Relationship between train horn sound levels tested at 25 m and sound levels experienced at distance by track workers

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Abstract. The factors that affect sound propagation and audibility of train horns were investigated. Sound levels from a static horn above a test track decayed by 6 dB per doubling of distance up to about 30 or 50 metres. At greater distances the level decayed by approximately 12 dB per doubling of distance – significantly higher than would be expected from spherical spreading. The effective range of a horn was found to depend on its height - at 400 metres, the sound level from a horn 2.5 metres above the ground was about 10 dB higher than one at 0.5 metres, despite levels at 25 metres being the same. At two mainline sites, the mean attenuation rates beyond 90 metres were around 9 and 11 dB per doubling of distance respectively. At the second site, horn sound levels were highly correlated with distance. At the first site, horn levels were poorly correlated, suggesting variability in propagation or source sound levels.

Keywords: Train horn, Sound propagation, Audibility.

1 Introduction

The current minimum and maximum sound levels for the warning horns of new classes of train in Great Britain are specified at 25 m from the train in EN 15153-2 [1] and Railway Group Standard GM/RT2131 [2]. Although sound levels from horns comply with the version of the standard in force when each train class enters service, the specified levels have changed over the years, and the Rail Safety and Standards Board (RSSB) has received reports from track workers that the horns of some newer trains are quieter and less audible than horns of older trains. This work was undertaken to determine horn sound levels in practice, and the various factors that affect sound propagation and the sound levels experienced by track workers at some distance down the track.

2 Methodology

In ‘static tests’, sound levels from a stationary, Trent KSJ-2 (370 Hz) horn, were measured at a railway test track near Tuxford. The sound levels were measured simultaneously at 5, 10, 25, 50, 100, 200, 400 and 800 metres from the horn. The height of the horn was varied in 0.5 m steps from 0.5 m to 3.0 m above the ballast. The tests were supplemented by modelling using *CadnaA* software. Figure 1 shows the spectrum of the horn which is rich in harmonics [3]. Figure 2 shows the static test site. The test track was straight to about 350 m, with a shallow curve beyond.

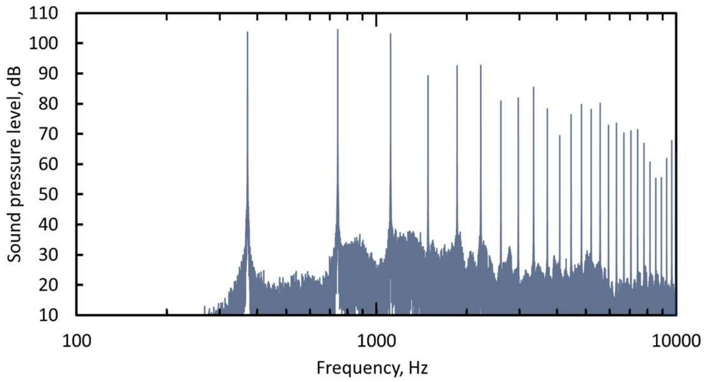

Fig. 1. Spectrum of the Trent Instruments KSJ-2 horn, nominally 370 Hz.

Fig. 2. a) View of test track b) The horn mounted above the test track

‘Dynamic tests’ were then carried out with in-service trains at two rural, mainline sites, shown in Figure 3.

At Site 1, near Didcot on the Great Western Main Line, the line speed was 200 km/h and traffic was a mix of Class 800 bi-mode powered multiple unit passenger trains operating in overhead electric mode and some Class 66 diesel-hauled freight. These passenger trains were fitted with horns about 0.4 m above the rails (0.6 m above the ground). The horns of Class 66 locomotives are nearly 4 m above ground.

Site 2, near Basingstoke on the South West Main Line, had a line speed of 160 km/h and traffic was mainly Class 444/450 passenger third-rail electric multiple units and some 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 in Britain.

Fig. 3. Dynamic test sites. a) Site 1 (Great Western Main Line; four track) b) Site 2 (South West Main Line; double track)

Measurements were made in February and March at Site 1 and in April 2021 at Site 2. Horn sound levels and ambient noise levels were measured with microphones at 7.5 m from the track centre ahead of the trains 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.

During both the static tests and the dynamic tests, panels of experienced track workers were asked to rate the audibility of the horns. These ratings were correlated against measured sound levels. Weather conditions, including wind speed and direction, were recorded.

3 Results

3.1 Static tests

The sound levels measured in the static tests are shown in Figure 4. Each data point is an average of three runs. The sound levels from the horn decayed at 6 dB per doubling of distance (6 dB/dd), due to 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.

The ground surface may affect the attenuation rate, e.g. for slab track the decay at 6 dB/dd might extend to greater distances. This could be investigated in future tests.

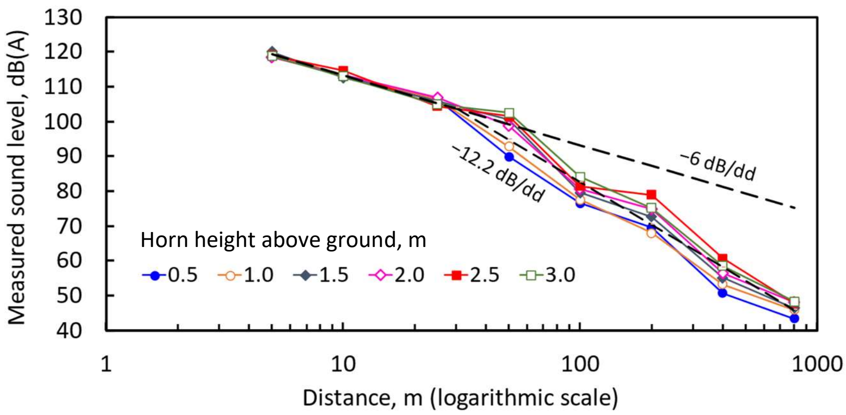

Fig. 4. Sound levels at distances from 5 m to 800 m from the horn in static tests, measured 1.5 m above the ground. The broken lines show −6 dB/dd and −12.2 dB/dd.

Figure 5 shows the variation in sound levels with the height of the horn. 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 a horn only 0.5 m above the ground, although there was virtually no difference in the sound levels measured at 25 m. The effect of horn height is very important.

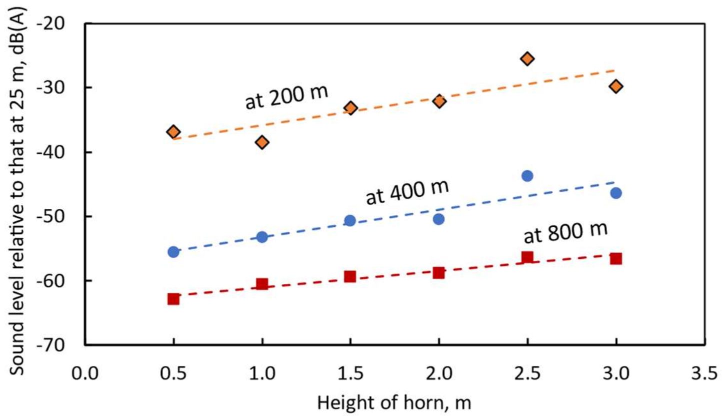

Fig. 5. Sound levels at 200 m, 400 m and 800 m relative to the level at 25 m

3.2 Modelling of static tests

A noise model of the static site was used to compare predicted levels with the measured levels along the track. The calculation procedures in ISO 9613-2:1996 [4] were implemented using *CadnaA* software and a digital terrain model of the local topography.

Receiver heights were 1.5 m above the ground, and the horn or source height was varied between 0.5 m and 3.0 m above the ground. Attenuation of the ground and ground cover were modelled and meteorological conditions including wind speed and direction were matched to those on the day that the measurements were made.

Although the horn sound levels predicted by the ISO 9613-2 model were roughly in agreement with measured levels when topology and weather conditions were accounted for, predicted sound levels were typically higher than those actually measured. The model overestimated sound levels at 200 m and 400 m by approximately 5 dB for horn heights of 1.5 m or 3.0 m. The ISO model is a simple ‘broad-brush’ model often used in estimating noise levels in land-use planning and noise mapping and is best suited for use in meteorological conditions favourable to propagation, usually downwind. It is less suited to conditions prevailing during the static tests, with a light breeze of 4 m/s towards the source. In practice, propagation will vary and not always be favourable. While the measurements showed the horn height to have a large influence on the sound levels at 200 m and 400 m, about 10 dB as shown in Figure 5, the model showed a more modest effect of horn height. A horn at 3.0 m above the ground had a predicted level only 2 dB higher than the horn at 0.5 m at 200 m, and only 4 dB higher at 400 m.

3.3 Dynamic tests

The sound levels measured 1.5 m above the ground in the dynamic tests at Sites 1 and 2 are shown in Figures 6 and 7 respectively. Both A- and C-weighted levels were measured but only the A-weighted levels are shown here. For comparison, the green crosses show the current maximum and minimum sound levels at 25 m, the levels in dB(A) are estimated by subtracting 2 dB from the C-weighted levels specified in GM/RT2131 [2]. In Figure 6, the specified levels at 25 m are for trains travelling above 160 km/h. In Figure 7, specified levels are for trains travelling at or below 160 km/h.

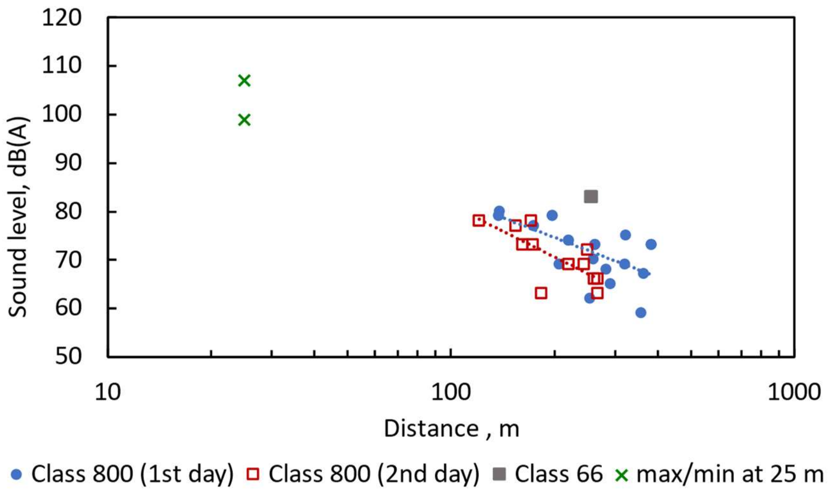

Fig. 6. Measured horn sound levels (L_{AFmax}) at Site 1 (Didcot)

Although Figure 7 shows the current maximum and minimum horn levels at 25 m, the horns of the trains shown in this figure comply with an earlier standard for trains travelling at or below 160 km/h. This earlier standard specified higher sound levels.

At Site 1 the correlation of sound levels of the Class 800 horns with distance was poor, with a wide scatter in sound levels ($R^2 = 0.45$ on Day 1; $R^2 = 0.55$ on Day 2). 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, at Site 2 the sound levels 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 could be caused by minute-to-minute variations in propagation but it could also indicate some variability in the sound levels from the horns at source.

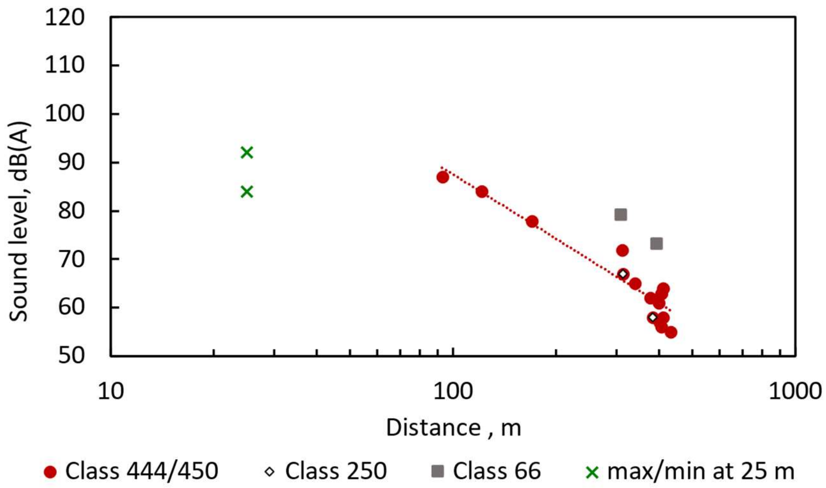

Fig. 7. Measured horn sound levels (L_{AFmax}) at Site 2 (Basingstoke)

Two or three microphones were placed at various positions alongside the tracks at each test site, 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.

The average attenuation rates at distances beyond 90 m were, as expected, usually 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 each attenuation rate was derived from measurements at two positions of the same horn, the measured attenuation rates do not depend on the absolute sound level output of each individual horn, provided that the horn sound levels are sufficiently above the background noise.

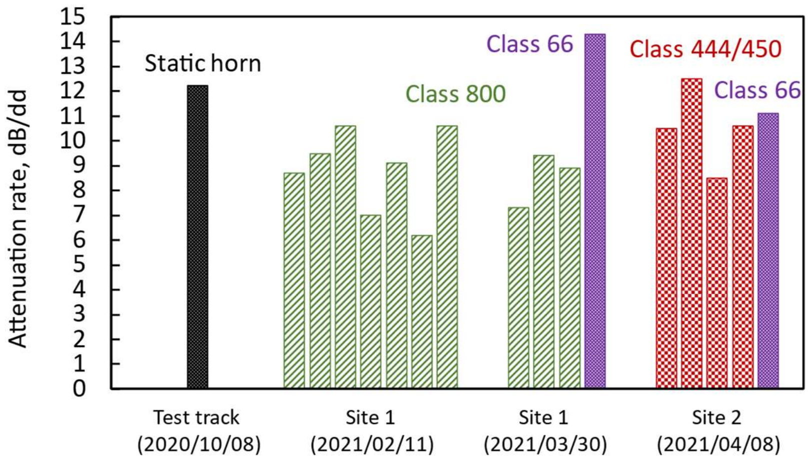

Fig. 8. Measured attenuation rates of individual horn soundings at distances greater than 90 m

4 Audibility

During the static and dynamic tests, experienced track workers whose hearing met the requirements for their job were asked to rate the sound levels of the horns they heard. 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. In the dynamic tests track workers were asked Q2 above but 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) the *Detectsound* software [5] and (ii) the one-third octave band method, method (c), of ISO 7731 [6] 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. 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 sound level could only be varied by positioning the track workers closer or farther from the whistle boards, but the train drivers also sounded their horns as soon as they spotted the track workers in the cess. This is standard practice, but also gave a wider range of horn sound levels for the track workers to rate.

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, simpler and quicker in practice, and the better accuracy of *Detectsound* is outweighed in practical outdoor applications which are less well controlled than indoor environments.

It was also noted 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 may not be universally applicable.

At Site 1 track workers commented that horns of the Class 800 trains were quieter than the horns of the Class 43 trains that they replaced. Class 43 trains no longer run at Site 1, so it was not possible to measure their horn sound levels for comparison. Also, at Site 1, the whistle boards are presumably positioned so that a horn should be audible at their associated foot crossing. Nevertheless, in 24% of the pass-bys, only half the subjects or fewer located at this crossing rated the horns as "clearly audible".

5 Conclusions

Sound levels from a stationary train horn measured along the track decayed at 6 dB/dd, 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, with ballasted track, the sound attenuated at about 12 dB/dd.

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 distance of 25 m specified in EN 15153-2. The fitting of horns close to the ground would best be avoided in future designs.

The mean attenuation rates beyond 90 m for trains travelling at speed varied considerably. At Site 1, the attenuation rate for individual horn soundings 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.

6 Acknowledgements

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

7 References

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