (impact load) in the train speed interval 30 – 60 km/h. It has also been reported that the speed of this local maximum was increased with increasing axle load [7]. For comparison, the simulated influence of train speed and depth of a wheel flat on the generated impact load is illustrated in Figure 1 [11]. With increasing flat depth d, it is shown that the magnitude of the impact load increases and momentary loss of wheel–rail contact occurs at a lower train speed. In the figure, it is observed that the speed dependence is essentially similar for different depths, but the local maximum and minimum of each curve are more pronounced for larger depths and are also shifted to higher speeds.

Note that for a new wheel flat with sharp edges, the length l_0 and depth d of the flat can be assumed to be correlated. Based on the chord theorem, it can be shown that $l_0 \approx \sqrt{8R_\mathrm{w}d}$, where R_w is the wheel radius and $d \ll R_\mathrm{w}$. However, the initial wheel flat with sharp edges will soon be transformed into a longer flat with length l and rounded edges because of wear and plastic deformation of the wheel material due to subsequent impacts with the rail. The depth at the centre of the flat can be assumed to remain relatively unchanged [12], but flat depth is more difficult to measure in the field and is thus not regulated by Trafikverket.

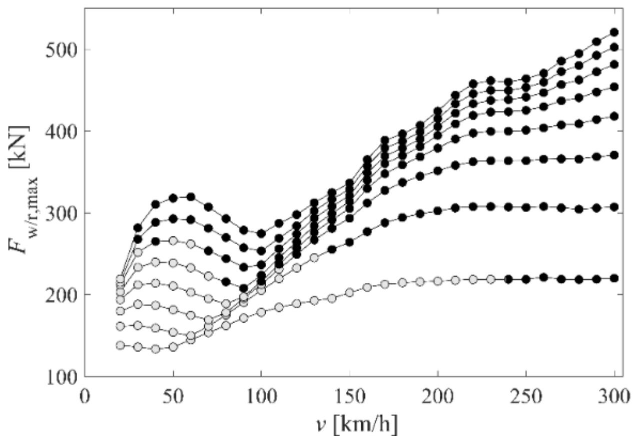

Figure 1: Simulated peak loads (including static wheel load 118 kN) due to a rounded wheel flat with length $l = 1.76 \cdot l_0$. The lines (from lower to upper) correspond to flat depths d = [0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75, 2.00] mm. Each circle illustrates the maximum of the impact loads from eight simulations with different initial angular positions of the wheel within one sleeper bay. Black circles indicate that loss of contact occurs for at least one of these eight simulations. From [11].

2 Wheel impact load detectors and regulations

To mitigate wheel–rail impact loading due to out-of-round wheels, the main priority should be to control and monitor the development of discrete wheel tread irregularities by vehicle and brake design, and by regular maintenance. Wheel flats can be detected by acoustic or visual inspections, and by measurements of vertical wheel–rail contact force in wheel impact load detectors (WILDs). In this way, condition monitoring of measured force levels provides operators with information on the status of their wheel fleet. In the case of evolving RCF damage leading to moderate increases of peak loads with time, these force levels could be used to schedule preventive maintenance before the wheel out-of-roundness grows to unacceptable levels, while wheels with flats can be taken out of service for corrective maintenance. Various types of sensors have been deployed in commercial wayside WILD systems to measure wheel–rail contact force. This includes strain gauge load circuits and fibre optic sensing technology for measurements of rail bending, and load cells for measurement of rail seat loads [1].

WILDs are typically placed on tangent track with concrete sleepers on premium ballast and well-compacted subgrade to reduce dynamic wheel load variation due to irregularities in track geometry and sleeper support conditions. Trafikverket specifies regulations in terms of maximum track irregularities along the detector (gauge, cross level and twist), maximum sleeper deflection, and dynamic strength of the foundation [13]. Further, there should be no curves, transition curves, switches & crossings, viaducts, severe rail surface irregularities (such as corrugation or squats), rail joints or broken sleepers within a distance of at least 150 m on either side of the detector. In Sweden, with around 11 000 km of track, around 30 WILDs are distributed across the country with a higher representation in the north. Most of these detectors are currently based on the measurement of rail seat loads. Regular monitoring (and rectification) of track geometry and calibration of the detectors are key for accurate measurements [14].

Based on post-processing of the measured signals, the detectors provide information about the mean load and peak load generated by each passing wheel. The dynamic load contribution and the ratio are also evaluated. The dynamic load is the difference between the peak load and the mean load, while the ratio is the peak load divided by the mean load. The peak load is useful for heavy haul operations with high axle loads to control that the wheels do not induce loads that could damage the track, while the ratio is mainly applied for unloaded wagons to detect wheel damage that could become harmful when the wagon has been loaded.

To prevent unacceptable deterioration levels and safety-related failures, alarm limits are prescribed. The UIC recommended alarm limit for peak load mandates an immediate stop of the train if the peak wheel–rail contact force exceeds 350 kN, with an alert level at 300 kN [15]. The regulations [16] applied by Trafikverket can be distinguished into 'high' and 'warning' alarm levels:

- For a passenger coach or a freight wagon, the 'high' alarm level is 350 kN. If this level is exceeded, the train may continue at reduced speed to the nearest passing siding where the vehicle with the wheel tread damage must be decoupled from the train [3].
- For locomotives, the 'high' alarm level is 425 kN.
- If a locomotive wheel generates a peak load exceeding 350 kN and the ambient air temperature is below -10 C°, train speeds in the interval 15 – 45 km/h should be avoided [16], cf. the local force maximum in Figure 1.
- 'Warning' levels are set at 280 kN (peak load), 180 kN (dynamic load) and 4.8 (ratio) independent of vehicle type.
- If the measured peak load, dynamic load or ratio exceeds a 'warning' level (but not the peak load 350 kN), cf. Figure 3, the train may continue without regulations to its destination. From there it is not allowed to continue operating until the wheel has been rectified and approved by certified staff. This regulation holds unless it is found that the length of the wheel tread damage exceeds 60 mm.

3 Analysis of wheel impact load detector data

An analysis has been carried out by extracting data from six WILDs that are positioned between Luleå and Borlänge along the route for the so-called *Stålpendeln* [17]. All these WILDs are of the same brand and are based on load cells for measurement of rail seat load. The route is used by the freight traffic operator Green Cargo AB to haul steel slabs on commission for the Swedish steel company SSAB. The maximum allowed axle load on the line is 25 tonnes. Data from the detectors were collected from December 2022 to March 2023.

The analysis started by examining a document containing information about wheel replacements in the workshop in Luleå. The document included information about when and for what reason a wheel was replaced. If the reason for replacement was a wheel flat, the length of the non-rounded part of the wheel flat had been measured in the workshop before wheel turning. As measurement of wheel flat length is notoriously difficult, flat lengths had generally been rounded up to the nearest 5 millimetres. For each detected wheel flat, data from the six WILDs was compiled for the corresponding wagons and the studied time period. The date of discovered damage that was stated in the document from Luleå was used as a starting point to manually find in between which two detectors the wheel flat was generated. In total, 823 detector passings by 149 different wheelsets (with at least one of the wheels on the axle being defective) were included in the analysis. Figure 2 illustrates an example of how four data points were extracted to the database.

All data from passages at train speeds below 40 km/h were filtered out since the RFID tag used for identifying wheelsets was not considered accurate for those speeds. Only the highest peak load per axle and detector passage was included in the analysis. The wagons in the analysis were either loaded or unloaded. The analysis of unloaded wagons consisted of wagons with axle loads in the interval 4.5 – 6 tonnes and speeds between 69 and 120 km/h. The number of detector passages with unloaded wagons was 645. The loaded wagons, on the other hand, had a range of axle loads between 17 and 25 tonnes and speeds in the interval 64 – 90 km/h. The number of detector passages for the loaded cases was 159. Figure 3 illustrates a summary of peak loads for all detector passages included in the analysis. The blue line indicates the warning levels issued by Trafikverket. It is observed that most warning alarms were set off for unloaded wagons in the form of ratio alarms for wagons with axle loads of around 5 tonnes.

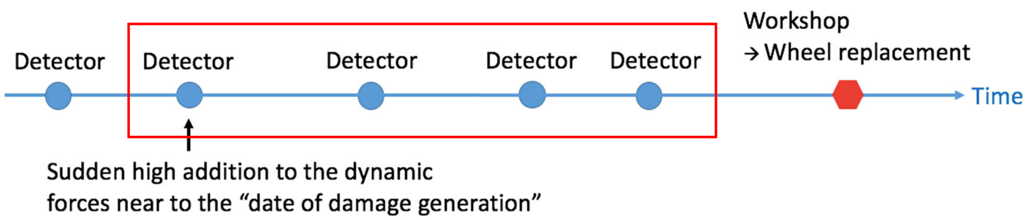

Figure 2: Timeline describing the approach used to extract detector data to be included in the analysis. In this example, data from four detector passages by the same wheelset were selected for the analysis. From [17].

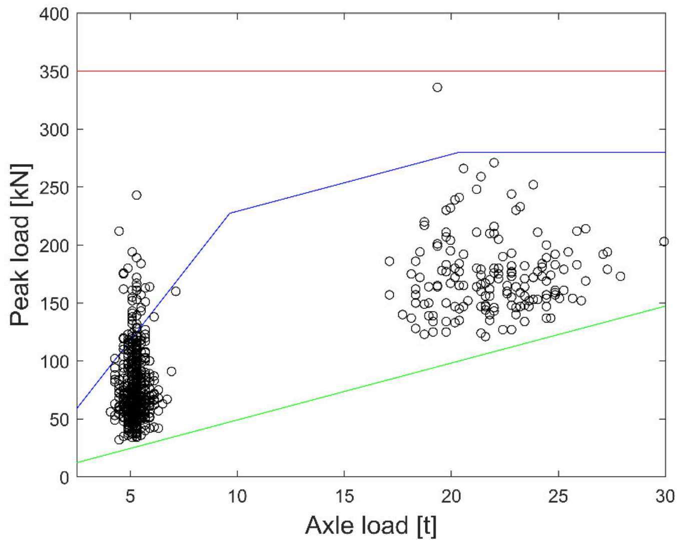

Figure 3: Influence of axle load [tonnes] on measured peak load for all 823 analysed detector passages. The red line is the 'high' alarm at 350 kN. The blue line indicates warning levels set by Trafikverket in terms of ratio (axle loads up to 10 tonnes), dynamic load (axle loads in the interval 10 – 20 tonnes) and peak load. The green line illustrates the relation between mean load and axle load. From [17].

4 Influence of wheel flat length and train speed

For different intervals of wheel flat length, and for loaded and unloaded wagons, Figures 4 and 5 present the influence of train speed on measured peak loads. A linear regression has been made in each subplot to indicate any possible trend in the data, but as the R^2-value (coefficient of determination) is generally very low this could not be confirmed. In some of the subplots, the number of data points is very small. Nevertheless, based on these measurements, there seems to be no evident increase in peak load with increasing train speed for any of the wheel flat length intervals. Neither can a local maximum as in Figure 1 be observed. In each subplot, each colour represents one specific wheel flat. Thus, if the same colour is repeated several times, this means that the same wheel flat has passed several detectors. For the two wheels on an axle, the highest peak load was extracted from each detector passage. Thus, the same colour could potentially represent either the left or the right wheel on the same axle. As mentioned above, wheel flat lengths were measured in the workshop before the wheels were turned. Figures 6 and 7 show the same data, but in this case for different intervals of train speed. Although the scatter in data is again very significant, an expected trend indicating higher peak loads with increasing flat length can be distinguished in most subplots.

There are several potential reasons for the large spread in the data. One reason could be differences in lateral wheel contact position relative to the position of the wheel flat while passing over the different detectors. For example, in one detector the contact position on the wheel might have been well aligned with the centre of the flat (with the maximum depth), while in another detector the wheel–rail contact might have occurred towards (or even outside of) the inner or outer edges of the flat. Based on simulation, it can be shown (not shown here) that the significance of wheel flat depth on the generated impact load is larger than the corresponding significance of flat length. However, the measured wheel flats may have had rounded edges, and the depths of the flats are unknown. Other reasons could be related to differences in the position within a sleeper bay where the flats made impact with the rail. Differences in wheelset design, wheel radius and unsprung wheelset mass, as well as variation in track stiffness between different detectors and irregularities in track geometry, are other factors contributing to the scatter in data.

Figure 8 presents the cumulative distributions of peak load for the same data as in Figure 4. The red line indicates the 'high' alarm limit of 350 kN, while the orange dashed line is the warning level 280 kN set by Trafikverket. In summary, based on the 823 investigated detector passages with wheel flats of different lengths, there was no case of peak load exceeding 350 kN. This was surprising since several of the investigated cases involved wheel flats significantly longer than 60 mm.

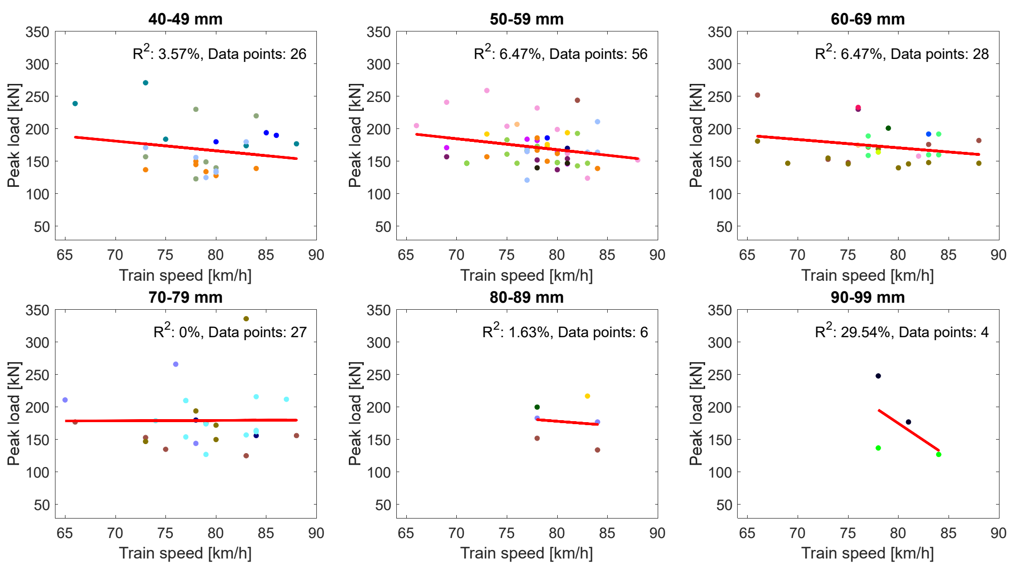

Figure 4: Influence of train speed on measured peak loads: different wheel flat length intervals, loaded wagons with axle loads 17 – 25 tonnes. From [17].

5 Detector time history for a given wheel flat

For a given 75 mm wheel flat, all registered peak loads and mean loads in six different WILDs along the route of Stålpendeln have been studied, see Figure 9. The presented data covers the period from when the flat had been generated until the wheelset was taken out of service for repair. Two journeys in loaded conditions and three journeys in tare conditions are considered. A large variation in measured loads between different detectors during a given journey is observed. Further, a clear pattern in how the detectors measured relative to each other is noted, see for example differences in data from the detectors at Degerbäcken and Skorped. This indicates that besides the variation in speed and other influencing variables, the condition of the detectors might have affected the measured loads. The time since calibration, and measurement accuracy, may vary between individual detectors. In particular, it may be argued that the ability of the detectors to measure high-frequency impact loads is uncertain.

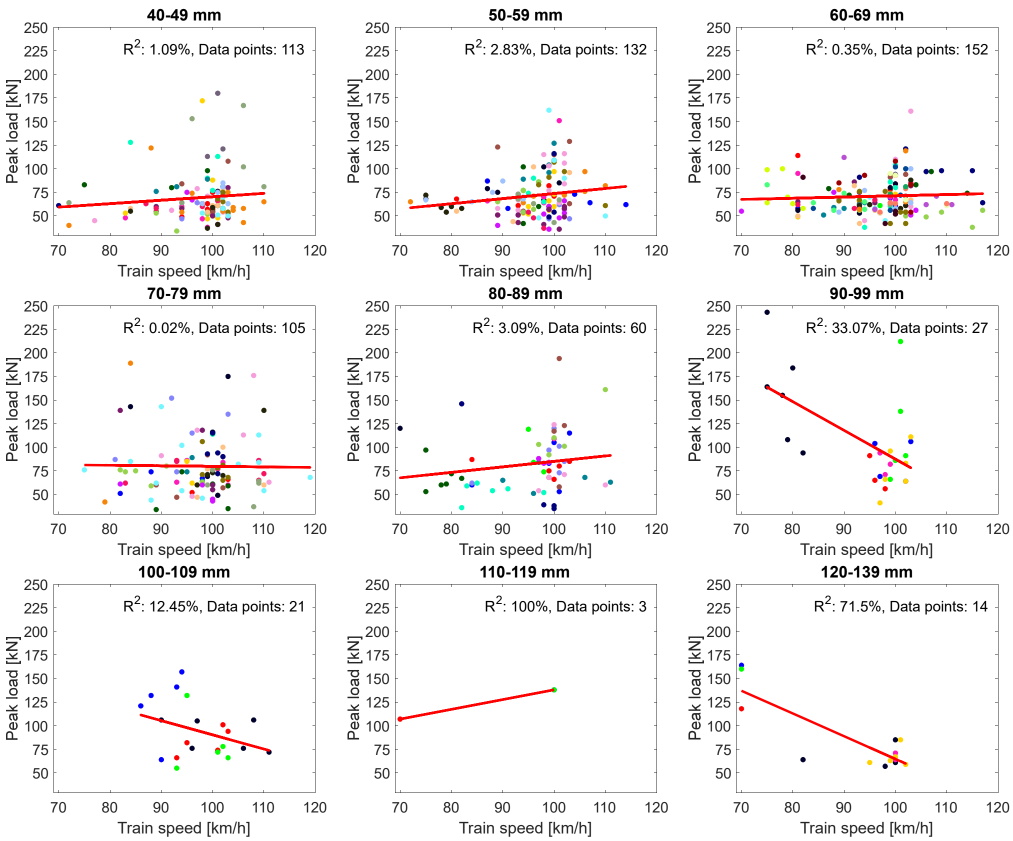

Figure 5: Influence of train speed on measured peak loads: different wheel flat length intervals, unloaded wagons with axle loads 4.5 – 6 tonnes. From [17].

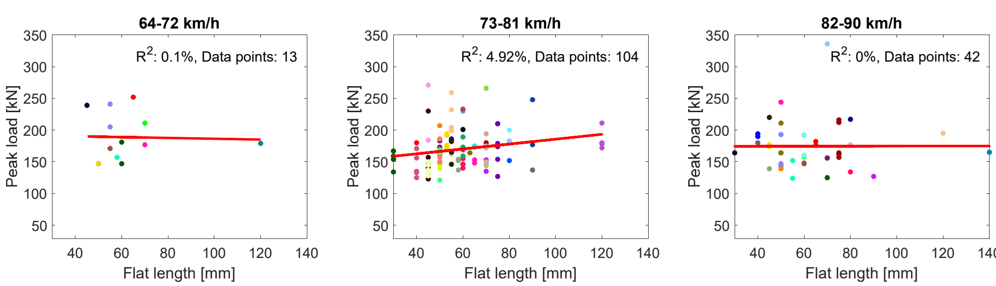

Figure 6: Influence of wheel flat length on measured peak loads: different train speed intervals, loaded wagons with axle loads 17 – 25 tonnes. From [17].

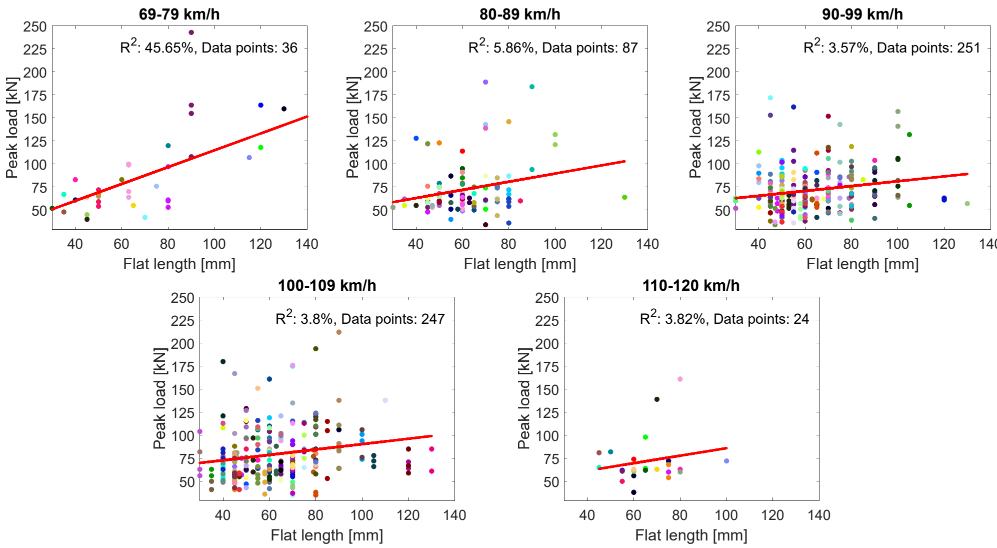

Figure 7: Influence of wheel flat length on measured peak loads: different train speed intervals, unloaded wagons with axle loads 4.5 – 6 tonnes. From [17].

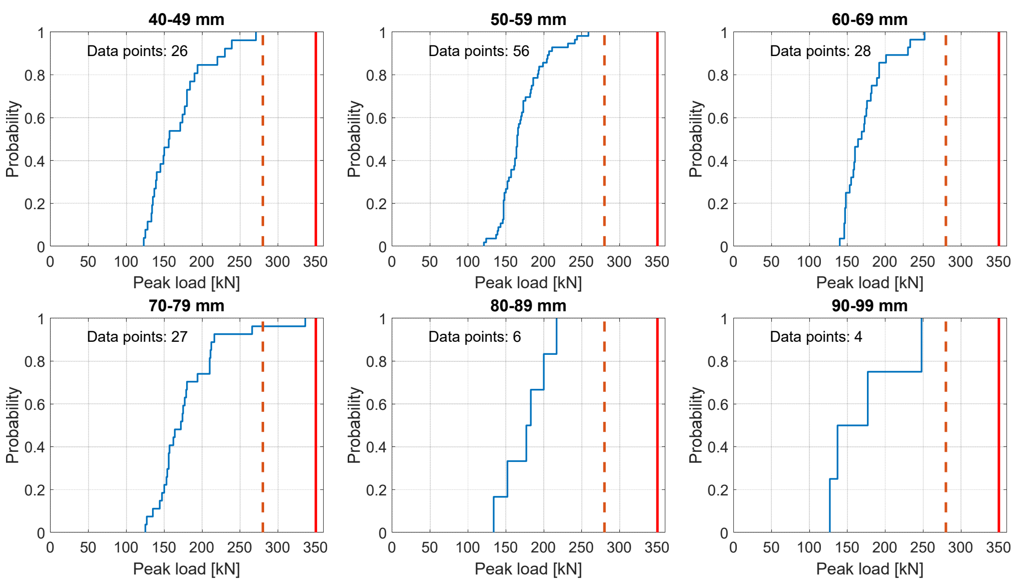

Figure 8: Cumulative distributions of peak load for different intervals of wheel flat length: loaded wagons with axle loads 17 – 25 tonnes. From [17].

According to regulations set by Trafikverket, measured mean loads for locomotives should be within a tolerance of ± 5%. The accuracy of mean loads measured in the detectors at Degerbäcken and Skorped have been assessed by collecting measured loads from the Transmontana CoCo locomotives that are used to pull the *Stålpendeln* wagons. For each wheelset, the mean loads of both wheels on the same axle were summed and divided by the nominal axle load of the locomotive. Note that the nominal weight (125 tonnes) of the locomotive may vary during the winter due to accumulation of ice in the bogies. The evaluated ratios between mean load and nominal axle load are presented in Figure 10. A linear regression has been made based on all data in each plot. For both detectors, it is observed that the measured loads for axles 2 and 5 are consistently lower than for the outer axles in each bogie. Nevertheless, it is argued that the measurement accuracy (in terms of mean load) of the detector at Degerbäcken is considerably higher than for the detector at Skorped.

In parallel, track foundation stiffness and track irregularities in the detectors along the route of *Stålpendeln* have been measured by track recording cars [18], see Figures 11 and 12. For the WILD at Degerbäcken, it was found that measured vertical track stiffness is relatively uniform and that the track geometry is within the proposed tolerance limits. On the other hand, it is observed that the WILD at Skorped has irregularities within the detector area both in terms of track stiffness and track geometry, which could affect the vehicle dynamics while passing through the detector. In summary, the calibration of the detectors, as well as the measured variations in track stiffness and track geometry at the detector sites might have contributed to the scatter in measured peak loads.

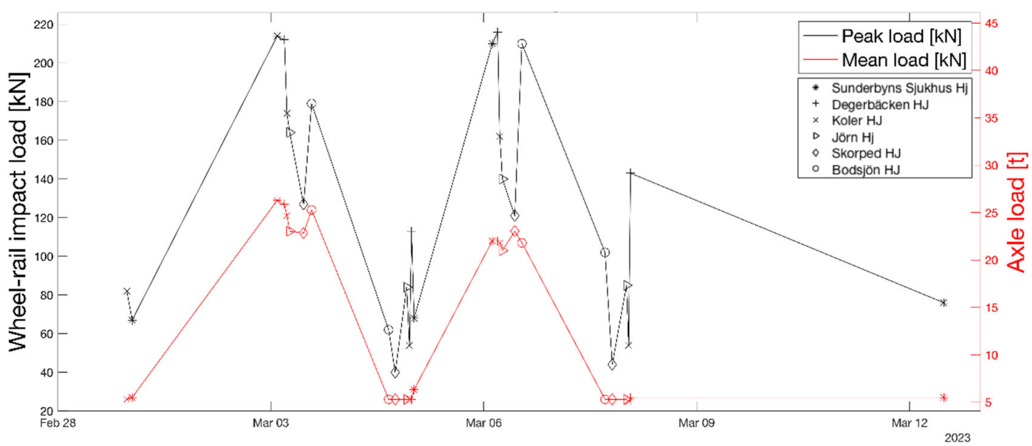

Figure 9: Peak loads and axle loads for one given wheel flat with length 75 mm measured in six WILDs along the route of *Stålpendeln.* From [17].

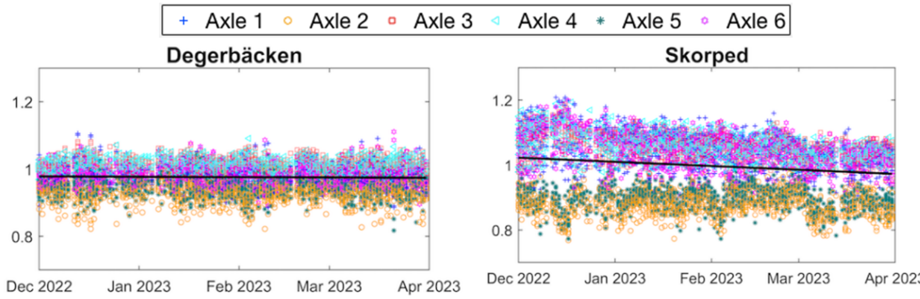

Figure 10: Ratio between measured mean load and nominal axle load for Transmontana CoCo locomotives. WILDs at Degerbäcken and Skorped.

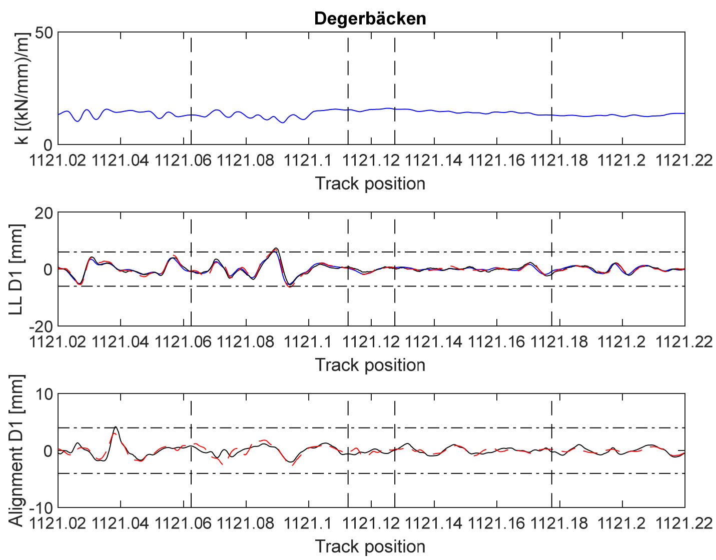

Figure 11: Foundation stiffness, longitudinal level (bandpass filtered 1 – 25 m) and alignment (1 – 25 m) measured over a distance of 200 m in the WILD at Degerbäcken. Blue curves were measured on 2022-06-07. Black (left rail) and red (right) curves were measured on 2023-05-31. The inner pair of vertical lines indicates detector area 1 (15 m), while the outer pair of vertical lines indicates detector area 2 (50 m on either side of detector area 1). Horizontal dash-dotted lines indicate suggested tolerances in terms of planned maintenance for tracks with maximum allowed speed up to 160 km/h.

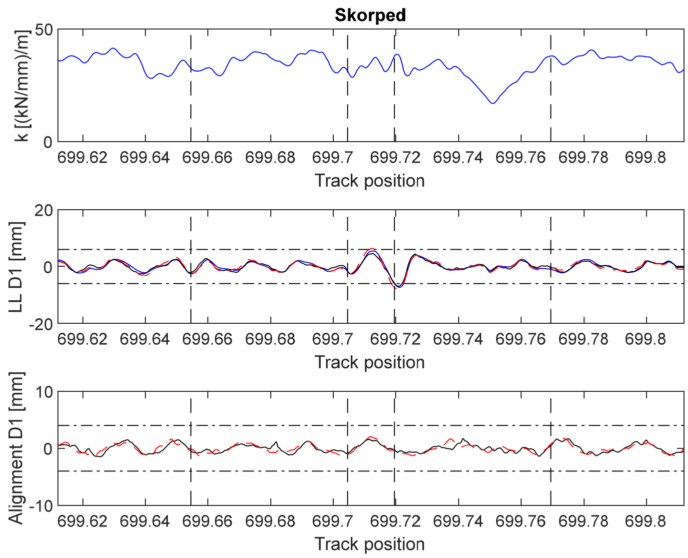

Figure 12: Foundation stiffness, longitudinal level (bandpass filtered 1 – 25 m) and alignment measured in the WILD at Skorped. Blue curves: 2022-10-05. Black and red curves: 2023-08-13.

6 Conclusions

For a given traffic situation on a specific railway line, wheel–rail impact loads (peak loads) due to wheel flats of different lengths as measured in six detectors have been analysed. In total, 823 detector passages by 149 different wheelsets were considered in the data analysis. No evident correlation between wheel flat length, train speed and peak load could be found. Thus, it seems more reasonable to base regulations and removal of out-of-round wheels on measured peak loads than on visual inspection of wheel tread damage and measurement of wheel flat length.

Since peak loads generally increase with increasing mean loads, it is argued that a wheel flat on an unloaded wagon with a low axle load is less detrimental compared to the same flat on a loaded wagon with a higher axle load. If this is considered in the regulations, it would result in more flexibility if unloaded wagons with wheel tread damage (independent of wheel flat length) were allowed to continue their operation to a workshop for repair as long as the alarm level (350 kN) is not exceeded. If unloaded wagons were allowed to continue (at recommended speed) to their final destination, this would lead to fewer traffic disruptions while maintaining safety.

Detector data needs to be reliable with a robust and transparent procedure for calibration and post-processing of data. To this end, detectors need to be calibrated regularly. A calibration of mean (quasi-static) load can be employed based on passages of axles with known axle loads (typically a fleet of locomotives) at low speed. The calibration of the dynamic load is more cumbersome as it can be expected that the detector measurements are dependent on the frequency contents of the load, load magnitude, temperature, etc. The calibration should be based on the traffic on the line (axle load, speed, passenger/freight etc.). Further, as illustrated in Figures 11 and 12, irregularities in track geometry and track stiffness should be monitored and rectified.

Acknowledgements

The current work is part of the activities within the Centre of Excellence CHARMEC (CHAlmers Railway MEChanics, www.chalmers. se/charmec). Parts of the study have been funded within the Horizon-ER-JU-2022-FA5-01 project TRANS4M-R under grant agreement no. 101102009. Parts of the study have also been funded by the Swedish innovation agency VINNOVA, contract no. 2023-01218. Discussions with Mr Roger Byström and Dr Matthias Asplund of Trafikverket, and Dr Peder Lundkvist of Nordkonsult AB, are gratefully acknowledged. The track stiffness data was provided by Dr Eric Berggren, EBER Dynamics AB.

References

[1] S. Iwnicki, J.C.O. Nielsen, G. Tao, ”Out-of-round railway wheels and polygonisation”, Vehicle System Dynamics, 61(7), 1785–1828, 2023.

[2] J.C.O. Nielsen, A. Pieringer, D.J. Thompson, P.T. Torstensson, ”Wheel–rail impact loads, noise and vibration: A review of excitation mechanisms, prediction methods and mitigation measures”, Notes on Numerical Fluid Mechanics and Multidisciplinary Design, 150, 3-40, 2021.

[3] Trafikverket, “Detektorer. Hantering av larm samt åtgärder efter konstaterade skador”, (“Detectors. Handling of alarms and measures following ascertained damages”, in Swedish), TDOK 2020:0074 v2.0, 2021.

[4] H.H. Jenkins, J.E. Stephenson, G.A. Clayton, et al., “The effect of track and vehicle parameters on wheel/rail vertical dynamic forces”, Railway Engineering Journal, 3(1), 2–16, 1974.

[5] S.G. Newton, R.A. Clarke, “An investigation into the dynamic effects on the track of wheelflats on railway vehicles”, Journal of Mechanical Engineering Science, 21(4), 287–297, 1979.

[6] M. Fermér, J.C.O. Nielsen, ”Wheel/rail contact forces for flexible versus solid wheels due to tread irregularities”, Vehicle System Dynamics, 23(S1),142–157, 1994.

[7] M. Fermér, J.C.O. Nielsen, ”Vertical interaction between train and track with soft and stiff railpads – Full-scale experiments and theory”, Proceedings of the Institution of Mechanical Engineers, Part F Journal of Rail and Rapid Transit, 209, 39–47, 1995.

[8] R.V. Dukkipati, R. Dong, “Impact loads due to wheel flats and shells”, Vehicle System Dynamics, 31, 1–22, 1999.

[9] A. Johansson, J.C.O. Nielsen, “Out-of-round railway wheels – Wheel–rail contact forces and track response derived from field tests and numerical simulations”, Proceedings of the Institution of Mechanical Engineers, Part F Journal of Rail and Rapid Transit, 217, 135–146, 2003.

[10] M. Asplund, P. Söderström, “Detector response from a defective wheel”, Wear, 542–543, 205282, 2024.

[11] A. Pieringer, W. Kropp, J.C.O. Nielsen, ”The influence of contact modelling on simulated wheel/rail interaction due to wheel flats”, Wear, 314, 273–281, 2014.
[12] T. Snyder, D.H. Stone, J. Kristan, ”Wheel flat and out-of-round formation and growth”, Proceedings 2003 IEEE/ASME Joint Rail Conference, Chicago IL, USA, 143–148, April 2003.
[13] Trafikverket, “Detektorer – Krav vid val av detektorplats”, (”Detectors – Regulations for specification of detector position”, in Swedish), TDOK 2013:0689 v3.0, 2020.
[14] Trafikverket, “Detektorer; förutbestämt underhåll detektoranläggningar i spårmiljö järnväg”, (”Detectors; regulations on maintenance for detectors in railway track”, in Swedish), TDOK 2019:0478 v1.0, 2019.
[15] UIC, “Prevention and mitigation of derailment (PMD)”, IRS 70729, 2019.
[16] M. Asplund, “Larmnivåer hjulskadedetektor”, (”Alarm levels for wheel impact load detector”, in Swedish), Trafikverket, TRV 2020:96962 v 4.0, 2023.
[17] K. Mattsson, “Wheel–rail impact loads generated by wheel flats – Detector measurements and simulations”, MSc thesis, Department of Mechanics and Maritime Sciences, Chalmers University of Technology, Gothenburg, Sweden, 53 pp + Appendices, 2023.
[18] J.C.O. Nielsen, E.G. Berggren, A. Hammar, et al., ”Degradation of railway track geometry – Correlation between track stiffness gradient and differential settlement”, Proceedings of the Institution of Mechanical Engineers, Part F Journal of Rail and Rapid Transit, 234(1), 108–119, 2020.