Sound propagation and audibility of train horns

Martin Toward[1], Michael Lower, Marcus Wiseman, David Thompson
Institute of Sound and Vibration Research, University of Southampton, Southampton, SO17 1BJ, UK

Paul Ferraby[2]
Rail Safety and Standards Board, London, EC2M 2RB, UK

ABSTRACT

Horn sound levels and sound propagation along railway tracks were investigated after track workers reported that some newer trains have quieter horns than older trains. Sound levels from a static horn above a test track decayed by 6 dB per doubling of distance, but only up to about 30 or 50 metres depending on the horn height. At greater distances the level decayed by approximately 12 dB per doubling. At 400 metres, the sound level from a horn 2.5 to 3.0 metres above the ground was about 10 dB higher than the level from the horn 0.5 metres above the ground, although the levels at 25 metres were the same. The effective range of a horn depends on its height. At two mainline sites the mean attenuation rates beyond 90 metres were 10.7 and 9.2 dB per doubling of distance. At one site, horn sound levels were highly correlated with distance. At the other, with newer trains, horn levels were poorly correlated, suggesting some variability in horn sound levels at source, or moment to moment variability in sound propagation. Track workers' ratings of the audibility of the horns were compared to horn levels as recommended by Detectsound and by ISO 7731.

1. INTRODUCTION

The maximum and minimum sound levels of train horns are currently specified at 25 metres in BS EN 15153-2:2020 [1] and in the Rail Safety and Standards Board (RSSB) standard GM/RT2131 [2]. The sound levels from horns are required to comply with the versions of the standards in force when each train class enters service, but the specified levels have changed over the years, and new sound levels are not retrospective. The RSSB has received reports that track workers found the horns of some newer trains to be quieter and less audible than horns of older trains. A project was therefore undertaken to investigate the factors affecting the propagation of the sound, and the horn levels of approaching trains experienced in practice by track workers. Measurements of sound levels were made, first in an anechoic chamber, then with a static or stationary horn at a test track, and then at two sites on operational mainline railways.

[1] m.g.r.toward@soton.ac.uk

[2] paul.ferraby@rssb.co.uk

2. LABORATORY TESTS

Measurements were made in the Large Anechoic Chamber at the ISVR to test the basic performance of various train horns before measurements on site. Figure 1 shows the spectrum of a commonly used horn from Trent Instruments (KSJ-2) as an example. The fundamental frequency of 368 Hz was close to the nominal value of 370 Hz. The spectrum was rich in harmonics which is desirable to enhance audibility and minimise masking by background noise. Sound levels measured on axis from 1 m to 5 m showed the horn to behave as a point source with sound levels decaying at 6 dB per doubling of distance (6 dB/dd).

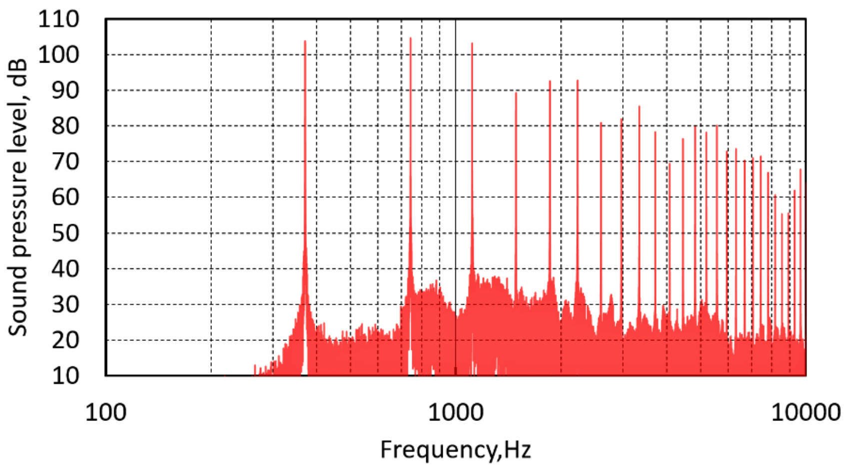

Figure 1: The spectrum of the Trent KSJ-2 horn

The directivity of the horn was measured. The sound level at 30° off axis was approximately 1 dB below the level on axis. The range from 0° to 30° would encompass the angle between horn and track workers in most cases.

The sound output of a horn can reduce over time with the collection of debris, dependent on the routes served. Consequently train horns are often covered by a mesh or grille to minimise damage or debris such as insects, leaves or larger objects. Sometimes the grille is part of the train bodywork; sometimes grilles designed to cover the mouths of specific models of horn are available as accessories. In the anechoic tests, placing a grille over a horn showed little or no reduction in the sound level. Obstructing 25% of the grille's surface area reduced the sound level by less than 1 dB. Obstructing 75% of the grille reduced the sound level by about 6 dB. This demonstrates that sound levels and consequently audibility can be significantly compromised if the grille is not kept clean.

Fabric coverings known as horn socks have been frequently used to prevent a horn freezing and failing to sound in cold weather. The anechoic tests showed that covering a horn with a dry horn sock reduced the sound level by 3 dB while a wet horn sock reduced the level by 7 dB. This would considerably reduce the distance at which a horn would be audible to track workers. Low voltage 'trace heating' is now commonly used instead of socks to prevent freezing. Trace heating is reliable, easily retrofitted to existing horns, and does not reduce the sound levels.

The effect of the installation of a horn on a train was investigated using a baffle to represent a train's front. When horns were mounted flush with, or in front of a baffle, sound levels were increased for angles between 10° to 90° off the horn's axis. Sound radiated to the sides of the train would be expected to increase. Recessing the horn behind the baffle showed sound levels to the side were not increased.

3. STATIC TESTS WITH A STATIONARY HORN

In the 'static tests', sound levels from a stationary horn were measured at a railway test track near Tuxford. Figure 2 shows the test site. The horn, a Trent KSJ-2, was mounted on a tripod support. Meteorological conditions were measured. The average wind speed at the horn was 4 m/s, a gentle breeze generally towards the horn, and the temperature was 15 °C.

Figure 2: The horn above the test track and the view from the horn position. The horn is at different heights in the two photographs

The sound levels were measured at 5, 10, 25, 50, 100, 200, 400 and 800 metres from the horn simultaneously. The measurement microphones were all at a height of 1.5 m above the ballast. The height of the horn was varied in 0.5 m steps from 0.5 m to 3.0 m above the ballast. Three tests were made at each horn height. The mean measured levels are shown in Figure 3.

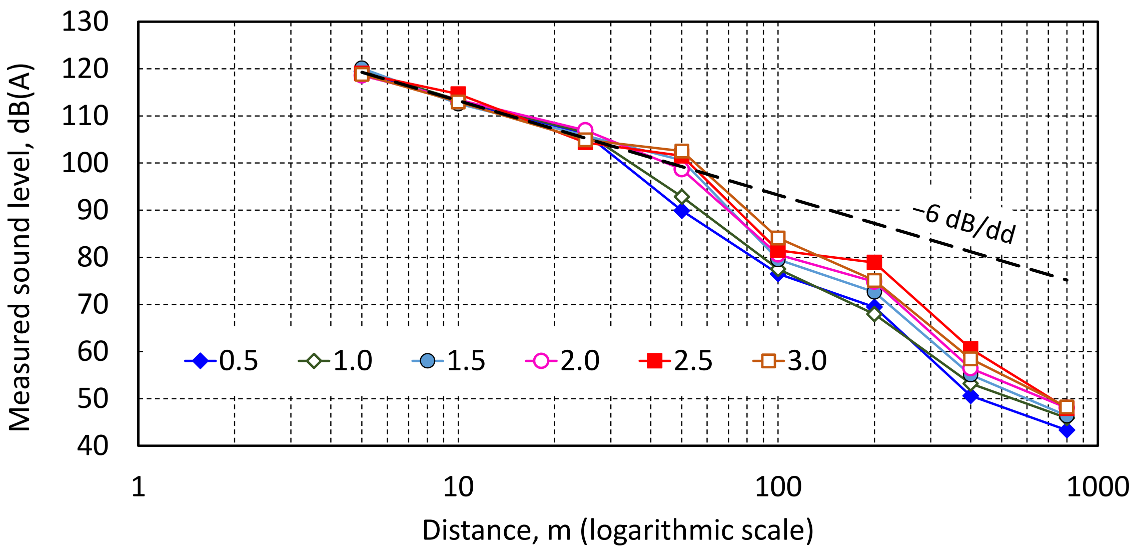

Figure 3: Sound levels at distances from 5 m to 800 m from the horn in static tests with the horn at different heights above the ballast. The key indicates the horn height from 0.5 m to 3.0 m.

The sound levels from the horn fell by 6 dB per doubling of distance (6 dB/dd), as expected from spherical spreading, but only up to a distance of about 50 m for a horn mounted at a height of 1.5 m or above, and only up to about 30 m for a horn at a height of 0.5 m or 1 m. Beyond 50 m for the high-mounted horn, and beyond 30 m for the low-mounted horn, the sound level decayed at approximately 12 dB/dd.

Figure 4 shows the sound levels at 200 m, 400 m and 800 m. At 200 m and 400 m, the sound level from a horn 2.5 m or 3 m above the ground was about 10 dB higher than the sound level from the horn only 0.5 m above the ground, although there was virtually no difference in the sound levels measured at 25 m. The installed height of the horn has a significant influence on the audibility at distance.

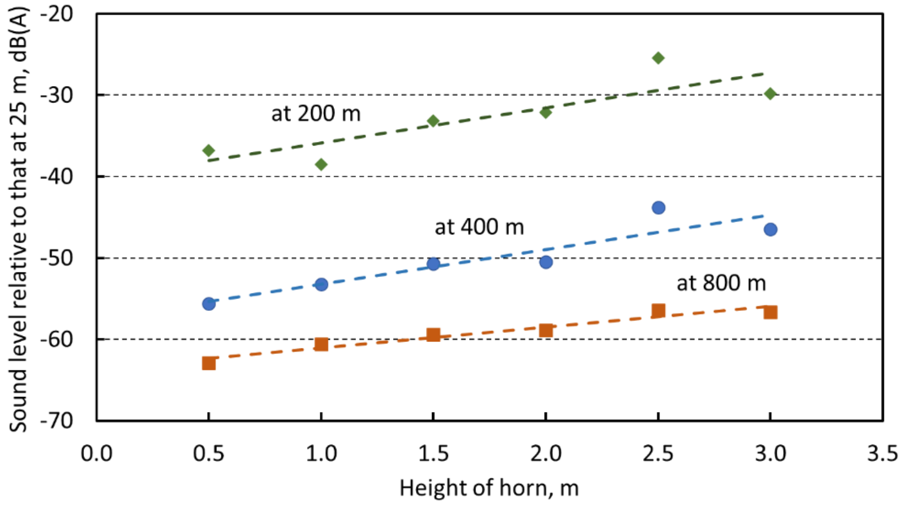

Figure 4: Measured sound levels at 200 m, 400 m, and 800 m relative to the level at 25 m

The sound levels measured during the static tests were compared to predicted levels from a *CadnaA* model of the topography, ground cover and wind direction and speed. The model, based on ISO 9613-2:1996 [3], overestimated sound levels at 200 m and 400 m by approximately 5 dB for horns at 1.5 m or 3.0 m above the ground. The model also showed only a modest effect of horn height; a horn at 3.0 m above the ground gave a predicted level only 2 dB higher than a horn at 0.5 m above the ground at a distance of 200 m, and only 4 dB higher at 400 m. In contrast, the measurements showed a horn 3.0 m high gave approximately 10 dB higher sound levels than a horn at 0.5 m above the ground at 200 m and 400 m. The ISO 9613-2 method is a ‘broad-brush’ method of estimating sound levels and is intended for use under ‘meteorological conditions favourable to propagation’, typically downwind, whereas during the static tests, the wind was generally towards the horn, conditions for which the method is less well suited. In practice, conditions will not always favour the audibility of horns.

4. DYNAMIC TESTS ON OPERATIONAL MAINLINE RAILWAYS

‘Dynamic tests’ were carried out at two rural, mainline sites, shown in Figure 5.

Figure 5: Dynamic test sites; Site 1 (Great Western Main Line), and Site 2 (South West Main Line)

Measurements were made on 11 February and 30 March 2021 at Site 1 and on 8 April at Site 2. Site 1 was a fairly flat and open site near Didcot on the Great Western Main Line. The line speed was 200 km/h (125 mph) and traffic was a mix of Class 800/802 (generically Class 80X) bi-mode powered multiple unit passenger trains operating in overhead electric mode at or around line speed, and some slower Class 66 diesel-hauled freight. The Class 80X trains are fitted with horns behind grilles about 0.4 m above the rails or 0.6 m above the ground. Class 66 locomotive horns are approximately 3.5 m above the rails.

Site 2, near Basingstoke on the South West Main Line, was in a cutting. The line speed was 160 km/h (100 mph) and traffic was mainly Class 444/450 passenger third-rail electric multiple units travelling at or around line speed and some slower Class 66 diesel-hauled freight. The electric passenger trains had horns close to the coupler, about 1 m above the ground. Both sites were chosen because they were close to uncontrolled foot crossings with ‘whistle boards’ which ensured that horns would be sounded on approach. Horns at both sites had nominal fundamental frequencies of 311 Hz and 370 Hz, the two tones generally in use on Britain’s mainline railways.

Horn sound levels and ambient noise levels were measured with microphones at 7.5 m from the track centre ahead of the trains, and at a height of 1.5 m above the ground. The rail vibration was recorded synchronously using accelerometers and enabled the train speeds to be accurately determined. The position of each train when the horn was sounded could be calculated from the train speed, the speed of sound, and the time of arrival of the sound at the microphones.

The sound levels measured in the dynamic tests at Sites 1 and 2 are shown in Figures 6 and 7 respectively. Both A-weighted and C-weighted levels were measured but only the A-weighted levels are shown here. The red crosses show the maximum and minimum sound levels at 25 m required for the horns of Class 80X and Class 444/450 trains in the standards in force when these train classes first entered service [4, 5]. In Figure 6, the maximum and minimum levels in dB(A) are estimated by subtracting 2 dB from the C-weighted levels specified, but the A-weighted horn levels are measured values.

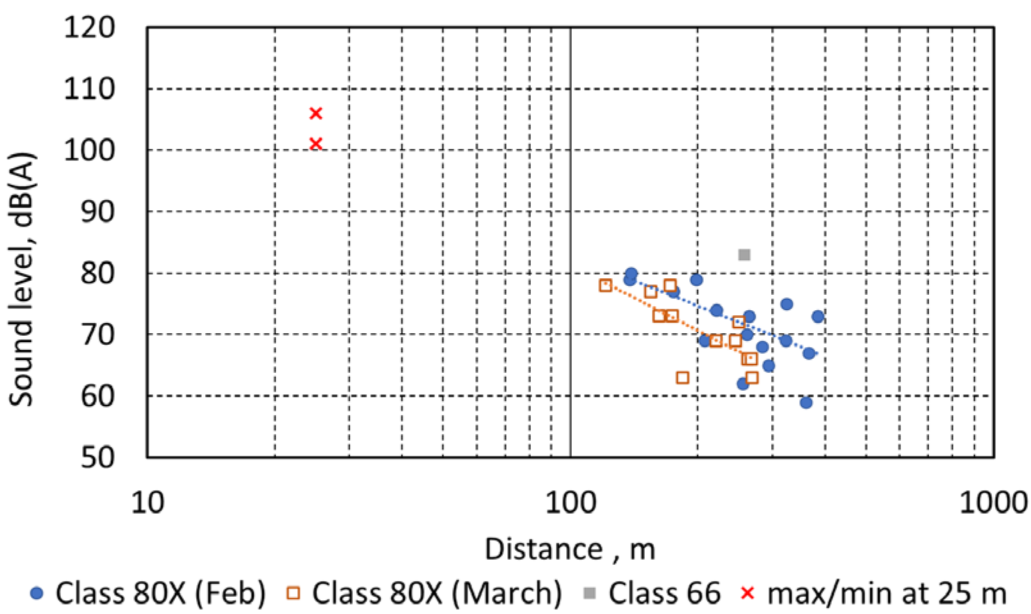

Figure 6: Measured horn sound levels (L_{AFmax}) at Site 1 (Didcot)

At Site 1 the correlation of sound levels of the Class 80X horns with distance was poor, with a wide scatter in sound levels ($R^2 = 0.45$ on 11 February; $R^2 = 0.55$ on 30 March). The trend lines were −8.2 dB/dd on Day 1 in February, and −10.7 dB/dd on Day 2 in March. In contrast, the sound levels at Site 2 for the Class 444/450 horns were highly correlated with distance from the train ($R^2 = 0.90$), and the slope of the trendline was −13.3 dB/dd.

Although there may have been some differences in the sound propagation between the two days at Site 1, there was little wind on both days. It is possible that the wide scatter of results on each day may be caused by minute-to-minute variations in propagation but could also indicate some variability in the sound levels from the horns at source.

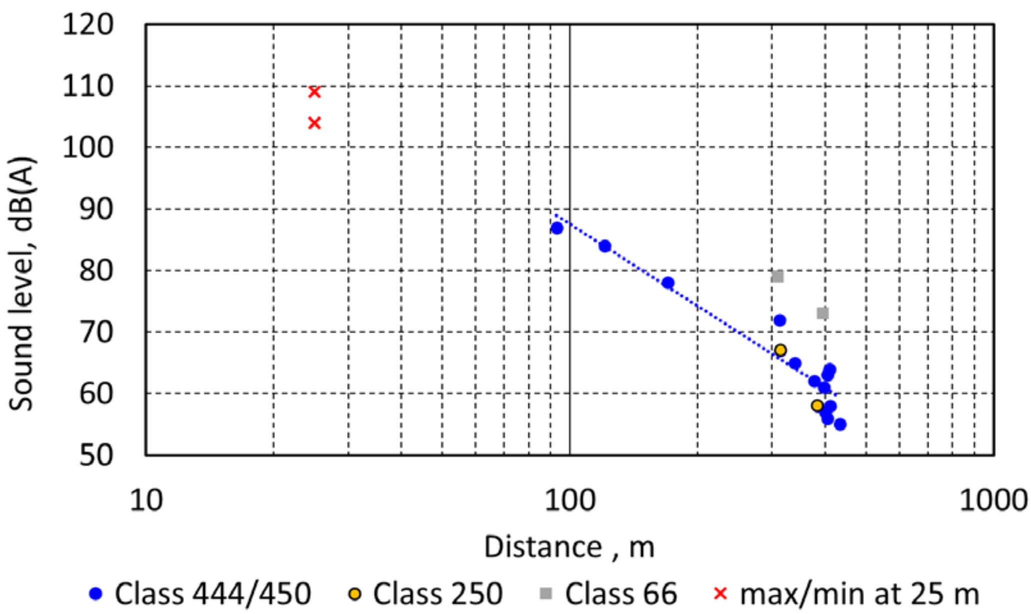

Figure 7: Measured horn sound levels (L_{AFmax}) at Site 2 (Basingstoke)

Two or three microphones at each test site were placed at various distances along the track, and in some cases the same horn sounding was recorded at two microphones. Because the position of each train was known when its horn was sounded, the sound attenuation rate could be calculated for individual horn blasts from the difference in sound levels between two microphones each at a known, but different, distance from the train. The distances from the train ranged from 90 m to 450 m. The measured attenuation rates are shown in Figure 8 below.

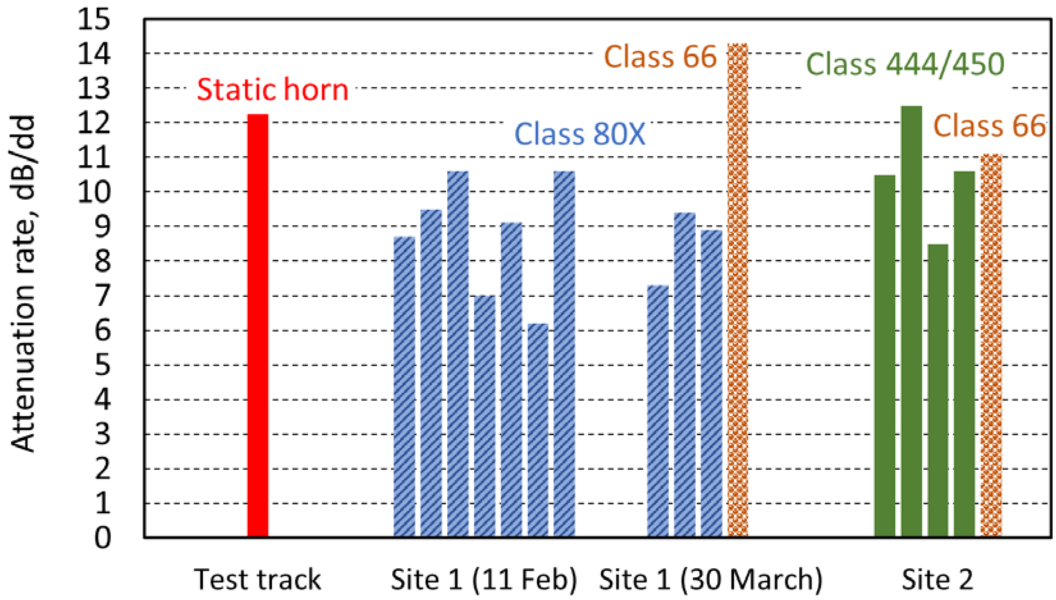

Figure 8: Measured attenuation rates of individual horn soundings

The average attenuation rates at distances of 90 m or more were, as expected from the static tests, higher than 6 dB/dd. At Site 1, the attenuation rate varied between 6.2 dB/dd and 14.3 dB/dd with a mean of 9.2 dB/dd. At Site 2, the attenuation rate varied from 8.5 dB/dd to 12.5 dB/dd, with a mean of 10.7 dB/dd. As these were derived from simultaneous measurements at two positions, the measured attenuation rates do not depend on the absolute sound level output of each individual horn, provided that the sound levels are sufficiently above the background noise.

5. AUDIBILITY CRITERIA

During the static and dynamic tests, panels of track workers were asked to rate the sound levels of the horns they heard. They all had experience of working on track and listening for train horns, and their hearing met the minimum levels required for track workers. In the static test, they were asked two questions; Q1: was the horn 'clearly audible' or 'not clearly audible' and Q2: was the horn a) easy to hear, b) difficult to hear, or c) inaudible.

Different track workers took part in the various dynamic tests. For each passing train, they were asked to rate the first horn sound that they heard. They were asked Q2 above, for consistency with the static tests, and were also asked to rate the horn sound levels on a five-point scale from 'not audible' to 'clearly audible'.

Two established methods were used to determine the minimum recommended levels for warning sounds. Both methods, (i) using the *Detectsound* software [6] and (ii) the one-third octave band method, method (c), of ISO 7731:2003 [7] calculate the masked threshold imposed by the background noise and then recommend that the components of the warning horn should exceed the masked threshold by a specified margin. The background noise (also referred to as the ambient noise in ISO 7731) was measured in one-third octave bands in the eight seconds immediately preceding the horn sound.

During the static tests, the horn level at the workers' location was controlled by varying their distance from the horn and by adjusting the air pressure that controlled the horn's output. In the dynamic tests, the horn sound level at the track workers' positions could only be varied by positioning them closer to or farther away from the whistle boards. The train drivers also sounded their horns as soon as they spotted the track workers in the cess. This is standard safety practice, but the track workers were asked to rate only the first horn sound and to ignore any subsequent sounding.

The track workers found the horn sound levels clearly audible when the horn levels were at or above the minimum predicted using either *Detectsound* software or method (c), of ISO 7731, with *Detectsound* being more consistent and accurate. Method (c) of ISO 7731 is, however, much simpler, far quicker in practice, and the better accuracy of *Detectsound* is outweighed in practical outdoor applications which are less well controlled than indoor environments.

During the analysis it was also observed that horn sound levels were 'clearly audible' to the track workers when the A-weighted horn level was 7 dB above the A-weighted background noise. However, this finding is based on limited data and a simple signal-to-noise ratio may not be a good predictor of audibility at other sites, or with different background noise spectra. Method (a) of ISO 7731 suggests that the A-weighted level of a warning sound should be 15 dB above the A-weighted background noise if only the overall levels and not spectra are available. This method based on the overall signal and overall noise levels (method a) does not take into account the noise and signal spectra and is therefore less precise, with a margin of safety built in. The margin of 15 dB seems unnecessary for track workers with good hearing, but nevertheless may be appropriate when the listeners are members of the public, with a range of ages and hearing abilities, who may or may not be paying attention.

At Site 1 track workers commented that horns of the relatively new Class 80X trains were quieter than the horns of the Class 43 trains that they replaced. As Class 43 trains are no longer in use at Site 1, it was not possible to measure the horn sound levels of these older trains for a direct comparison. However, the sound levels from the horns of the older trains would have been higher than those of the newer trains as they complied with an earlier standard. The horns of the newer trains were also close to the ground which would adversely affect sound propagation. Also, at Site 1, the whistle boards are presumably positioned so that a horn should be audible at its associated foot crossing. Nevertheless, in 24% of the pass-bys, only half the subjects or fewer positioned at the crossing rated the horns of the newer trains as “clearly audible”.

6. CONCLUSIONS

Sound levels from a stationary train horn measured along a test track decayed at 6 dB per doubling of distance, but only up to 30 m or 50 m depending on the height of the horn above the ground. Beyond 30 m or 50 m, the sound attenuated at about 12 dB per doubling of distance on average.

At 200 m and 400 m, the sound level of a horn mounted 2.5 m or 3.0 m above the ground was about 10 dB higher than the sound level of the same horn at 0.5 m above the ground. The height of a horn is important; it will affect sound levels at long distances, but not at the standard test position of 25 m specified in BS EN 15153-2. For this reason, mounting horns close to the ground should be avoided.

The mean attenuation rates beyond 90 m for horns of mainline trains travelling at speed varied considerably. At Site 1, the attenuation rate for individual horn soundings varied between 6.2 dB per doubling of distance and 14.3 dB per doubling of distance with a mean of 9.2 dB per doubling of distance. At Site 2, the attenuation rate varied from 8.5 dB per doubling of distance to 12.5 dB per doubling of distance, with a mean of 10.7 dB per doubling of distance.

The recommended minimum sound levels given by both the *Detectsound* software and method (c) of ISO 7731, the one-third octave band method, are consistent with the horn levels that track workers regard as ‘clearly audible’. The speed and simplicity of the ISO 7731 method will outweigh the better accuracy of *Detectsound* in practice outdoors.

In part, track workers’ reports that horns of newer trains are less audible than horns of older trains can be explained by a reduction in the minimum required sound levels of train horns over time. The horns of the newer Class 80X trains are much closer to the ground than the horns of the older trains they replaced, resulting in lower sound levels at distances beyond about 50 metres. The wide scatter in measured sound levels of train horns at Site 1 could also indicate some variability in output among horns of the newer trains.

7. ACKNOWLEDGEMENTS

This project was undertaken for, and funded by, the Rail Safety and Standards Board as part of project T1205. Trent Instruments of Nottingham made horns available for the laboratory and static testing.

8. REFERENCES

1. British Standards Institution: *BS EN 15153-2:2020. Railway applications — External visible and audible warning devices. Part 2: Warning horns for heavy rail*. British Standards Institution, London. (2020). (Identical to European Standard EN 15153-2:2020)
2. RSSB: Railway Group Standard GM/RT2131 Issue 1. *Audibility and visibility of trains*. Rail Safety and Standards Board, London (2015).
3. International Organization for Standardization: *ISO 9613-2:1996. Acoustics — Attenuation of sound during propagation outdoors — Part 2: General method of calculation*. Geneva, Switzerland (1996).
4. RSSB: Railway Group Standard GM/RT2484 Issue 2. *Audibility requirements for trains*. Rail Safety and Standards Board, London (2007). (Superseded by [2]).
5. Railtrack: Railway Group Standard GM/RT2180 Issue 3. *Visibility and audibility requirements for trains*. Railtrack PLC, Derby (2000). (Superseded by [2]).
6. Zheng, Y., Giguère, C., Laroche, C. and Sabourin, C.: Detectsound Version 2: A software tool for adjusting the level and spectrum of acoustic warning signals. *Canadian Acoustics* **31**(3), 76–77 (2003).
7. International Organization for Standardization. *ISO 7731:2003. Ergonomics — Danger signals for public and work areas — Auditory danger signals*. Geneva, Switzerland (2003).