Railway noise mitigation factsheet 04: Tunnels

1.1 Overview

Whilst tunnels may be used in themselves as an effective noise mitigation measure, it is recognised that new noise sources may arise as a result of their implementation. This factsheet focuses on the mitigtaion of these other sources.

Literature suggests that noise radiated from tunnel portals can be a source of annoyance from high-speed rail lines. When a train enters a tunnel at high-speed, a pressure wave is generated which propagates down the tunnel at the speed of sound and, on reaching the end of the tunnel, is propagated as a pulsing pressure wave (micro-pressure wave), recognisable as a sonic boom (Degen et al, 2008) as illustrated in Figure 2. This phonenmenon has been experienced in Japan and in trials in Germany. The effect can result in residents in the vicinity experiencing vibration of doors and windows; Degen et al (2008) note that depending upon conditions, the sound can be clearly audible even at distances far away from the tunnel portal (up to approximately 1km).

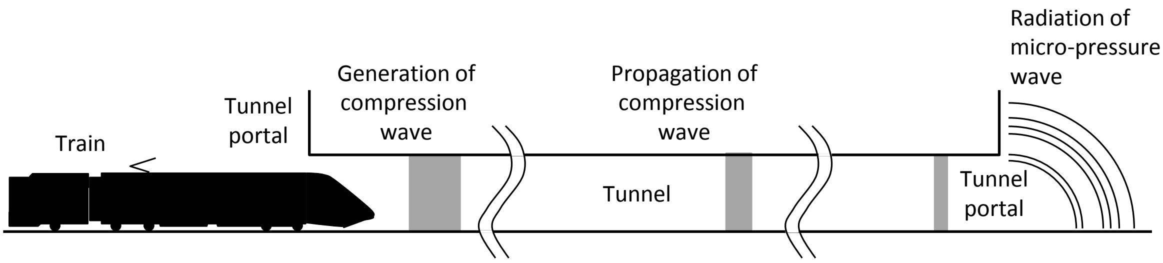


Figure 2: The creation of micro-pressure waves resulting in noises at the exit of rail tunnels

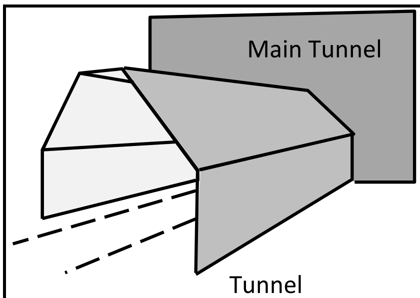
Noise emissions are a particular problem with high speed trains in excess of 250km/h. Maeda (1999) notes that these effects are not an issue where a ballasted trackbed is used instead of slab-track.

Whilst optimising the shape of the nose of the train can have a limited effect, other methods are required to better address the problem.

Bopp and Hagenah (2009) summarises different measures for reducing pressure variation in tunnels; from an operational perspective these include reducing train speeds and prohibiting close-following or crossing trains. From a engineering perspective, these include portal design, openings between tunnel bores or between tunnel bores and the atmosphere (although there may be safety and noise issues asscoiated with these) or the use of larger cross-sectional areas for the tunnels. Similarly, measures for reducing sonic boom are listed by the same authors; from an engineering perspective, these include the above measures as well as the use of ballasted track, and the installation of absorber materials on the tunnel walls.

Research has been undertaken into addressing this problem, through the use of sound absorbing elements between the tracks, i.e. on top of the slab-track, and particularly through the modification of tunnel portals using either tunnel hoods to increase the cross-sectional area or using flared portal designs to achieve a similar physical effect. The use of absorptive materials to line/clad the tunnel walls can also have beneficial effects.

1.2 Mitigation modes



Tunnel hoods (Figure 3) mitigate the effects of these micro-pressure waves by reducing the pressure gradient (the rate of change of pressure) and amplitude of the pressure wave. The effect of noise mitigation depends upon the hood length (Maeda, 1999). The use of windows (open holes) with ducts on tunnel hoods improves the reduction of the pressure gradient and allows the use of shorter tunnel hoods (Sakurai *et al*, 2008).

The use of ballasted tracks and absorbers in-between the rails also helps to reduce the pressure gradient.

1.3 Tunnel design: hoods and portals

Tunnel construction methods, either by boring or cut-and-cover[1]: the latter referred to

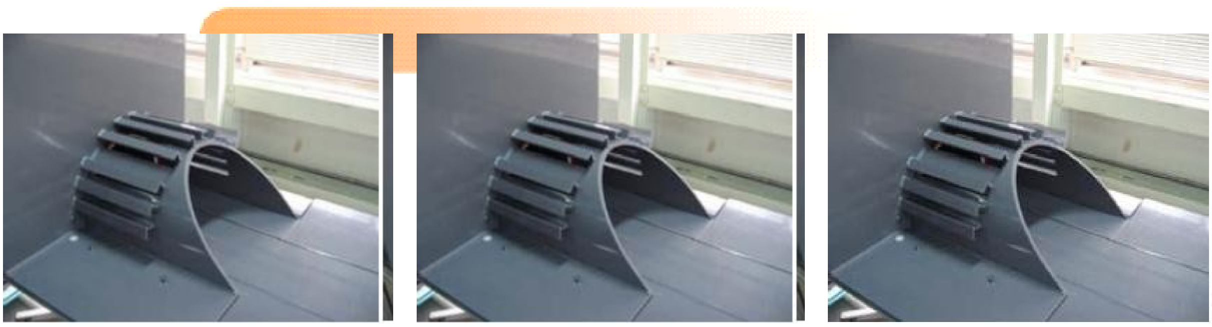
[1] Where a trench is excavated and roofed over with an overhead support system strong enough to carry the load of what is to be built above the tunnel.

under HS2 as 'green tunnels,' are outside of the scope of this factsheet. However, key factors in the choice of method will be determined by the depth of the tunnel relative to the existing terrain, the length of the tunnel and the type of ground through which the tunnel will run.

The most common materials used for tunnel hoods are concrete and steel (Saeki and Watanabe, 2008), see for example Figure 4, with concrete structures generally used on new-build lines and steel structures used where the hoods are constructed after the railway line becomes operational. Tunnel hoods vary in their design but for optimum performance, the cross-sectional area is about 1.4 times that of the main tunnel with openings in the side (Maeda, 1999).

Kim *et al* (2008) discussed the importance of the tunnel cross-section design in the use of hoods based on model studies at train speeds from 275-350 km/h. The hood shown in Figure 5(c) was found to be the most effective. It was also determined that those with a high degree of inclination (approximately 45°; Figure 5(a) and Figure 5(c)) were about 12% more efficient in mitigating micro-pressure waves than the vertical hood, although again this is not translated into changes in noise level.

Increasing train speeds have resulted in the necessity for longer and more extensive hoods; however this can result in high on-site construction costs so cheaper alternatives have been sought out. Hoods have been equipped with ducts (external tubes leading to the inside of the hood) with the objective of shortening the length of the hood by reducing the pressure gradient of the compression wave, e.g. Figure 6(a).



(a) Tunnel hood with 45° inclination and longitudinal slots

(b) Tunnel hood with vertical inclination and side slots

(c) Tunnel hood with 45° inclination, top slots and ducts

Figure 5: Example tunnel hoods as tested by Kim et al (2008)

Ishikawa *et al* (2010) found that when tunnel hoods are equipped with ducts, they are most effective with the ducts near the main tunnel. Field tests using Shinkansen trains showed that tunnel entrance hoods with ducts ease the pressure gradient more than conventional entrance hoods. Tunnel hoods have also been adapted with membrane materials, as shown in Figure 6(b) with the objective of reducing construction costs (Saeki and Watanabe, 2008).

(a) Tunnel hood with ducts
(Photo: East Japan Railway Company)

(b) Tunnel hoods made with lightweight membrane panels (Photo: East Japan Railway Company)

Figure 6: Examples of tunnel hoods using ducts and membrane panels

A report prepared by McAllistair (2010) for the California high-speed train project suggests that smooth tapered hoods may need to be up to 45 m in length to mitigate the sonic boom effect, with the face of any hood structure being inclined at least 45° from the vertical. The same document suggests that tunnels over 2 miles in length may require a portal hood that is at least 20m in length and that these should include openings/ducts.

Similar effects on reducing the pressure gradient can be achieved by flaring the tunnel portal.

It is also noted that noise mitigation is likely to be required for any ventilation shafts associated with the tunnels; this mitigation will not only have to address noise generated directly by ventilation equipment within the shafts but also the effects of the micro-pressure waves generated by the trains. The use of acoustic baffles within the shafts is one approach that could potentially be adopted. No information has been identified on potential noise levels relative to those at the main tunnel portals.

1.4 Use of absorptive materials in tunnels

The demands on materials in tunnels, including high fire safety, impact resistance, weather resistance and non-toxicity complicate the issues of selecting sound absorptive materials for use as tunnel linings or claddings. However, a number of different solutions have been identified. These include the use of porous panels manufactured from resin-bonded aggregates, prefabricated aluminium sound absorptive panels, vitreous enamel panels with calcium silicate or gypsum backing and cement-bonded wood chips. No information has been identified looking at noise levels at tunnel portals with and without the use of such cladding/lining materials or at the amount of cladding required (in terms of the length inwards from the portal to be treated).

Resin-bonded aggregates, porous concrete and cement-bonded wood chips have also been used as acoustic absorbers sited on the track bed (Figure 7), although no specific examples have been found of application on high-speed rail besides the trials by Degen et al (2008).

1.5 Indicative performance levels

The majority of work on tunnel hoods has been conducted in Japan using Shinkansen (bullet) trains; the following are just a few examples of the work that has been reported.

Maeda (1999) confirmed that the use of a tunnel hood can significantly reduce the pressure gradient. It was determined that without a tunnel hood, a train travelling at 250km/h generates micro-pressure waves of approximately 300Pa, which then falls to about 20Pa when a tunnel hood is implemented. However no information is given as to the change in noise levels as a result of mitigating the sonic boom. The use of ducts with tunnel hoods and absorptive lining material have also been tested in pilot projects, which clearly noted that they have similar results in reducing micro-pressure waves to conventional tunnel hoods; Ishikawa *et al* (2010) found that during field tests, tunnel hoods equipped with ducts can reduce the pressure gradient better than conventional entrance hoods. Again, no information on actual noise level changes is presented.

Degen performed practical measurements in 2006 at two 7 km long tunnels in Germany laid with slab track. Microphones were positioned at various distances from the tunnel portals and measurements taken for train speeds up to 300 km/h. Measurements at 65m from the tunnel portal showed a micro-pressure sonic boom of the order of 112 dB(C)[2] as the train entered the tunnel, with noise levels rising from approximately 85 dB(C) to 90 dB(C) as the train moved through the tunnel, peaking at approximately 100 dB(C) as the train passed the microphone. At the same position, the C-weighted Sound Exposure Level[3] for a full high-speed train pass-by is approximately 108 dB(C). When the slab track was treated with sound absorptive material, the C-weighted SEL corresponding to the sonic boom was

[2] A-weighting, dB(A), is the main way of adjusting measured sound pressure levels to take account of human hearing; C-weighting, dB(C), is another method of weighting data, but is a relatively small correction sometimes applied to very loud noise sources.

[3] The sound exposure level, SEL describes the cumulative noise exposure from a single event. It is represented by the total sound energy during the event normalised to a one second time interval.

reduced by approximately 5 dB(C) if only the inner 200m from each portal was treated or approximately 12 dB(C) if the whole 7km track slab was treated.

1.6 Indicative costs

The use of tunnels themselves as noise mitigation will be considerably more expensive than conventional noise mitigation methods such as noise barriers.

Tunnel hoods are very expensive, which is why hoods with ducts and the use of absorptive material on hoods has been developed to reduce costs. These modified hoods can provide a similar, if not better level of noise protection. However, if tunnel hoods or flared portals can be incorporated as part of portal design on new-build tunnels, this may significantly reduce the costs

The length of the tunnel will have a key bearing on the costs of using cladding materials and/or sound absorptive materials on the track bed, unless application is restricted to short distances in from each tunnel portal.

1.7 Benefits and disbenefits

The **benefits** of tunnel noise mitigation measures can be summarised as follows:

- A number of different design measures are available which can be used to mitigate the sonic boom effects caused by high-speed trains entering tunnels. However, the results in the published literature do not allow for a comparison of the relative effectiveness of these methods.

The **disbenefits** of tunnel noise mitigation can be summarised as follows:

- Tunnel hoods, such as those found in the literature, can look aesthetically unpleasing and do not integrate well into the natural environment; however, since HS2 will be new-build, it should be possible to incorporate such features as part of the design process and to consider alternative options such as using flared tunnel portals;

- The use of sound absorptive materials on the track bed or tunnel lining may be cost prohibitive depending upon the quantity required for effective noise mitigation; no information has been identified on the acoustic durability of these materials in this environment, e.g. whether cleaning/maintenance is required to maintain the acoustic performance;

- Care must be taken in the selection of materials based on the safety requirements, e.g. fire resistance, toxicity etc. associated with tunnels.

1.8 Suitability for use on HS2

The proposed route map for HS2 identifies a single 13.3 km twin-bored tunnel (with portals at Ch31+400 and 44+700) and two green tunnels (the first 1.1 being km long with portals at Ch46+250 and 47+350; the second being 1.28 km long with portals at Ch 53+750 and 55+050). Since all of these will be new-build tunnels it is considered that mitigating sonic boom effects through the careful design of flared tunnel portals will be the effective solution; no literature has been identified where tunnel hoods have been effectively constructed as part of the tunnel, i.e. so that the tunnel hood itself is part of the subsurface structure (so that the tunnel effectively has at least two bore diameters).

Only the twin-bored tunnel is of sufficient length to require the inclusion of tunnel shafts (with approximate positions indicated at Ch 34+200, 37+175 and 43+000); the first shaft would be sited approximately 500m from properties on the outer edges of Chalfont St Peter and the other shafts are in the proximity of individual farms; care may need to be taken in the design of the shafts to minimise the risk of noise disturbance when trains pass through the tunnels.

The use of absorptive materials on the track beds throughout the length of the tunnels may be prohibitive due to the length (particularly for the twin-bored tunnel), but benefits will still be achievable through treatment of short sections inwards from each portal.

1.9 Examples of application

Entrance hoods are the most popular choice of noise abatement measure for tunnel portals in Japan with many being installed for the Sanyo and Tohuku Shinkansen tunnels (Ozawa and Maeda, 1988). Although flared tunnel portals are referred to in the literature, no clearly identified examples have been found in practice; however photographs of tunnels on high-speed lines in Germany suggest that such designed portals are in use.

The use of absorptive materials on track slabs has been trialled in Germany; examples on conventional railway lines have been found in Germany and, Australia, however no projects related specifically to high-speed rail have been identified from commercial websites.

1.10 References

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