The Noise of Rail Transport

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M Cavacece[1]

[1] University of Cassino and Southern Lazio, Department of Civil and Mechanical Engineering, Via G. Di Biasio, 43 Cassino (FR) Italy

E-mail: cavacece@unicas.it

Abstract. The research examines the sources of rail transport noise. Noise depends on the type of locomotives, warning signals, maintenance, and construction equipment. The wheel–to–rail contact of the rolling stock and the locomotives' propulsion systems are the noise sources. Static and dynamic loads have intensities that depend on the masses and speeds of the trainsets. In addition, static, dynamic loads of the rolling stock, thermal loads, and the action of rainwater stress the ballast. The stresses lead to tensions on the rail that can affect fatigue, wear and tear, and railway line maintenance. Fatigue and wear are related to the intensity of traffic rail traffic, developing an abrasive action of the wheels on the rail and contributing to rail–to–rail misalignment concerning the underlying ballast.

Keywords: Sources of noise, Prediction, Noise control, Impact, Frictional instability, Railway degradation, Detection, Maintenance

1. Introduction

The railway line is subject to spatial stresses generated by the vehicle, the seasons' temperature fluctuations, and the water's washout actions on the ballast beneath the rail [1]. The vehicles impose static and dynamic loads. The magnitude of the external load depends on the mass and speed of the trains [2]. The weight per axle, the primary suspension's high rigidity, and the engines' unsprung masses, brake discs, and bushings represent the vehicle's dynamics. The thermal stresses depend on the temperature differences between those imposed by the seasons and those of the track [3]. The static and dynamic loads of the rolling stock act on the ballast. The action of rainwater increases the rails' free deflection length and changes the track's stiffness. The stresses cause tensions on the railway that can affect fatigue, wear and tear, and maintenance of the railway line. Average operating speeds of the traffic intensity influence fatigue and wear parameters [4]. Traffic speeds and intensities affect fatigue stress and cycles, the abrasive action of the wheels on the railway, and the misalignment of the rail–track complex to the underlying ballast. A global investigation examines the parameters that limit the life of the railway line.

2. Weighted sound level prediction

The weighted sound level L_A takes on distinct expressions in the case of welded and bolted tracks. In the case of the welded track, the acquisitions of the A-weighted sound levels L_A depend on the speed of the passenger carriages, normalized to the distance and length of the train. The 90% of the measurements are between $\pm 6dB$ with respect to the following relation:

$$L_A \text{ normalized} = 74 + 30 \log \frac{v}{v_0} \quad [dB(A)] \tag{1}$$

where v is the speed of the carriage in km/h and v_0 is a reference speed of 60 km/h. Doubling the train's speed increases the A-weighted sound level by 9 dB(A) (Fig.1).

The 90% of the measurements of weighted sound levels, normalized A–scale, for passenger carriages on bolted track, meets the following relation with a tolerance of $\pm 6dB$:

$$L_A \text{ normalized} = 81 + 30 \log \frac{v}{v_0} \quad [dB(A)] \tag{2}$$

The noise of the railway system depends on the type of car–cars, locomotives, warning signals, freight storage depots, and maintenance and construction equipment. The wheel-to-rail contact of rolling stock and the propulsion systems of locomotives are noise sources.

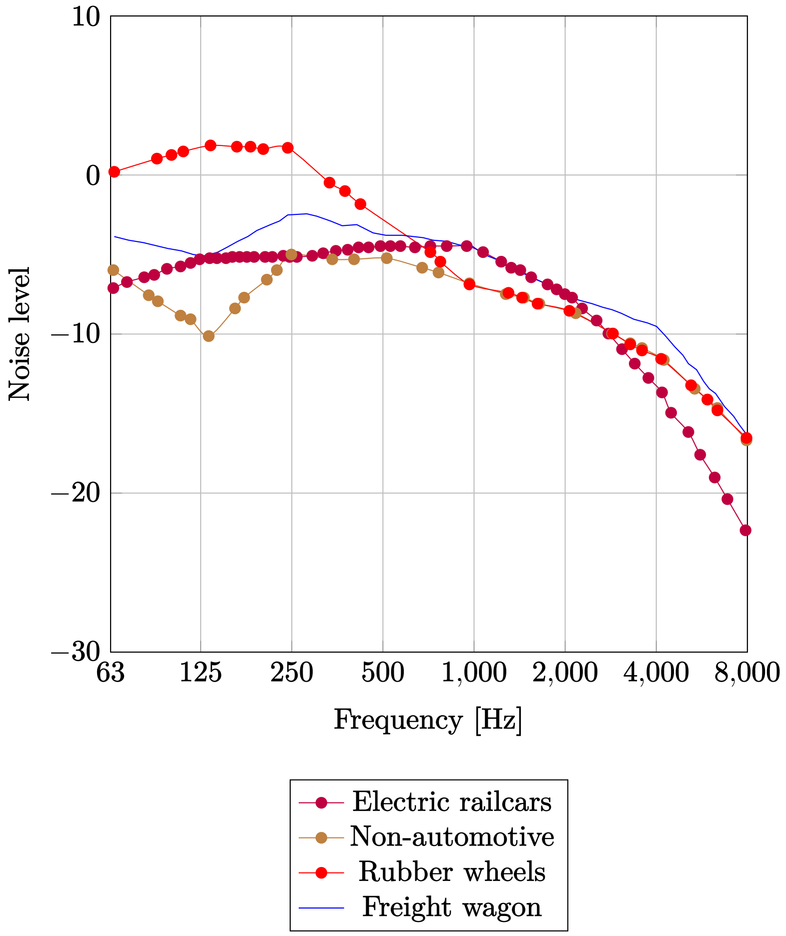

Figure 1. Octave band spectra for open–air transit wagons

3. Results

The experimental investigation was carried out on the Italian railway network with a SVAN 979 sound level meter with a wide dynamic measuring range over 110 dB. The high–quality GRAS 40AE microphone allows measurement in the frequency range from 3 Hz.

3.1. Noise produced by wheel–rail contact

The leading cause of noise for rail cars is the interaction between the wheels and the track over a wide speed range. The noise of railway carriages depends on the play in the wheel and track contact and the surface roughness of the rail and the wheel. Railway carriages ran on smooth wheels and welded tracks (without joints), emitting a broadband noise called rolling noise. The choice of continuous welded track avoids noise due to joints. The joints of the railway must be smooth and tight. Grinding new rails at the end of production removes iron oxide. Wear generates roughness on rails and wheels. Roughness increases the A–weighted sound level. Roughness develops on the contact surface of the track in the vicinity of curves. The wheel is subject to a periodic excitation generated by the roughness. The periodic excitation produces higher A–weighted sound levels than those caused on a smooth track. The wheels may exhibit localized flattening if the carriages travel over discontinuities in the track surface and track joints. The noise produced by wheel-track contact presents a succession of broadband impact sounds with a rise time of 0.01 s and a duration of 0.05 s. Current braking systems minimize wheel flattening to prevent wheel slip. It needs to remove roughness on the wheels.

3.2. Noise levels generated by carriages travelling on straight–line tracks

Directionality, used to characterize noise sources, is critical in the case of large, moving sources such as locomotives and engines. The A–weighted sound level for a train pulled by a locomotive presents a maximum generated by the locomotives and a lower average value caused by the noise of the wagons. The time course of the A–weighted sound level during the 30 m passage of a locomotive-driven passenger train traveling at 114 km/h has two maximum values. The locomotives cause the first maximum at 94 d(A), and the floating wagons generate the second maximum at 86 dB(A) (Fig.2).

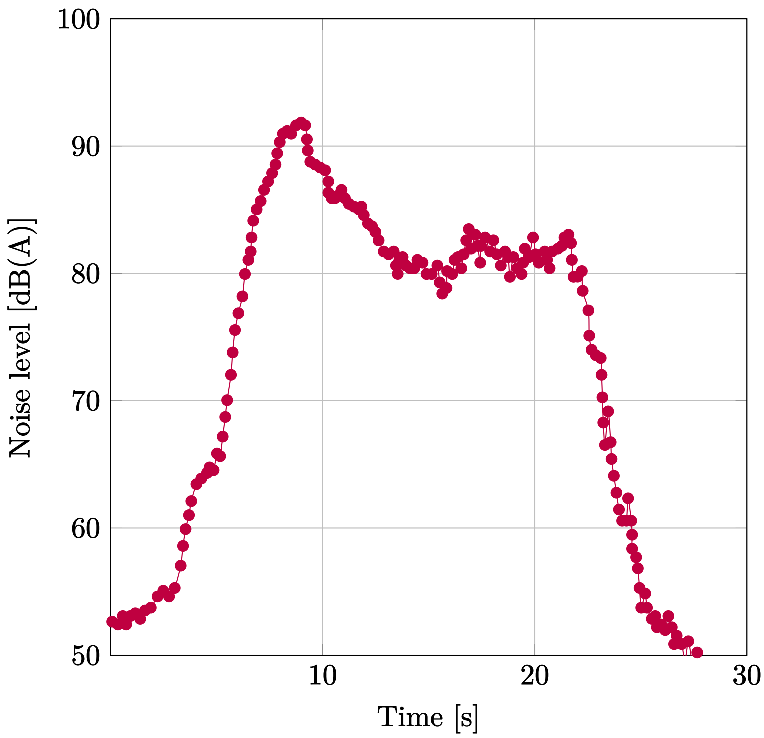

Figure 2. Time course of the A–weighted sound level during the passage at 30 m of a passenger train pulled by a locomotive traveling at 114 km/h

3.3. Noise levels generated by carriages travelling on curved tracks

The spectrum represents the peak values in the frequency domain of the noise emitted by a rail car traveling on a 43 m curve (Fig.3). The noise of carriages traveling on curved tracks with a radius of less than 100 m is a screech of one or more pure tones (Fig.4). The noise produced on curved tracks presents pure tones. The characteristic feature of the spectrum of this squeak is the presence of high peaks.

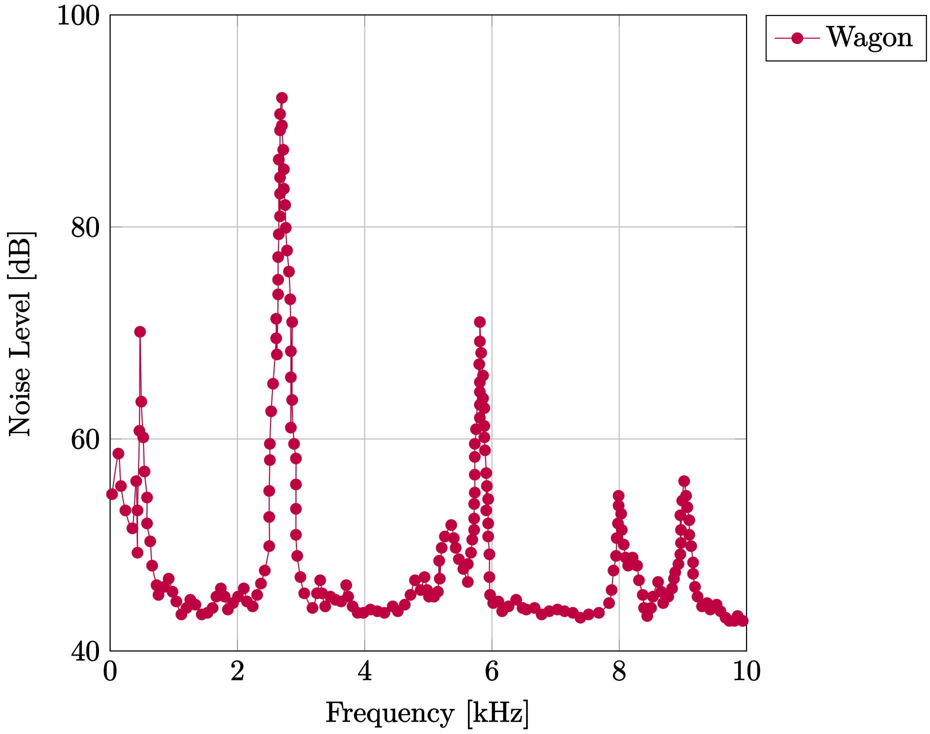

Figure 3. Spectrum taken from a wagon in transit on an urban railway as it passes through a curve with a radius of 43 m

3.4. Noise levels and noise spectra for locomotives and passenger carriages

The sources of noise generated by the propulsion system include the traction motor, the traction motor's air cooling system, and the air conditioning system. Aerodynamic noise due to the motion of the vehicle does not contribute significantly. Electric turbine locomotives produce sound levels 6–7 dB (A) lower than electric–diesel locomotives without silencers. The noise of the exhaust is the dominant source. This noise is not speed-dependent. Silencers can reduce the A–weighted sound level of the exhaust noise by about 10 dB (A). Silencers on diesel-electric locomotives generate a reduction of 4–8 dB(A). Engine vibrations and cooling fans are sources of noise. The Fig.5 shows the octave-band spectra for electric–diesel locomotives relative to the A-weighted sound level.

The Fig.6 shows the comparison of noise spectra inside six passenger carriages. The Fig.7 proposes the comparison of noise spectra between inside underground and high–speed train. The highest noise levels occur in the 0–125 Hz range.

3.5. Noise level generated by trains passing through tunnels

The noise reaches the buildings adjacent to the underground tunnel, producing noise within

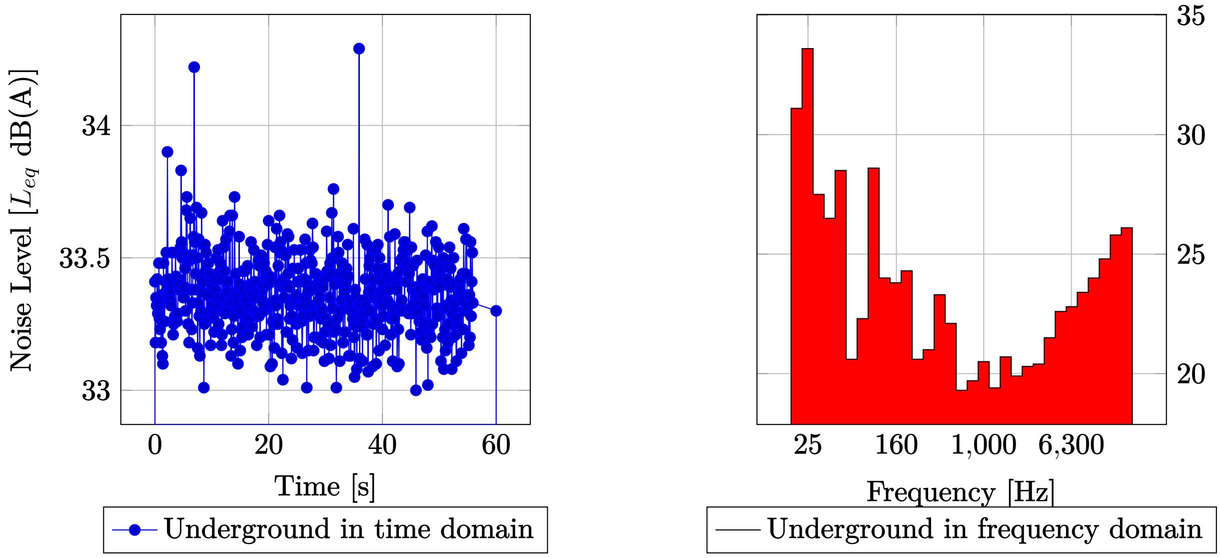

Figure 4. Underground on a curve with a radius of 40 m

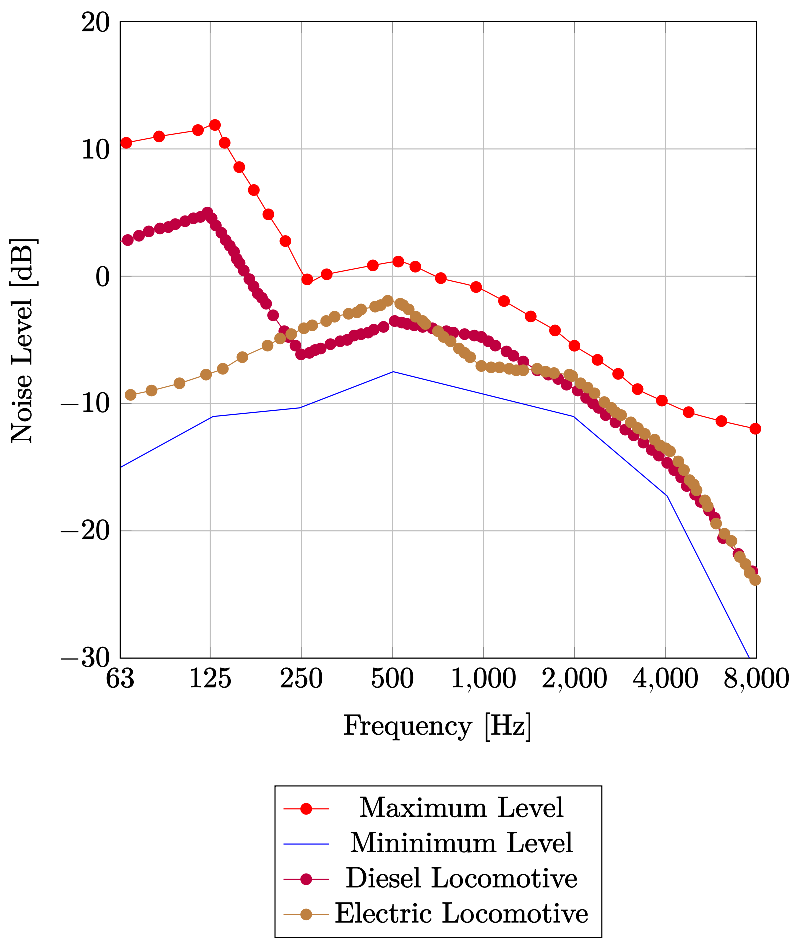

Figure 5. Octave–band spectra of locomotives in open–air transit

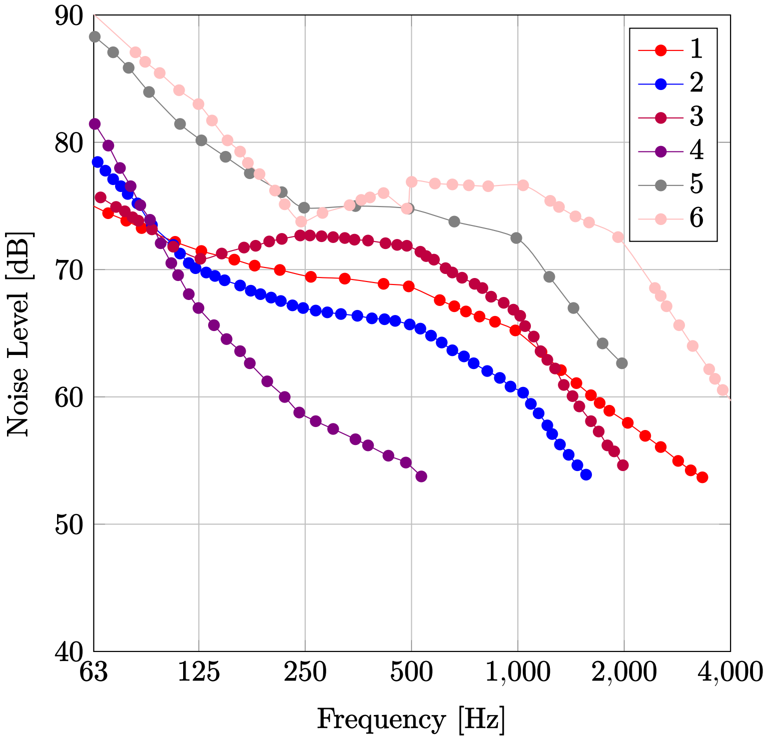

Figure 6. Comparison of noise spectra inside six passenger carriages

the buildings. The train and the track interaction generates vibrations transmitted to the tunnel structures and the surrounding ground. The pulse propagates through the bottom to the adjacent buildings, causing the floors and walls to vibrate and producing secondary noise radiation into the rooms. Due to structure–borne noise from the passing train, the noise level can be heard before vibration levels (Fig. 8).

3.6. Noise in Stations and Tunnels of Urban Rail Transport

Fig.9 illustrates a typical time domain recording of the A–weighted sound level measured on a platform with a train entering the station. The train stops and then starts again. Noise sources during train entry and departure include wheel/track contact, mechanical braking, air pulses released by the braking system, door opening and closing operations, air conditioning, and the train's auxiliary systems.

The Fig.10 shows the average values of octave–band spectra of local trains expressed for a set of stations and underground tunnels. During normal outdoor and tunnel operations, a-weighted sound levels in underground trains reach 65–105 dB A. This amplitude is due to track construction and maintenance differences, carriages, and speed. The Fig.11 illustrates the A–weighted sound levels inside steel–wheeled and open–air metro trains as a speed function.

3.7. Noise Control in Stations

Sound–absorbing treatments and barriers minimize the airborne reflected noise generated by the wheel–to–rail contact. Underground stations, characterized by sound-absorbing treatment and rails with beams and gravel, present 5 to 15 dB(A) lower A–weighted sound levels than stations without stone. A sound-absorbing ceiling above the station platform reduces the A–weighted sound level by 5 to 10 dB(A) compared to stations without sound-absorbing treatment. The

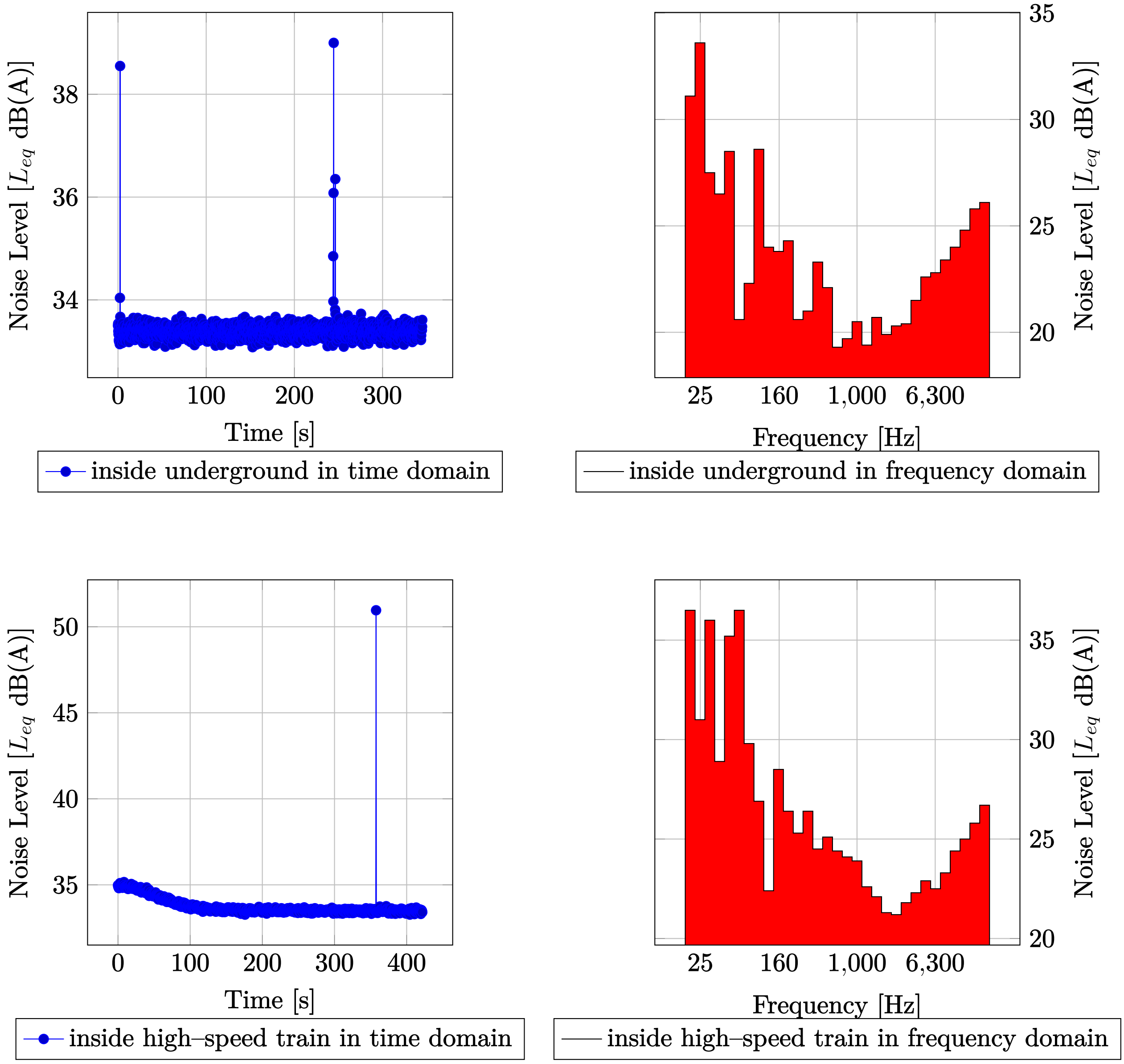

Figure 7. Comparison of noise spectra between inside underground and high–speed train

ballast can be located near noise sources, offering considerable sound absorption (Fig.10).

4. Discussion

4.1. Noise produced by wheel–rail contact

The sliding and rolling of the wheels on the tracks generate noise in curves. Sliding occurs for the following reasons:

- The two–axle carriage keeps its axles parallel. If the carriage goes around a bend, the wheels run perpendicular to the rolling direction;
- The outer wheel travels more distances than the inner wheel during the curve. The wheels, connected to the same axle, describe the same arc but different travel lengths. The difference generates a sliding of the wheel according to the rolling direction.

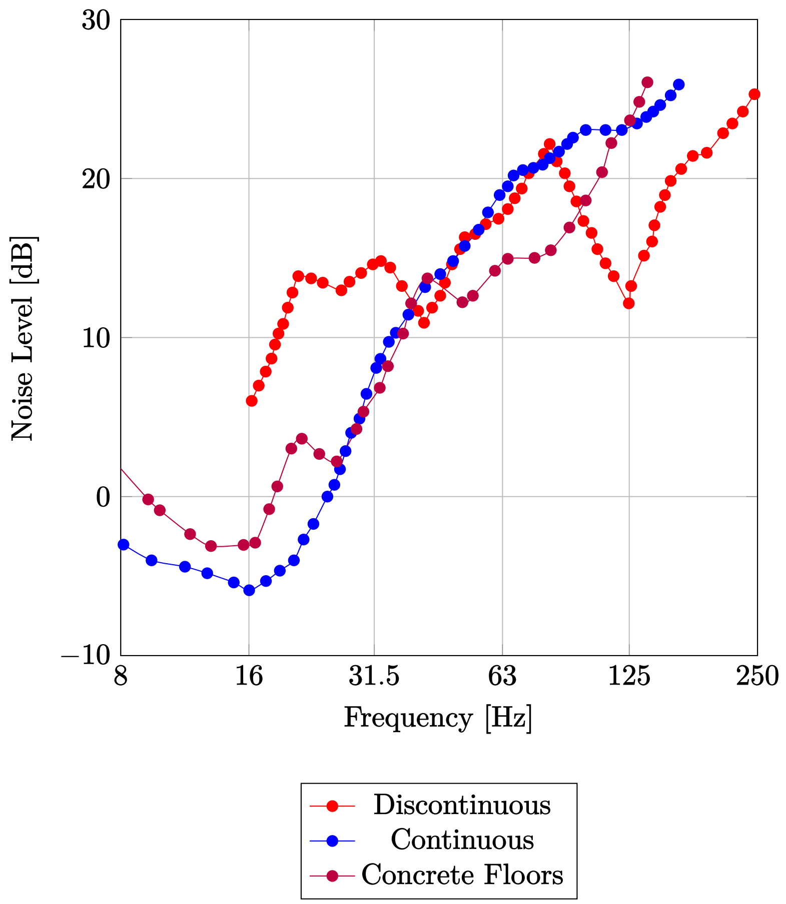

Figure 8. The difference in noise levels for continuous, concrete floors, and concrete floors

- The wheel flange can touch the rail in sharp bends.

The squeal generation depends on the radius of the curve, the vehicle's speed, the geometry, the wagon's stiffness, the wheel's damping, and the friction characteristics of the contact surfaces. The dominant excitation frequencies should not correspond to the natural frequencies of the wheels in contact with the track to avoid significant amplitude vibrations corresponding to a mode of vibration of the wheel. The vibrating surfaces radiate the sound. The damping can control the squeal in curves. The following approaches are available:

(i) Damping using an elastic ring which fills a groove inside the wheel hub;
(ii) Damping with compressed material layers;
(iii) Resilient wheels of elastomeric material between steel hub and stem.

These approaches result in a significant reduction of the sound pressure level.

Noise control methods other than damping include the following:

- Construction of bends with a radius greater than 100-150 m;
- Use of radial carriages with axles according to the radii of the curve instead of running parallel;
- Lubrication of the wheel flange in contact with the rail.

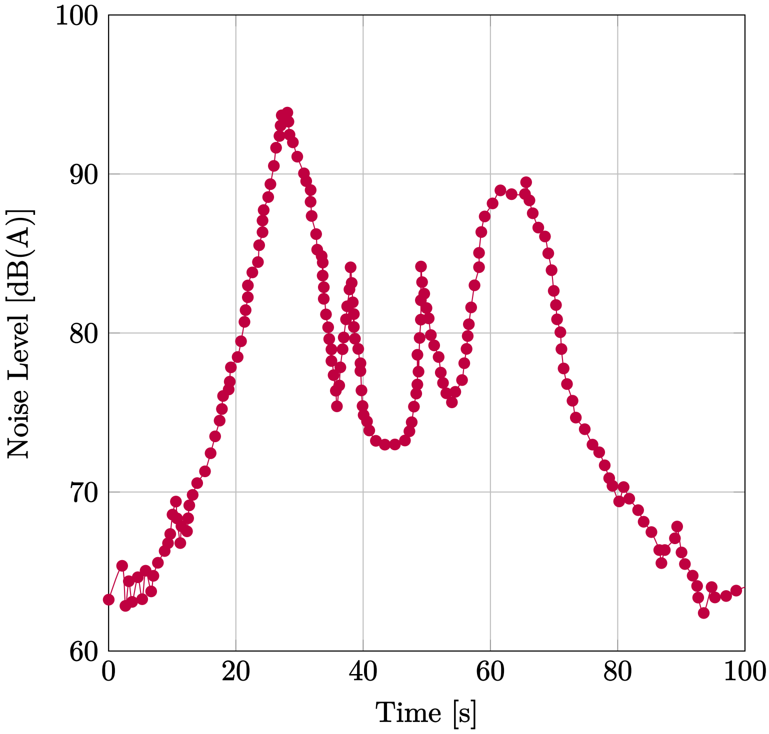

Figure 9. Noise on the platform caused by a train entering the station

4.2. Noise level generated by trains passing through tunnels

Tunnel vibration levels depend on the following aspects:

- *Train speed.* A doubling of the train speed results in a 4 to 6 dB increase in the vibration acceleration levels of the tunnel and ground in the 25–110 km/h.
- *Axial Load.* A doubling in axial load produces a 2 to 4 dB increase in the tunnel wall vibration levels, independent of train speed and track construction.
- *Resilient wheels.* Resilient wheels reduce tunnel vibration levels by approximately 4 dB in the frequency range of 40–250 Hz.
- *Resilient Mass.* The non-elastic mass represents the mass of the non-isolated trolley. The non-elastic mass can include the wheels, axles, gearbox, and traction motors. Halving the non-elastic mass can produce a 6 dB reduction in ground vibration levels.
- *Wheel–to–wheel system conditions.* Wheel deformation, non–compacted rail joints, and roughness on the rails can increase vibration levels by 10 to 20 dB.
- *Contact conditions.* Roughness on wheels or rails can increase levels by 3 to 10 dB.
- *Exchanges.* Tunnel vibration levels for tracks with switches and crossing points are 10 to 15 dB higher than for continuous tracks.
- *Resilient Rail Connections.* If the stiffness of the rail connection is doubled, tunnel vibration levels increase by 6 dB at frequencies above 50 Hz.
- *Resilient Support.* Floating slabs or track beds significantly reduce the vibrations transmitted to the tunnel structures (Fig.8).
- *Ballast material.* The rubber material placed between the ballast and the tunnel foundations produces a significant decrease in vibration levels in the tunnel (greater than 5 dB) for

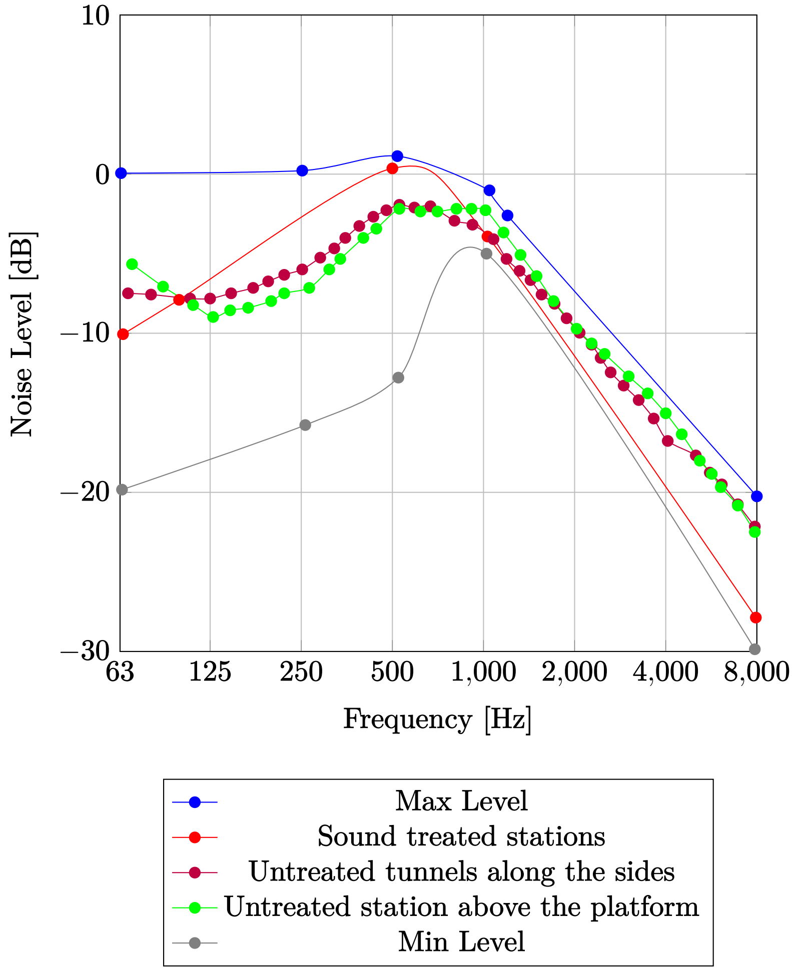

Figure 10. Noise Control in Stations

frequencies above 63 Hz. Figure 8 represents the difference in acceleration levels for continuous concrete floors with a support frequency of 16 Hz, for continuous concrete containing a conventional track with rubble and joints with a support frequency of 10 Hz, and for small precast concrete floors with a frequency of 10 Hz.

- *Tunnel construction.* The type of tunnel structure and its mass influence the vibration levels in the tunnel and on the ground. Doubling the average wall thickness reduces wall vibration levels by 5 to 18 dB for the same materials.

5. Conclusion

The research proposes a comprehensive investigation of the parameters that limit the life of the railway line. The study assesses the noise produced by wheel-rail contact, noise levels generated by carriages traveling on straight–line tracks and curved tracks, noise spectra for locomotives and passenger carriages, and noise levels caused by trains passing through tunnels and stations. Noise control methods produce a significant reduction of the sound pressure level.

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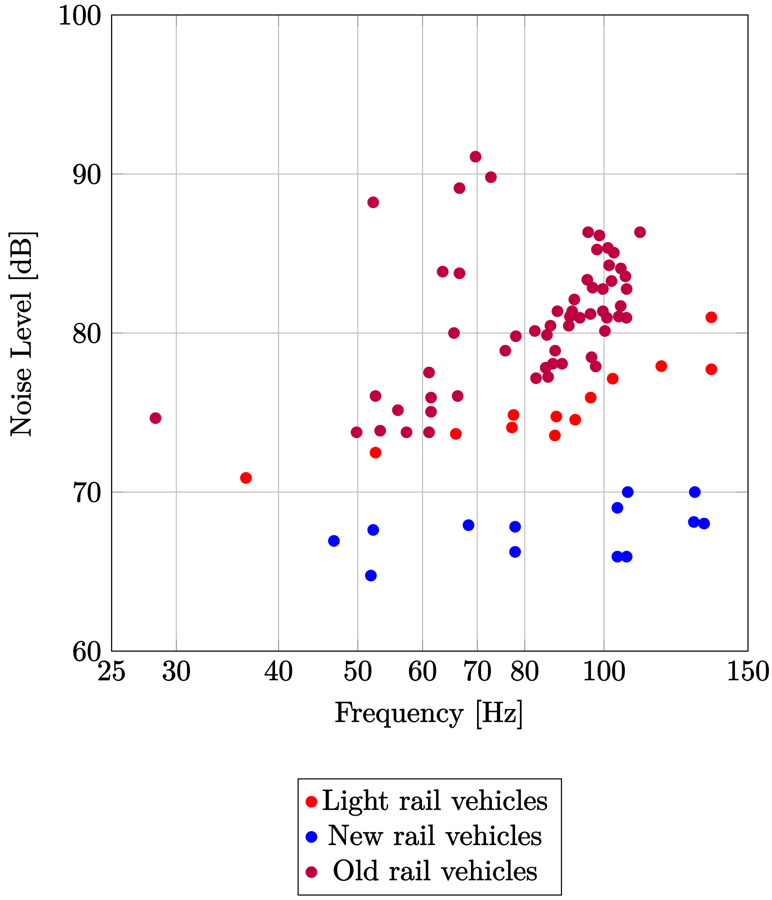

Figure 11. A–weighted sound levels inside steel–wheeled underground trains and outdoors

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