Proceedings of the Sixth International Conference on
Railway Technology: Research, Development and Maintenance
Edited by: J. Pombo
Civil-Comp Conferences, Volume 7, Paper 11.10
Civil-Comp Press, Edinburgh, United Kingdom, 2024
ISSN: 2753-3239, doi: 10.4203/ccc.7.11.10

Assessment of Safety Against Derailment using Simulations and the Simplified Method of EN 14363 Standard

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Abstract

This work proposes the application of the simplified method comprised in the European standard EN 14363 as an indicator to assess the safety against derailment of railway vehicles using acceleration data from an on-board system. This approach is applied to a railway vehicle through numerical simulations with a Multibody model and a sensitivity analysis for different track irregularity scenarios in accordance with the levels established by European Standard EN 13848-5. The results show good sensitivity of the vehicle's responses to the different track irregularity scenarios, with higher acceleration values for higher peak values of track irregularities. In the most severe scenario, corresponding to the safety limit, in all simulations the vehicle derails. Finally, it is concluded that speed reduction is an effective measure to mitigate high acceleration amplitudes, thus promoting railway safety. In short, the preliminary results presented in this work showed the potential of this simplified method to be used as an indicator of track quality and consequently assist railway operators in guaranteeing traffic running safety.

Keywords: simplified method, European standard EN 14363, derailment of railway vehicles, on-board system, Multibody model, track quality, running safety.

1 Introduction

The railway sector plays an increasingly important role in society and traffic safety, with maintenance currently being a main concern for railway operators and infrastructure administrations. The railway industry has always been aware of the critical importance of defect detection and maintenance for ensuring its infrastructure's safe and reliable operation [1].

In most situations, track maintenance methods still rely on corrective and time-based preventive interventions. Such interventions may lead to the replacement of fully functional components just because they reached their theoretical life-cycle, even if their real condition state would allow them to be operational for more years [2]. Most of the methods to assess the track condition are based on Track Quality Indices (TQIs) which summarize a track section's quality. These indices are used to develop track degradation models to predict different types of track defects [3, 4].

Currently, the main monitoring systems used are on-board, which consist on installing the sensors on service trains or even on dedicated track inspection vehicles [5-7]. It is possible to use different types of measuring devices at the same time, for example accelerometers and GPS, making it possible not only to detect defects, but also to locate them in real time. Also, recent developments on sensing technologies and data analytics techniques open the possibility to identify track defects using this approach, where the measurement system is distant from the infrastructure, and under complex operational and environmental conditions [8].

This work proposes the assessment of the safety against derailment by applying the simplified method defined in the European Standard EN 14363 [9] , which allows limits to be set on the acceleration responses measured by sensors from an on-board monitoring system. This indirect monitoring has the advantage of making it possible to assess the condition of the track over long distances using a single monitoring system installed on the railway vehicle. This approach is applied to a railway vehicle through numerical simulations with a Multibody model and a sensitivity analysis for different track irregularity scenarios in accordance with the limits established by European Standard EN 13848-5 [10].

2 Condition assessment according EN 14363

The requirements for safety against derailment tests are defined in the EN 14363 [9] standard. According to it, the assessment of the running safety is based on the evaluation of the performance of the vehicle while running on the track. For this evaluation two different methods can be followed: (i) normal and (ii) simplified measuring method. The simplified method differs from the normal method in that no wheel-rail forces are measured, only accelerations on bogie and vehicle body. The simplified method is based on the quantities shown in Table 1.

Designation	Quantities	Location
$a_{bogie,y}$	Lateral acceleration in bogie frame [m/s^2]	Bogie frame above each wheel
$a_{body,y}$	Lateral acceleration in vehicle body [m/s^2]	Vehicle body above each running gear
$a_{body,z}$	Vertical acceleration in vehicle body [m/s^2]	

Table 1: Simplified measuring method: quantities to measure.

This standard outlines a minimum sample frequency of 200 Hz for the measuring signals and the processing of a low-pass filter with a cut-off frequency value according to each quantity, as shown in Table 2. Then, the results are compared with the limit values established in the standard for each measuring quantity. Table 2 presents the limit values for running safety assessment of vehicles with bogies.

Quantity	Filtering	Limit value
$a_{bogie,y}$	Low pass filter 10 Hz	12 - (m_{bogie}/5tons) [m/s^2]
$a_{body,y}$	Low pass filter 6 Hz	3.0 [m/s^2]
$a_{body,z}$	Band pass filter 0.4-4 Hz	5.0 [m/s^2]

Table 2: Simplified measuring method: filtering and limit values for running safety assessment.

3 Case Study

3.1 Vehicle model

The studied vehicle is constituted by two platforms connected by a Talbot Type articulation and is supported by three Y25 bogies: two at the end of each platform and the third below the articulation.

The multibody model was developed in commercial software Simpack [11] (see Figure 1), which allows the evaluation of the dynamic behaviour of the vehicle model by solving the equations of motion in three dimensions. The modelling of the connection between bodies is carried out through joints or constraints.

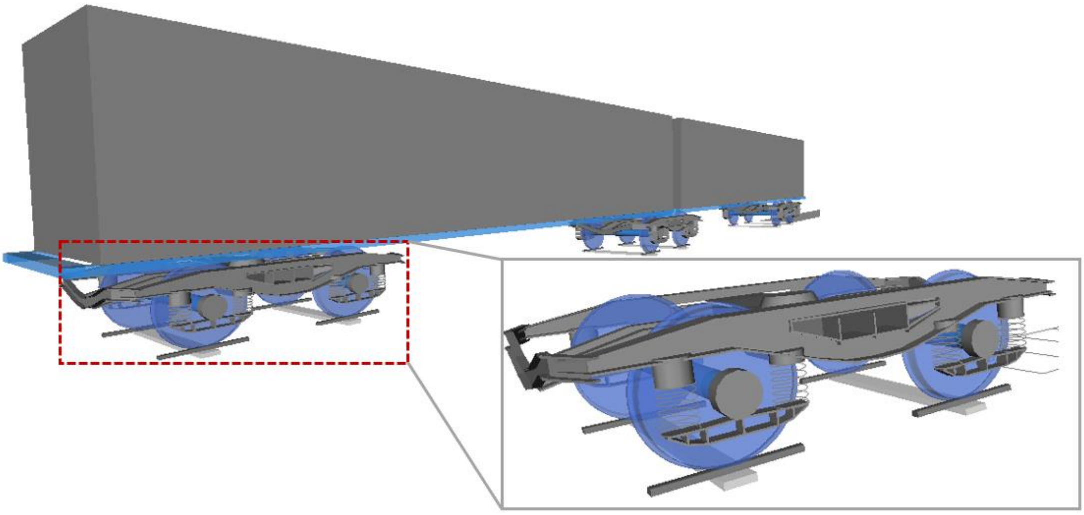

Figure 1: Vehicle multibody model full load and bogie detail.

The suspension system for each axlebox comprises four springs arranged in two pairs, consisting of internal and external springs (Figure 2). The concentric side pair, which includes a Lenoir link, is compressed between the spring cap and the axlebox. The other pair of springs directly connects the bogie frame to the axlebox.

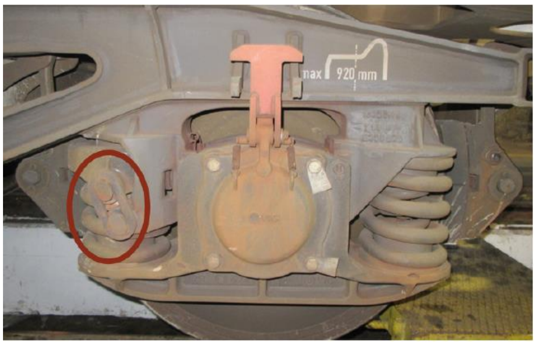

Figure 2: Y25 bogie with Lenoir link highlighted.

Regarding the spring behaviour, the vertical stiffness values are derived from a benchmark analysis conducted in a D-Rail project report [12], whereas the shear stiffness is based on the literature from a study by J. Pagaimo [13]. Table 3 presents the stiffness parameters for each pair of springs for a 22.5 ton/axle. The multibody model includes a force element called the Shear Spring Component, which describes a helical spring with coupled shear forces and bending torques. This component is applied along the z-axis (vertical variable).

A Spring-Damper Parallel Component is used to limit the lateral and longitudinal motion of the axlebox relative to the bogie frame and a non-linear Friction component to simulate the friction surfaces. The vehicle's three bogies are connected to the vehicle body by a central plate and two elastic side bearers functioning as secondary suspension. The stiffness parameters of centre plate and side bearers are presented in Table 3.

Direction	Adopted Value				Unit
	Outer spring	Inner spring	Centre plate	Side bearers	
k_x	469	555	60000	-	[N/mm]
k_y	469	555	60000	380	[N/mm]
k_z	997	1557	60000	570	[N/mm]

Table 3: Primary and secondary suspension stiffness values for 22.5 ton/axle bogie.

The articulation between the two platforms is represented by a universal connection with freedom of movement in the yaw and pitch axis. It is essential to guarantee freedom in these directions to avoid derailing the vehicle or breaking the articulation. Furthermore, it is considered an almost negligible stick and slip Coulomb friction law.

3.2 Track model

The track model has a total length of 1500 m and consists of two straight sections of 500 m and 300 m at the beginning and at the end, respectively, with a middle section of 300 m in curve with an 800 m radius. The transition from straight to curve is performed by a clothoid with a 200 m length. In Figure 3, the track layout is represented, including the scales and radii of both the transition and circular curves.

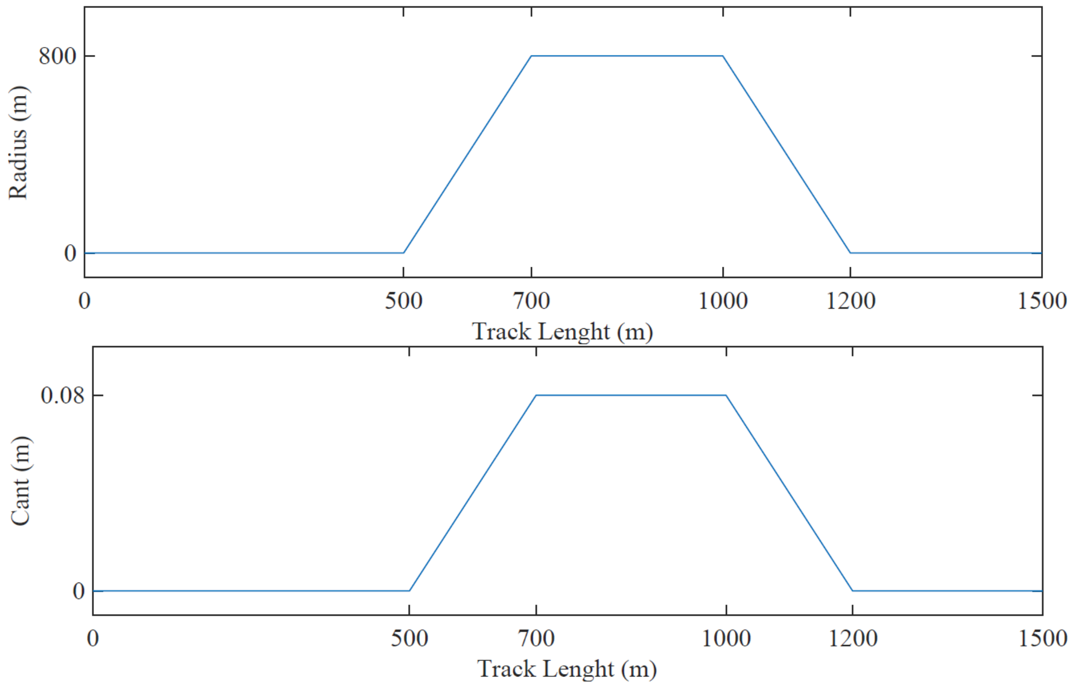

Figure 3: Top view of track layout.

Rail unevenness profiles are generated for wavelengths between 3 m and 25 m, corresponding to wavelength interval D1 defined by the European Standard EN 13848-2 [14]. Therefore, PSD curves are developed to generate artificial unevenness profiles. According to the European Standard EN 13848-5 [10] three main levels must be considered for assessing track quality: (i) safety, (ii) intervention, and (iii) alert limits. Depending on speed, the standard indicates the range of values for track longitudinal level and alignment in each of the scenarios. The adopted values are shown in Table 4.

*Values in mm.

Speed (km/h)	Safety limit		Intervention limit		Alert limit	
	Long.	Align.	Long.	Align.	Long.	Align.
$V \leq 80$	29	22	18	15	15	13.5
$80 \leq V \leq 120$	26	17	16	12	13	9.5

Table 4: Adopted mean peak values for longitudinal level and alignment based on EN 134848-5 [10].

Aligned with these assumptions, four different scenarios for rail unevenness are considered: good quality, alert, intervention, and safety. Figure 4 shows an example of four longitudinal level and alignment profiles for each scenario considering a range of speed between 80 and 120 km/h. For the good quality condition track the irregularity is generated based on experimental measurements (Mosleh et al. [15]), where the mean peak value for longitudinal level and alignment are 2.5 and 2 mm, respectively.

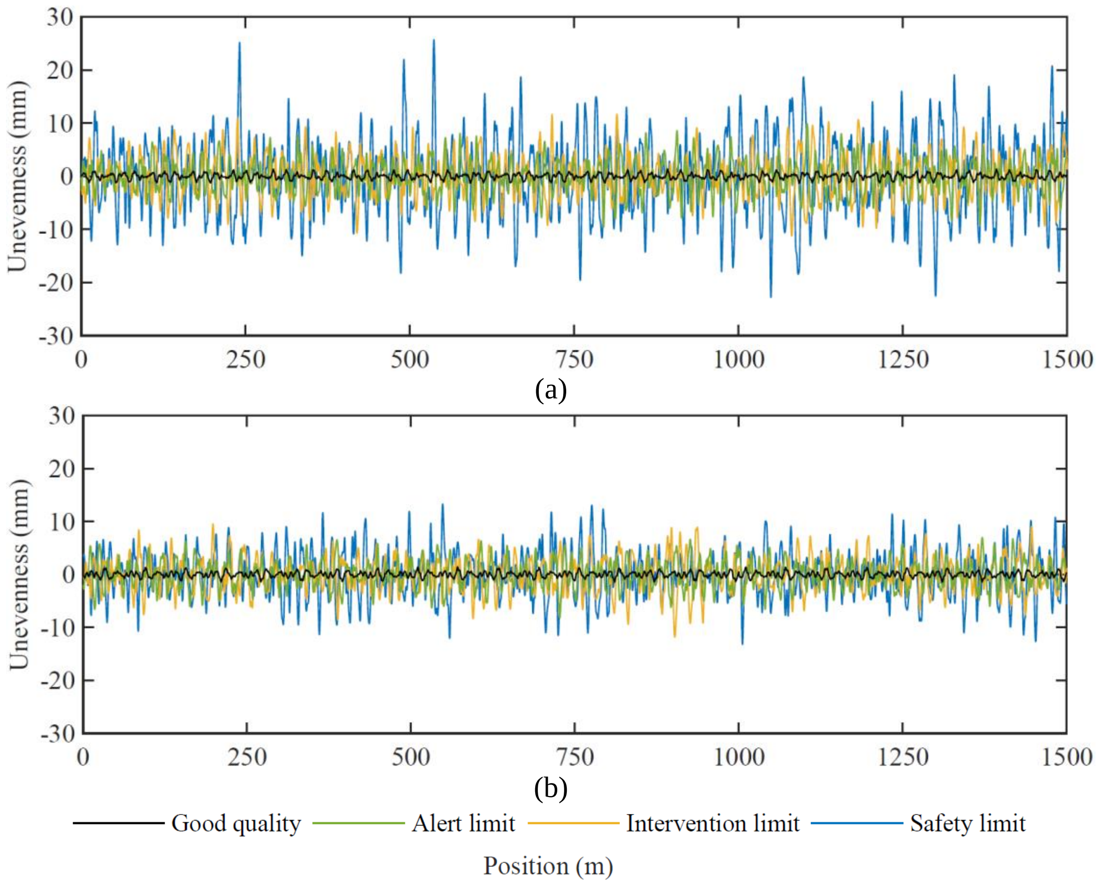

Figure 4: Track irregularity profiles: (a) longitudinal level, (b) alignment.

3.3 On-board system layout

A conceptual on-board monitoring system is defined to assess vehicle accelerations resulting from the passage of the train on a track considering the four different levels of irregularities. EN 14363 [9] requires the instrumentation of a bogie and the vehicle body above the bogie. Thus, choosing to position the sensors in the centre bogie has the advantage of instrumenting both vehicle bodies. In this sense, the accelerations are evaluated through four sensors positioned on the central bogie aligned with the wheels (B1 and B2) and on the vehicle body above the running gear (C1 and C2), as depicted in Figure 5. Furthermore, the accelerometers B1 and B2 are unidirectional (y-direction) and accelerometers C1 and C2 are bidirectional (y and z-directions).

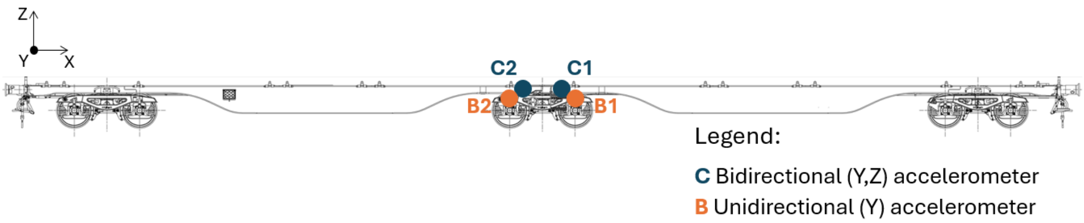

Figure 5: On-board monitoring system layout.

4 Results

The acceleration signals obtained from the on-board system are sampled at a frequency of 200 Hz for all vehicle simulations. Then, these numerical accelerations are filtered according with the EN 14363 guidelines and presented in Table 2: For the y-direction accelerations evaluated on the bogie and vehicle body, 4th order Butterworth low-pass filters with cut-off frequencies of 10 Hz and 6 Hz are applied, respectively; For the z-direction accelerations evaluated on the vehicle body, a 4th order Butterworth band-pass filter with cut-off frequencies between 0.4 and 4 Hz is applied.

Figure 6 shows the filtered acceleration responses obtained with a full load vehicle running at a speed of 100 km/h. The graphs show the different levels of track irregularities considered in the analyses and the limits defined by EN 14363 [9] marked by a red line. In general, the peak acceleration values measured on the vehicle increase with increasing track irregularity amplitudes and vehicle speed. In Figure 6a, the accelerations in the y-direction on the bogie are evaluated for sensor B2, while in Figure 6b and c, the accelerations in the y and z-direction are evaluated for sensor C2. For the track with good quality irregularities, the acceleration values are well below the normative limits for all sensors, which is a good result as no false alarm will prompt in these conditions. Analysing the graphs for the accelerations in the y-direction, in general the responses do not reach the normative limits, only occasionally for the safety limit scenario. On the other hand, a higher sensitivity is observed for the z-direction responses in the vehicle body (Figure 6c), where the amplitude of the accelerations successively exceeds the normative limit for the alert, intervention and safety limit scenarios. For the safety limit scenario, the vehicle derails in the curved section of the track, long after the accelerations have reached the limit for the first time.

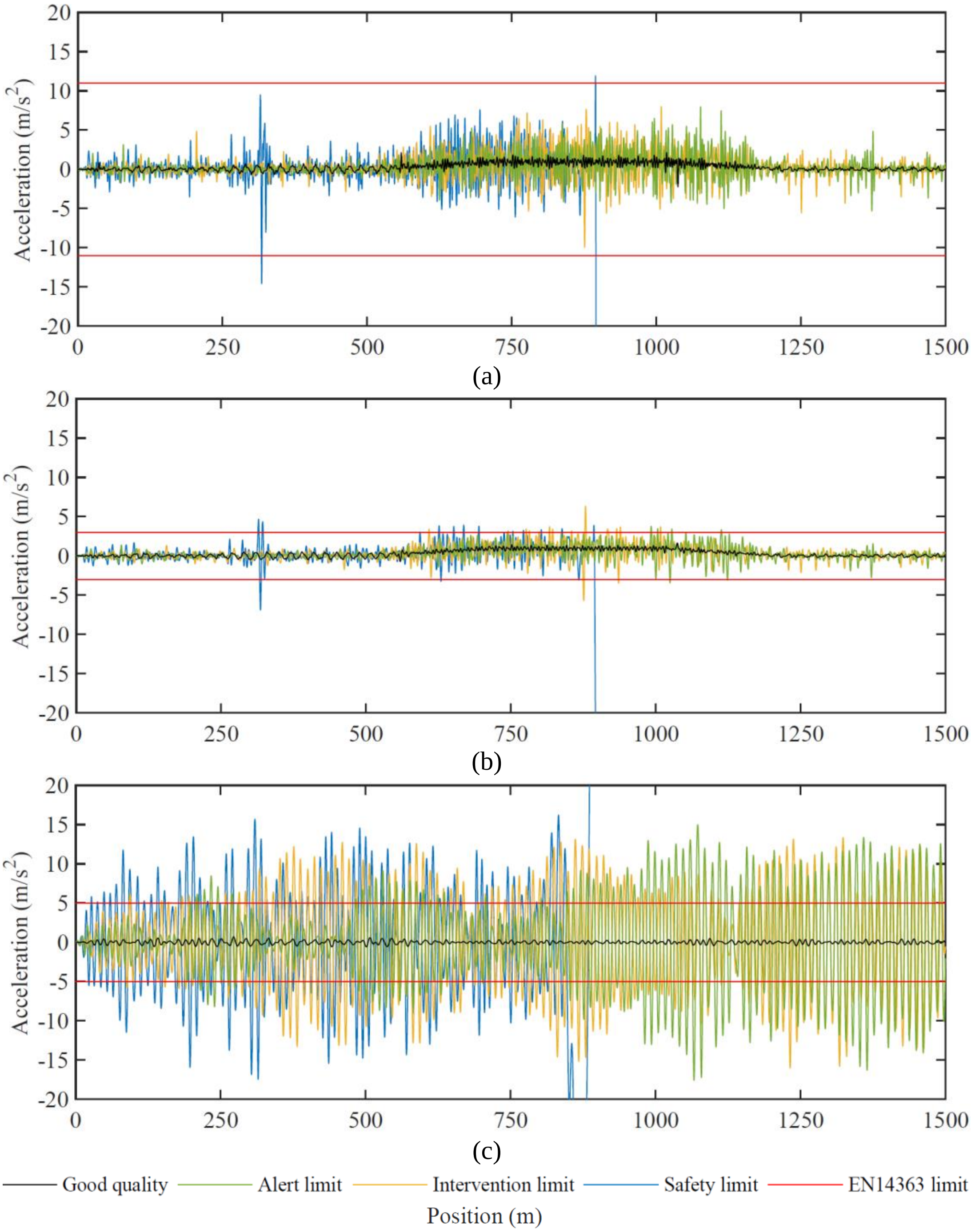

Figure 6: Acceleration time-series for 100 km/h: (a) bogie, (b) vehicle body y-direction., (c) vehicle body z-direction.

To mitigate the high accelerations observed in Figure 6, simulations were carried out considering a lower speed of 60 km/h. Figure 7 shows the acceleration responses evaluated for the same sensor positions, now considering this new speed. The results clearly show that the acceleration peaks for all track irregularity scenarios are considerably lower than those recorded for a speed of 100 km/h. Furthermore, only in the safety limit scenario do the accelerations in the vehicle body occasionally exceed the normative limit in the z direction (Figure 7c). Nonetheless, the vehicle does not derail.

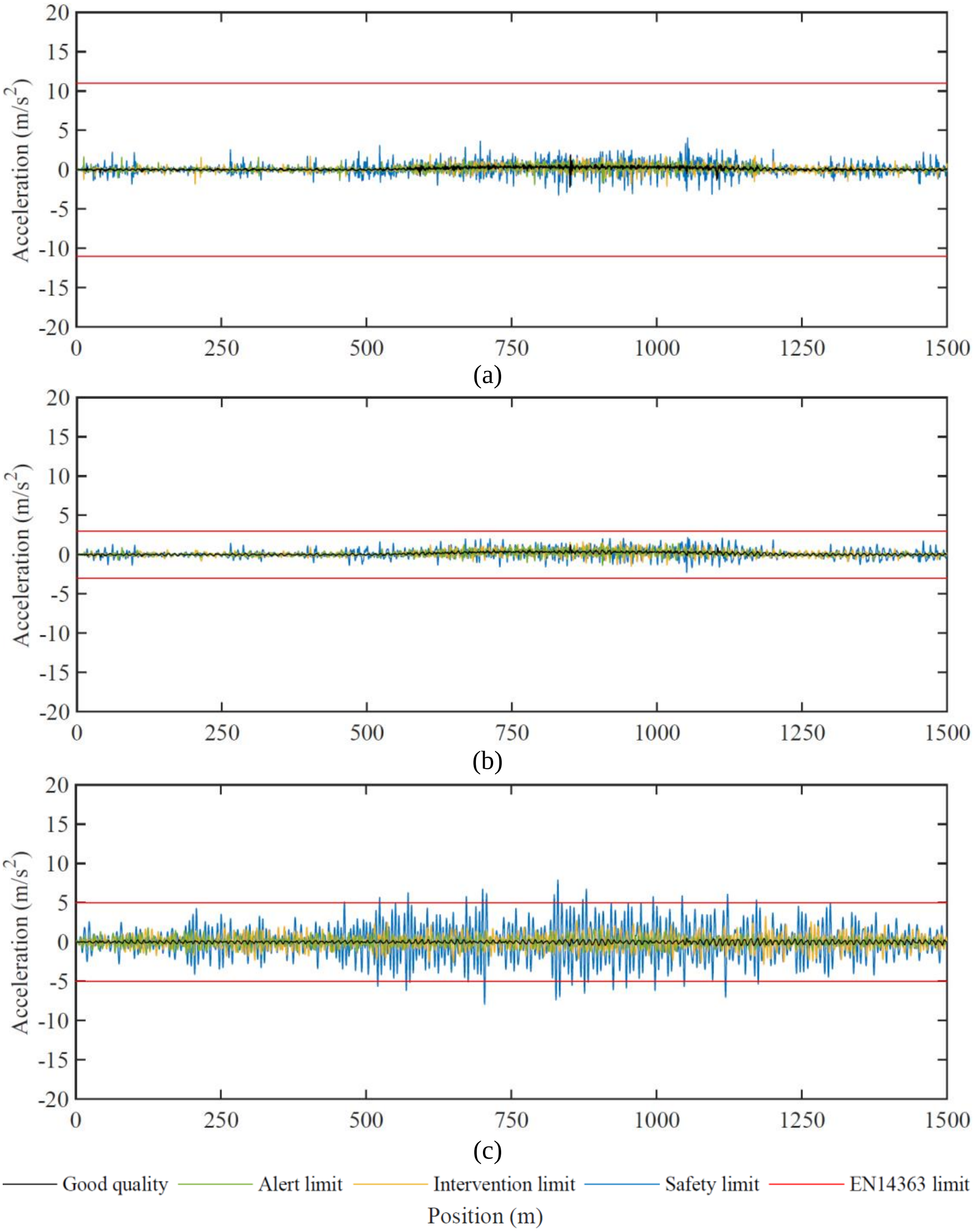

Figure 7: Acceleration time-series for 60 km/h: (a) bogie, (b) vehicle body y-direction, (c) vehicle body z-direction.

5 Conclusions

In this work, the application of the simplified method presented in the European standard EN 14363 [9] is proposed as an indicator to assess the running safety of railway vehicles using acceleration data from an on-board system. For this purpose, a multibody model of a railway vehicle is evaluated through numerical simulations considering speeds of 100 km/h and 60 km/h and different levels of irregularity are introduced to simulate the normative limit scenarios of alert, intervention, and safety. Additionally, a scenario of good track condition is also considered for comparative means.

The results show good sensitivity of the vehicle's responses to the different track irregularity scenarios, with higher acceleration values observed for higher peak values of track irregularities. For the track with good quality irregularities, the acceleration values are well below the normative limits for all sensors, which is a positive result as no false alarm will prompt in these conditions. For a speed of 100 km/h, the accelerations consecutively exceed the normative limit along the entire track section, for all three limit track scenarios. In the most severe scenario, corresponding to the safety limit, the vehicle derails. Nevertheless, the acceleration values exceed the normative limit long before the derailment occurs, providing an early warning before the event.

The results obtained for a speed of 60 km/h show a significant decrease in acceleration peaks for all track irregularity scenarios, lying below the normative limits. These limits are exceeded occasionally in the z-direction of the vehicle body for safety limit scenario, but without derailment. This shows that the speed reduction is an effective mitigation measure to limit the impact of the track condition on vehicle running safety.

In short, the preliminary results presented in this work show the potential of this simplified method to be used as an indicator of track quality and consequently assist railway operators in guaranteeing traffic running safety. Further testing and validation of the proposed methodology are to be conducted through additional scenarios and experimental tests based on real on-board measurements.

Acknowledgements

The authors would like to acknowledge the support of the Agenda "PRODUCING RAILWAY ROLLING STOCK IN PORTUGAL", nr. C645644454-00000065, investment project nr. 55, financed by the Recovery and Resilience Plan (PRR) and by European Union - NextGeneration EU.

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