GENERAL GUIDANCE FOR
Low Noise and Low Vibration Slab Track

ARUP
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Railway track is composed of rails, fasteners, sleepers and ballast. When there is no ballast, the track is referred to as slab track or ballastless track. Slab track is becoming more frequently employed due to its lower maintenance requirements, long design life and higher capability for high speed operation. Slab track has been successfully employed on many projects around the world including the Shinkansen in Japan, the TGV in France and the Channel Tunnel Rail link in the UK.

Relative to ballast track, slab track can provide opportunities to reduce the environmental noise and vibration generated by a railway. Equally, there are certain inherent parameters of slab track that can lead to increased noise levels relative to ballast track if these parameters are not considered during the design of the track system. This paper aims to give an overview of the key railway noise generating mechanisms, particularly those related to the track, as well as providing guidance on how to influence the slab track design parameters that influence the generation of noise and vibration.

Noise and vibration can lead to annoyance and sleep disturbance. Exposure to railway noise may also be associated with stress related illness and cognitive impairment. It is therefore important to consider the potential for noise and vibration impacts during the design of a railway.

For both surface and underground railway lines, there are several ways that railway noise and vibration can be transmitted to receptors in close proximity to the railway. These are illustrated in Figure 1. This document provides general information about the mechanisms which generate railway noise and vibration, and potential methods of mitigating them, focussing on aspects which can be controlled by track design.

Figure 1: Airborne noise, structure radiated and groundborne noise and vibration from railways.
Potential noise and vibration sources

2.1 AIRBORNE NOISE

Airborne noise from railways comprises the following sources:

• Rolling noise generated by wheel and rail vibrations that are induced at the wheel/rail interface. Rolling noise is generally the most predominant source of railway noise.

• Curving noise generated by unsteady transverse forces in the wheel/rail interaction during curving. This type of noise is very different in character to rolling noise.

• Aerodynamic noise caused by unsteady airflow over the body of the train. This source of noise becomes important at very high speeds (generally above 300 kph).

• Traction noise from diesel engines, intake and exhaust, traction motors and fans, gearboxes, turbocharges etc.

• Noise from train warning signals and fixed installations (level crossings, public address and voice alarm systems).

This document considers only noise generated at the wheel rail interface as these sources can be influenced by the design and construction of slab track.

2.2 STRUCTURE RADIATED NOISE AND GROUNDBORNE NOISE AND VIBRATION

Structure-radiated and groundborne noise and vibration derive from the same source as airborne rolling noise, namely vibration generated at the wheel/rail interface which is transmitted through the track and then into the railway support structure or surrounding ground. When the train is passing over a bridge or viaduct this can cause the structure to vibrate and radiate sound, known as structure radiated noise. When the train is running on the ground surface or in a tunnel, the vibration propagates through the ground where it may be experienced in buildings close to the railway as perceptible vibration, or as a ‘rumbling’ noise re-radiated by vibrating surfaces in the building, known as groundborne noise.

As with airborne noise, the potential for structure radiated noise, groundborne noise and groundborne vibration can be influenced by the design and quality of the track.

2.3 EXCITATION MECHANISMS

Rolling noise and vibration is generated by the interaction between the wheel and the rail at their point of contact. Since neither the wheel nor the rail are entirely smooth, they move relative to one another in a manner dependent on the “roughness” of the wheel and the rail. This movement generates vibrations, which radiate from the wheel and the rail into the air (airborne noise), the railway support structure (such as bridge or viaduct), or the ground (vibration, which can lead to groundborne noise).

Rolling noise and vibration generally increase with increasing train speed, and increasing wheel or rail roughness.

Rolling noise is also heavily influenced by the track type and its components. All other parameters remaining equal, continuously welded rail will generate less noise and vibration than jointed track, switches and crossings (S&C) or other types of discontinuity in the track. This is because vibration and noise is generated when the wheel comes into contact with discontinuities in the rail.

As well as being influenced by the conditions at the wheel/rail interface, the way in which the track responds to vibration is important and this can be influenced by slab track design to reduce noise. An important track component for influencing the noise and vibration generated by slab track is the rail fastening system. The rail fastening system can be chosen to provide performance optimum for surface, tunnel or viaduct operations.

This document provides a high level overview of the methods for controlling noise and vibration from slab track for a reader who is not a specialist in noise and vibration control. For a more comprehensive and technical information relating to all aspects of railway noise generation the reader is referred to Thompson1.

2 $f = \frac{v}{\lambda}$
3 EN 15610:2009 Railway applications— Noise emission— Rail roughness measurement related to rolling noise generation. EN 15610:2009 specifies a direct method for characterizing the surface roughness of the rail associated with rolling noise (“acoustic roughness”)
3 Control of airborne noise

3.1 SHORT WAVELENGTH RAIL ROUGHNESS

The predominant source of airborne railway noise are the combined roughness of the wheel and rail, which causes vibration of the train wheels, the rails and the track. This vibration then radiates into the surrounding air. Rail roughness is the variation in height of the rail running surface and can be either periodic or non-periodic.

High levels of periodic roughness which can be seen on the rail head is usually referred to as corrugation. Corrugation is most common on curved track, but it also sometimes occurs on straight track. More typically, roughness with amplitudes measured in microns, which is not clearly visible, will generate rolling noise and vibration. The frequency of vibration, \( f (\text{Hz}) \), excited by roughness of a given wavelength, \( \lambda (\text{m}) \), will depend upon trainspeed, \( v (\text{m} \cdot \text{s}^{-1}) \). This means that the roughness wavelengths important for airborne noise generation are usually in the range 0.25m to 3mm. The condition of rails for wavelengths less than 0.5m is usually controlled with rail maintenance grinding to prevent rail defects and fatigue cracks, meaning that noise reduction by controlling rail roughness is a maintenance activity rather than a design activity. There is evidence that use of soft rail pads can reduce the rate of roughness and corrugation growth, however, as will be described later, soft rail pads can also lead to more radiation of noise from the rail.

Longer wavelength roughness excites lower frequencies that are more relevant to groundborne noise and vibration and are described in Section 4.1.

3.2 RAIL FASTENER STIFFNESS

A key difference between slab and ballast track is that slab track will tend to incorporate rail pads or fastenings with a higher resilience (lower stiffness) than ballast track. This is because the resilience in a ballast track is provided by the ballast itself, whereas the resilience in a slab track is often incorporated into the rail fastening (Figure 3).

Figure 3: ÖBB-Porr slab track system with a resilient Vossloh System 300-1 baseplate.

All other parameters remaining equal, the sound radiated by the rails will tend to increase with decreasing rail pad or rail fastener stiffness. This is because the rail becomes more ‘mobile’ as rail fastening stiffness reduces, allowing the rails of the track to vibrate more freely and over a greater distance. For a railway operating on the surface this means that optimisation of rail fastener stiffness is important for controlling noise radiated by the rails. A measure of a tracks propensity to radiate noise is the ‘rail decay rate’. Noise radiated by the rail will tend to increase with decreasing rail decay rate.

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6 Poisson, F. et al. Global pass-by noise of high-speed train running onto slab track and ballasted track, proceedings of the World Congress on Railway Research (WCRR) 2013, Sydney, Australia.

3.3 RAIL DAMPERS
The rail decay rate can be increased, and hence noise radiated by the rail reduced, with the application of rail dampers. Rail dampers, shown in Figure 4, are a mass spring damper system which can be fitted to most rails. The benefit that rail dampers provide is largest on tracks with low decay rates, meaning that typically rail dampers will provide more reduction of rail noise on slab track than ballast track. Furthermore, the benefit of rail dampers on ballast track can be limited by the component of noise radiated by the sleepers. Many slab track system do not include sleepers meaning that the potential benefit of rail dampers on slab track is greater than on ballast track.

Figure 4: Silent Track rail dampers installed on the Sonneville Low Vibration Track system

3.4 BALLAST ABSORPTION
Another key difference between slab and ballast track is that ballast serves to absorb reflected noise generated at the wheel/rail interface. The sources of noise that receive the most absorption from ballasted track are the inner surfaces of the wheels and rail that radiate noise underneath the bogie which is partially absorbed by the ballast and partially emitted through gaps around the bogie frame. The noise increase for slab track due to the lack of ballast absorption is not considered to be as important as the inherent difference in rail decay rates for slab and ballast track, however it does contribute to an increase in noise. Slab track can be modified by providing absorptive layer to the top of the slab track (Figure 5) so that the track provides an equivalent level of absorption to ballast track.

Figure 5: LIAKUSTIK Absorptive panels applied to slab track
3.5 NOISE BARRIERS

The previous airborne noise control methods discussed focus on the noise reduction at source. Noise barriers screen the path of sound between the source and the receiver. In general, noise barriers are most effective when they are taller and placed close to the source of noise (the railway). Relatively low noise barriers can provide a significant benefit if placed very close to the track (Figure 7). Barriers can also be made more effective with absorption using perforated panelling exposing absorptive materials on the trackside of the barrier.

While the performance of a noise barrier is not directly affected by the design of slab track, consideration needs to be given to the fixing of barriers to the slab, viaduct or curb so that the barriers are sealed, particularly around drainage, cable routes and other penetrations. Barriers must also be isolated from the slab or support structure so that they do not radiate sound themselves. Consideration should also be given to the profile of the slab so that it contributes to a low noise system. For example, derailment containment or parapets could be incorporated into the design of the slab so that they screen noise to some degree. Embedded rail slab track systems will reduce noise radiated by the rails as the rails are inset to the slab.

Figure 6: Wayside noise barriers on a viaduct on High Speed 1, UK

Figure 7: Low level barriers on Medway viaduct on High Speed 1, UK
4.1 LONG WAVELENGTH ROUGHNESS AND ALIGNMENT CONTROL

The effect of rail roughness on airborne noise has been discussed. Rail roughness is also important for the generation of groundborne noise and vibration, though the wavelengths of importance are different. Whilst airborne noise is excited by roughness wavelengths of 0.25m to 3 mm, significant groundborne noise and vibration is generated by longer wavelengths, particularly for high speed railway where wavelengths of 10s of metres can be important. ‘Roughness’ at wavelengths greater than one metre is usually measured with a track recording car which measures vertical alignment.

Whilst controlling short wavelength roughness to reduce noise on surface railway is largely a maintenance activity, there is limited benefit from grinding to control wavelengths >1m. By implementing accurate alignment control during construction, slab track provides the opportunity to deliver a system with very low roughness at long wavelengths compared to ballast track. Furthermore slab track roughness at long wavelengths will not degrade with time like ballast track which requires tamping and realignment throughout its operational life.

‘Top down’ construction techniques – where the line and the level of the rail is fixed to a high tolerance before the sleepers and/or baseplates are hung from the rails and the second stage concrete is poured – are likely to deliver alignments with the lowest levels of roughness at long wavelengths. As opposed to ‘bottom-up’ construction – where the rail is the last track component to be installed and the vertical rail alignment is set once the sleepers and other components are in place – which has greater potential to introduce long wavelength variation in the alignment. Measurements of long wavelength roughness indicate that slab track constructed to a high level of accuracy can deliver roughness levels which are three times smoother than ballast track.

Figure 8: Top down construction in Crossrail tunnels, UK. Setting out of booted sleeper track (left) before the second stage concrete is poured (right).

8 Bewes, O. et al. Developing a prediction method for ground-borne sound and vibration from high speed trains operating at speeds in excess of 300km/h. Proceedings of the 21st International Congress on Sound and Vibration, 13th – 17th July 2014, Beijing, China

4.2 CONTROLLING VIBRATION IN TUNNELS WITH RESILIENT ELEMENTS IN THE TRACK

Slab track systems in tunnels are preferred to ballast track due to their lower maintenance requirements and reduced construction depths. Slab track also offers opportunities to incorporate a high level of groundborne noise control.

A slab track system can be designed to isolate vibration generated at the rail/wheel interface from the tunnel invert by incorporating resilient elements (such as soft rail pads, baseplates or under sleeper pads) and mass elements (such as sleepers or a floating slab). Within the constraints of allowable rail deflections on a railway, combinations of very low stiffness and high mass will lead to the highest level of vibration isolation. Modest improvements in isolation can be provided at low cost by optimising the rail pad alone while large improvements, at a higher cost can be achieved with floating slab track systems. Various forms of slab track are shown in Figure 9, demonstrating that increasing groundborne noise mitigation can be provided at the cost of increasing construction depth and increasing capital cost.

Figure 9: Slab track with various forms of resilient support
This document has provided an overview of the important aspects for the design of low noise slab track. It has highlighted that slab track offers both opportunities and risks in terms of environmental noise relative to traditional ballast track. It has also been demonstrated that the optimum low noise design solution is dependent on whether the train is running on the surface, in tunnel or on a bridge/viaduct.

For surface operation, slab track can lead to increased environmental noise emission relative to ballast track, however this increase can be mitigated by:

- regular rail maintenance grinding
- optimisation of the rail fastening system or the application of rail dampers to increase the rail decay rate
- incorporation of absorbing material on the slab; or
- screening with conventional noise barriers or with novel design of the profile of the slab

For tunnelled railways, rail roughness is also important, however, unlike surface railway, it is possible to influence the quality of the railway, in terms of its roughness, during construction of the slab track using ‘top down’ construction techniques. Slab track also offers many opportunities to incorporate vibration isolation in the system without significant increase in construction depth.

On bridges and viaducts the track design must be optimised to find a balance between noise radiated from the track and from the bridge or viaduct structure itself.
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