Preliminary Nord2000 noise results for Queensland NGR trains

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ABSTRACT

A sizable noise measurement programme was undertaken prior to the construction of a large infrastructure project in Southeast Queensland. The data acquired prior to any construction was used for the verification of a rail noise model where the Kilde calculation algorithm was used for the noise predictions and model verification.
The data obtained in the pre-construction phase included video recordings with simultaneously recorded noise levels near the rail track. The acquired noise data also include noise levels recorded at the facades of twelve dwellings situated from 35 m to 270 m from the rail tracks. It should be noted that the rail corridor only is used for passenger trains and that the majority of trains operating on the tracks are NGR trains.
The data was at a later stage revisited to develop the Nord2000 rail coefficients for the NGR trains and compare predicted noise levels at the facades of the dwellings when using the two different calculation algorithms.
This paper compares the predicted noise levels of the Kilde and the Nord2000 calculation algorithms to the measured noise levels.

1. INTRODUCTION

Noise monitoring was undertaken at several noise sensitive dwellings for a large infrastructure project that included a section of rail. As part of the project, noise verification was undertaken using the Kilde 67/130 calculation algorithm to determine the difference between modelled and measured noise levels.
The difference between measured and modelled levels was relatively small for locations close to the rail track, but the noise model overpredicted the noise level at one of the most distant locations by almost 20 dB.
It should be noted that the area between the rail track and this receptor was very dense vegetation, which was not included in the noise model.
The measurement data collected during pre-construction noise monitoring was assessed and analysed. The data was used to determine the Nord2000 emission levels such that the Nord2000 prediction method could be used to determine the difference between modelled and measured noise levels. This paper summarises how the source data was established. The paper also presents measured noise levels in various forms and finally the paper presents a comparison of the two methods.

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2. ESTABLISHMENT OF NORD2000 SOURCE DATA

Attended noise measurements were undertaken 40m from the southbound rail track and 44m from the northbound track. A camera was used to capture each passby which during postprocessing of the data was used to determine train speeds. Albeit noise measurements were taken at several locations in the project area only measurement from this one location was used to establish the noise source data presented in this paper. This measurement location was further away from the track than recommended 10m to 30m as outlined in the Nordic documentation.
Figure 1 shows the average of the measured sound exposure levels as a function of frequency. The figure shows that the measured noise levels in two of the frequency bands (40 Hz and 630 Hz) are higher for a trains speed of 80 km/s than for 135 km/h. The figure also shows that the frequency bands containing most energy with the A-weighting filter applied is the frequencies between 630 Hz to 4000 Hz when the train is travelling at 80 km/h and 1 kHz to 4 kHz when the train is travelling at 135 km/h.

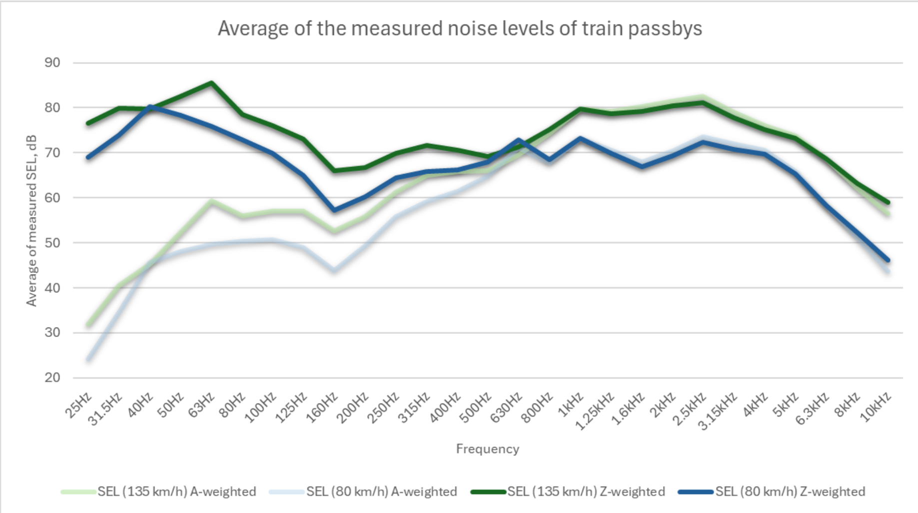

Figure 1: Sound exposure level of one train 40 m from the rail track

The measured noise levels were normalised to 10 m from the track and a train length of 100 m. Figures 2 to 4 shows the normalised noise levels in third octave data for the 15 train passbys as a function of train speed. The figures also include selected linear regression lines. The regression lines were applied to the data to determine the Nord2000 coefficients.

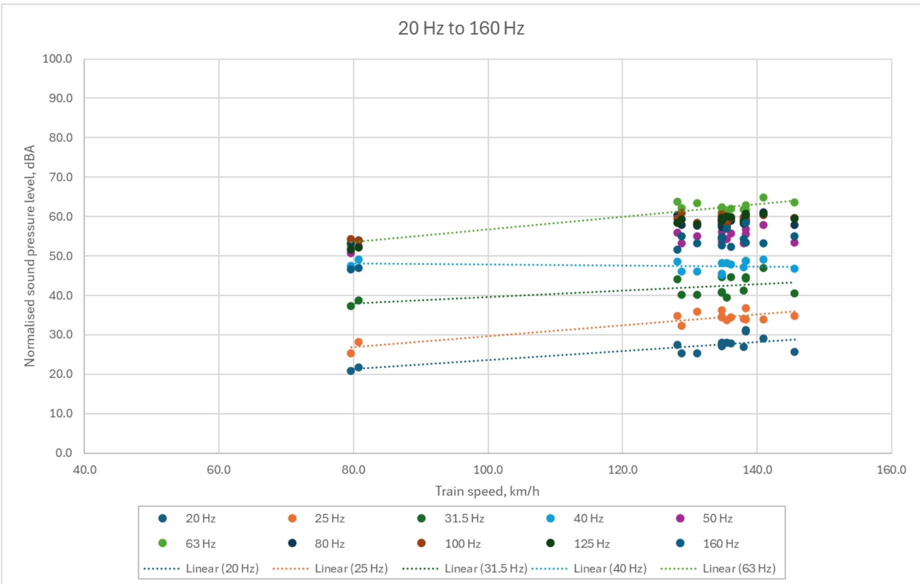

Figure 2: Normalised Sound Pressure Levels from 20 to 160 Hz

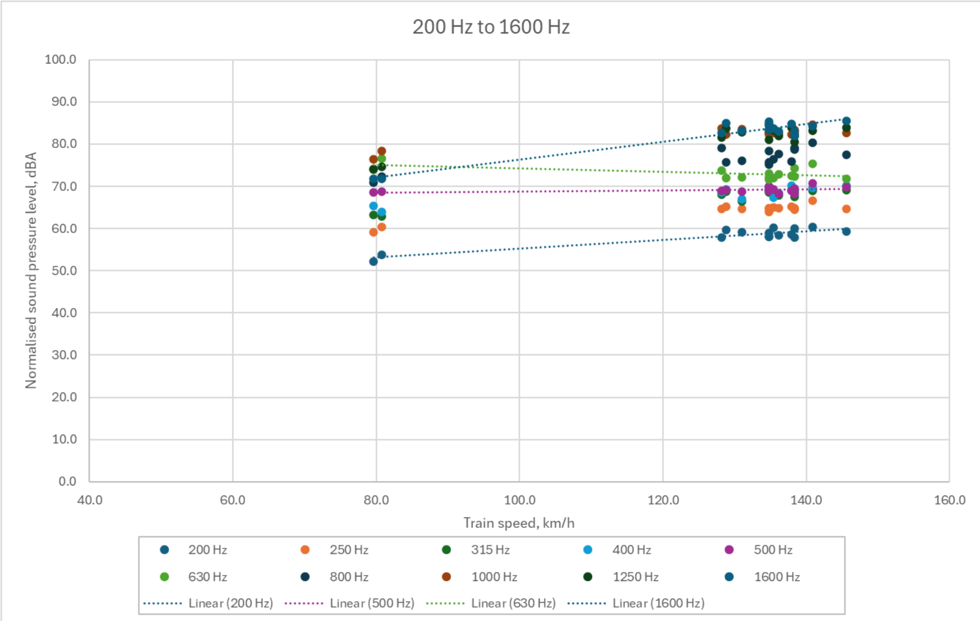

Figure 3: Normalised Sound Pressure Levels from 200 to 1600 Hz

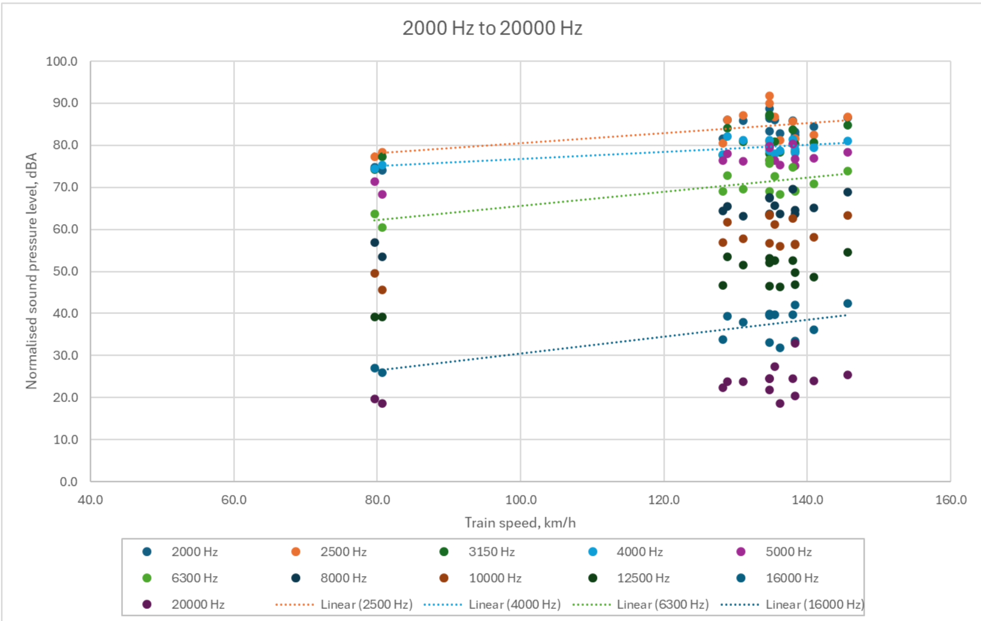

Figure 4: Normalised Sound Pressure Levels from 2000 to 20000 Hz

Figures 3 and 4 show that the frequency bands that predominantly drive the emission levels are the frequency bands between 1 kHz and 4 kHz. The figures also show that the noise level decreases for the 40 Hz and 630 Hz bands with increased train speed whereas the noise levels increase with increased speed for all other frequency bands.

The coefficients from the formulas of the linear regression lines were used for the determination of the Nord2000 coefficients.

The determined Nord2000 coefficients were inserted into SoundPLAN and predictions were undertaken. It is important to note that ground conditions were ignored for the initial determination of the coefficients.

The model was run to predict the noise levels at the monitoring locations to determine if the model predicted the measured noise levels at the measurement location.

Table 1 presents the settings used in the noise models.

Table 1: SoundPLAN settings

Parameter	Value
Ground absorption, α	0.3
Effective flow resistivity Sigma (kNs/m^4)	2000
Roughness Class (m)	+/-0.5
Train length, L (m)	145
Track length, Lt (m)	20000
Search radius, Sr (m)	5000
Assessment duration, t (hours)	24
Weather	DK Weather Statistics suppl. 4 cl

Figure 5 shows the difference between measured and predicted noise levels of the first iteration of determining the coefficients for the NGR train.

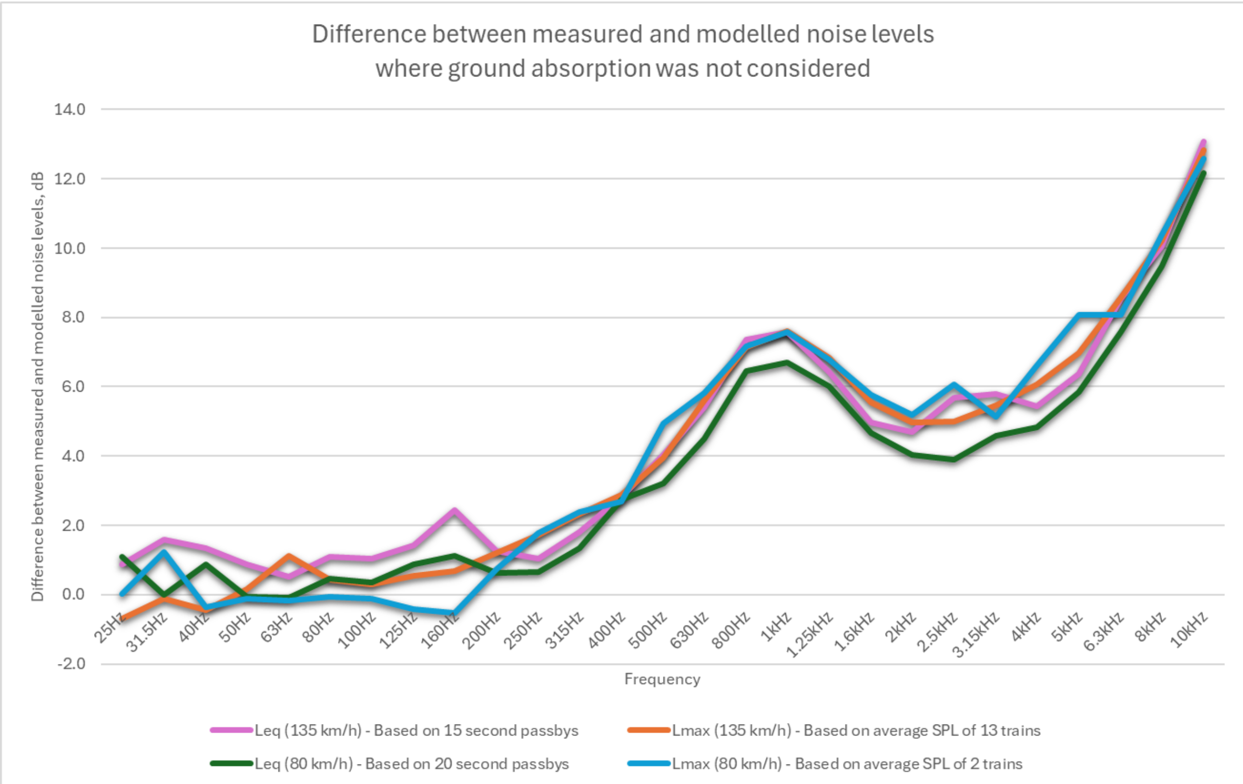

Figure 5: Difference between measured and predicted noise levels

Figure 5 shows that the prediction of the L_{eq} and the L_{max} noise descriptor for the two assessed train speeds follow the same trend closely. The figure shows that the noise model does not predict nearly enough acoustic energy in the frequency bands above 400 Hz.

The figure illustrates the importance of taking the ground conditions into account when determining the a and b coefficients for a train for the NORD2000 model. The Nordic method states that the a and b values should not include the effect of ground.

The paper: *"A Comparison of two engineering models for sound propagation: Harmonoise and Nord2000"*, also shows the effects of ground conditions as a function of frequency in relation to predicted and measured levels. Figure 6 and Figure 7 presents sound propagation as a function of frequency, note that the measured levels were from a 1:25 scale model.

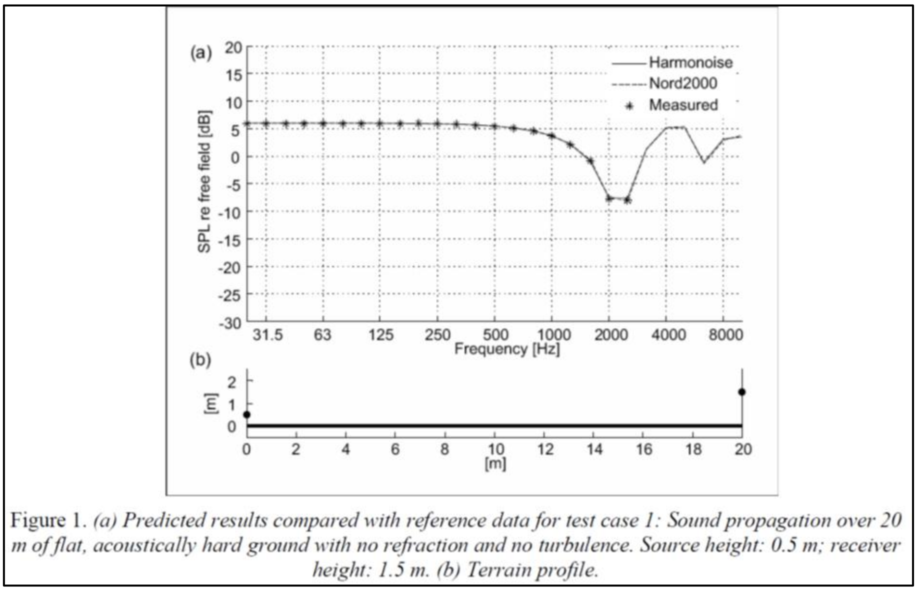

Figure 6: Difference between measured and predicted noise levels

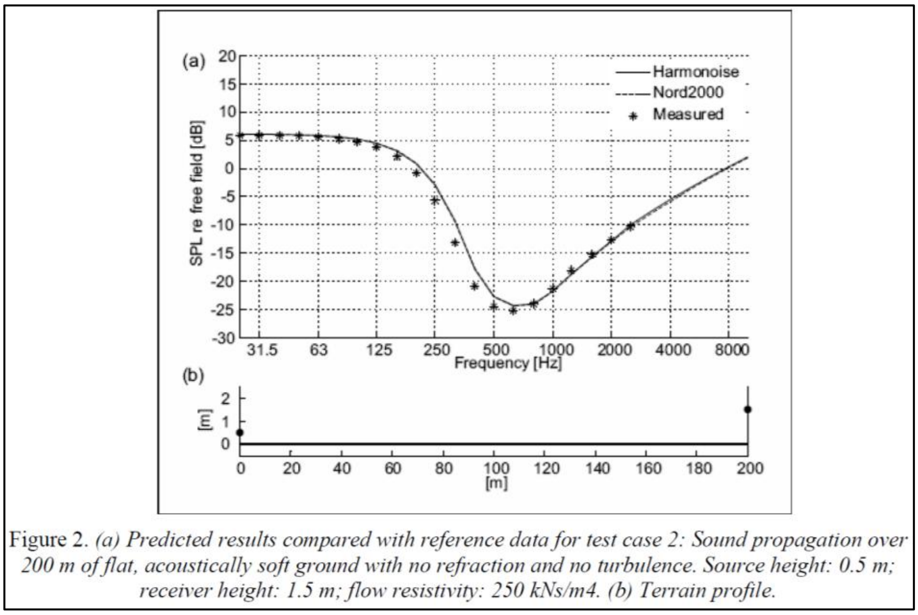

Figure 7: Difference between measured and predicted noise levels

Figure 6 and Figure 7 shows that significant noise attenuation occurs at mid to high frequencies for both the noise models as well as the measurements of the scale model.

2.1. Correction for ground conditions

The average of the difference between measured and predicted noise levels were calculated for each frequency band and applied to the measured noise levels to account for ground conditions. These new measured levels including corrections for ground conditions were used to determine the a and b coefficients for the NGR trains.

The model was run again to predict noise levels at the measurement location. The updated coefficients for the NGR train resulted in maximum deviations at any of the frequency bands of 1.5 dB and an average deviation at any band of up to 1 dB. Figure 8 presents the difference between measured and predicted noise levels for the NGR v2 train.

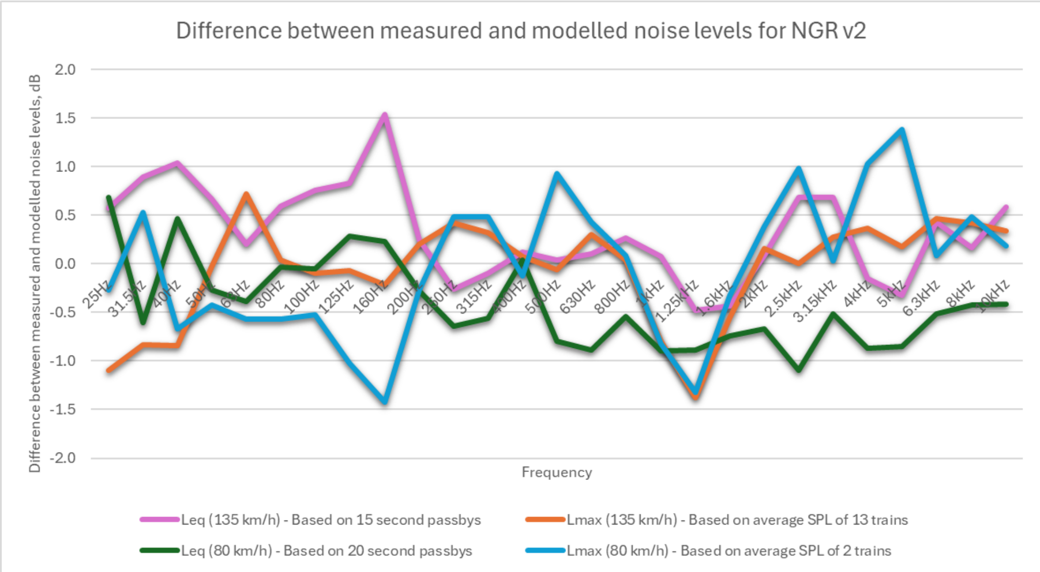

Figure 8: Difference between measured and predicted noise levels for NGR v2

Table 2 shows the coefficients determined for the NGR v2 train.

Table 2: Nord2000 coefficients for the NGR v2 train

Frequency, Hz	**25**	**31.5**	**40**	**50**	**63**	**80**	**100**	**125**	**160**	**200**	**250**	**315**	**400**	**500**
a-coefficient	44.2	29.6	5.9	24.6	50.3	31.6	34.0	42.9	42.9	35.9	32.3	33.5	29.0	12.2
b-coefficient	81.0	86.0	88.8	89.5	89.7	84.7	82.0	77.8	70.2	73.4	77.9	79.9	80.1	82.1
Frequency, Hz	**630**	**800**	**1000**	**1250**	**1600**	**2000**	**2500**	**3150**	**4000**	**5000**	**6300**	**8000**	**10000**	
a-coefficient	-1.0	35.3	34.2	46.4	62.8	55.5	40.6	35.9	31.0	42.4	51.4	55.6	61.8	
b-coefficient	87.4	87.8	93.1	89.8	87.1	88.3	90.6	88.3	87.7	85.4	80.4	76.7	73.9	

3. NOISE EMISSION LEVEL AS A FUNCTION OF SPEED

The determined Nord2000 coefficients were plotted to show the noise emission levels as a function of train speed, this data is shown in Figure 9. The figure also shows a linear line that increases by 1.25 dB per 10 km/h speed increase. The line denoted SUM on the figure is the overall A-weighted noise level.

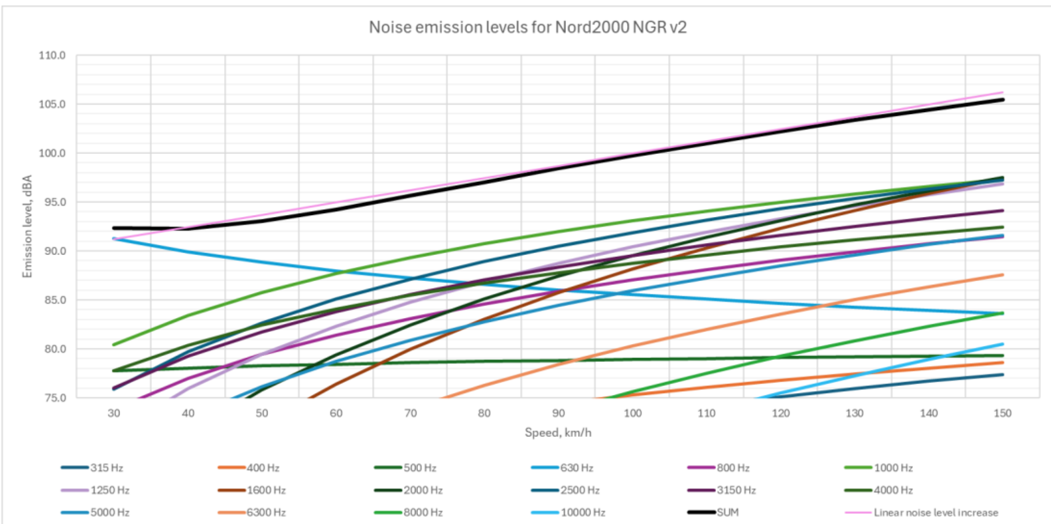

Figure 9: Train emission levels as a function of speed for NGR v2

Figure 9 shows that the noise emission of the 630 Hz frequency band becomes the dominating energy contributor at low speeds. As no train passbys were measured below 80 km/h it is recommended that the coefficients presented in this document only is used for train velocities between 70 km/h and 150 km/h.
The figure also shows that the overall A-weighted noise emission level of the NGR train increases by approximately 1.25 dB for each 10 km/h speed increment, which is a linear noise increase as a function of speed. In comparison the Kilde 67/130 method implements a logarithmic noise emission increase as a function of speed. Figure 10 shows a Kilde train as well as the NGR v2 train as a function of speed plotted on a logarithmic x-axis. The Kilde train was normalised to the same emission level at 140 km/h as the NGR v2 train.

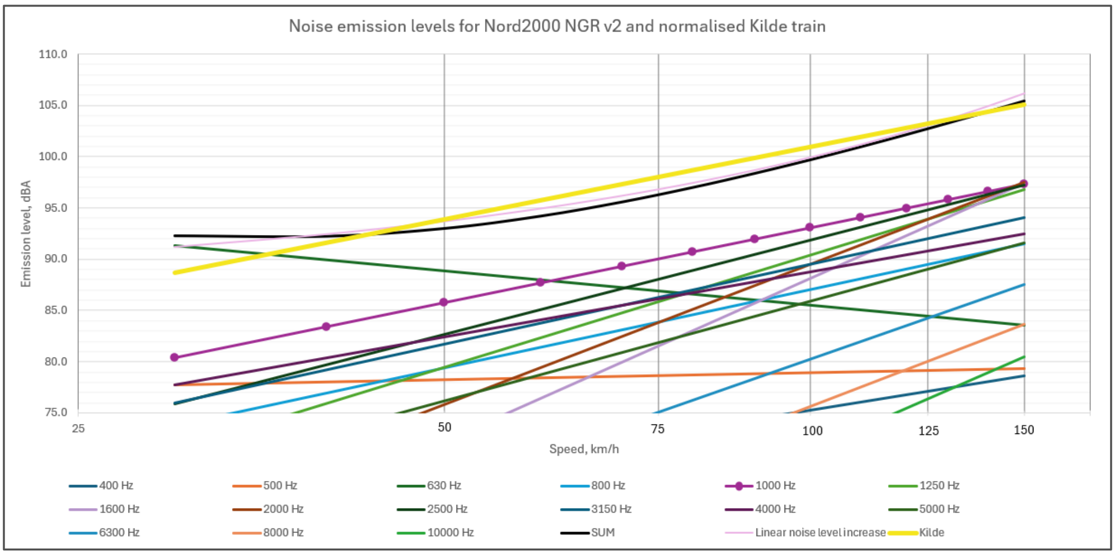

Figure 10: Train emission levels for NGR v2 and normalised Kilde train

Figure 10 shows that the emission lines for all the Nord2000 frequency bands and for the normalised Kilde train are straight lines, whereas the overall A-weighted noise level of the Nord2000 train is not a straight line. The figure further shows that the deviation between the Kilde train and the Nord2000 train in the usable speed range (70 km/h to 150 km/h) is up to 2 dB.

4. MEASURED NOISE LEVELS AT DWELLINGS

The recorded data for three consecutive days were analysed at the dwellings where noise monitoring was undertaken. It was noted that the noise level on the first day was significantly higher compared to day two and three. Figure 11 shows the recorded noise levels from 1 to 3 November 2023 for a location close to the rail track. Figure 12 shows the noise for the location furthest from the track. This location is also screened from the track due to a noise barrier and several buildings situated between this measurement location and the rail track.

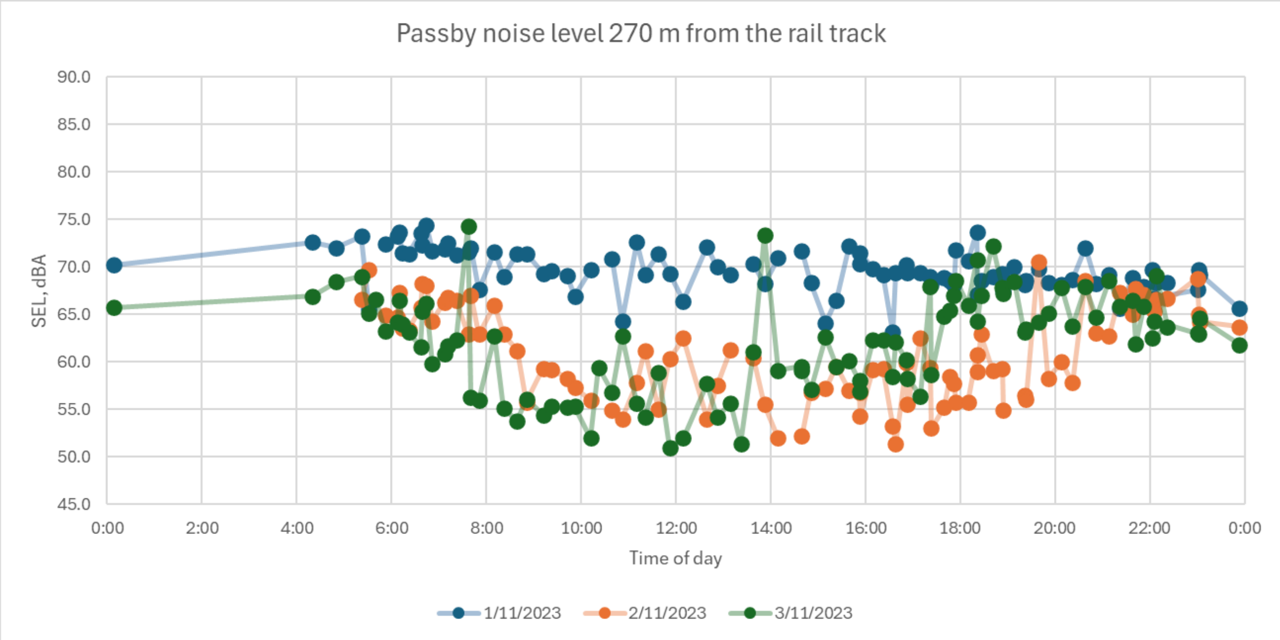

Figure 11: Measured noise levels 270 m from the rail track

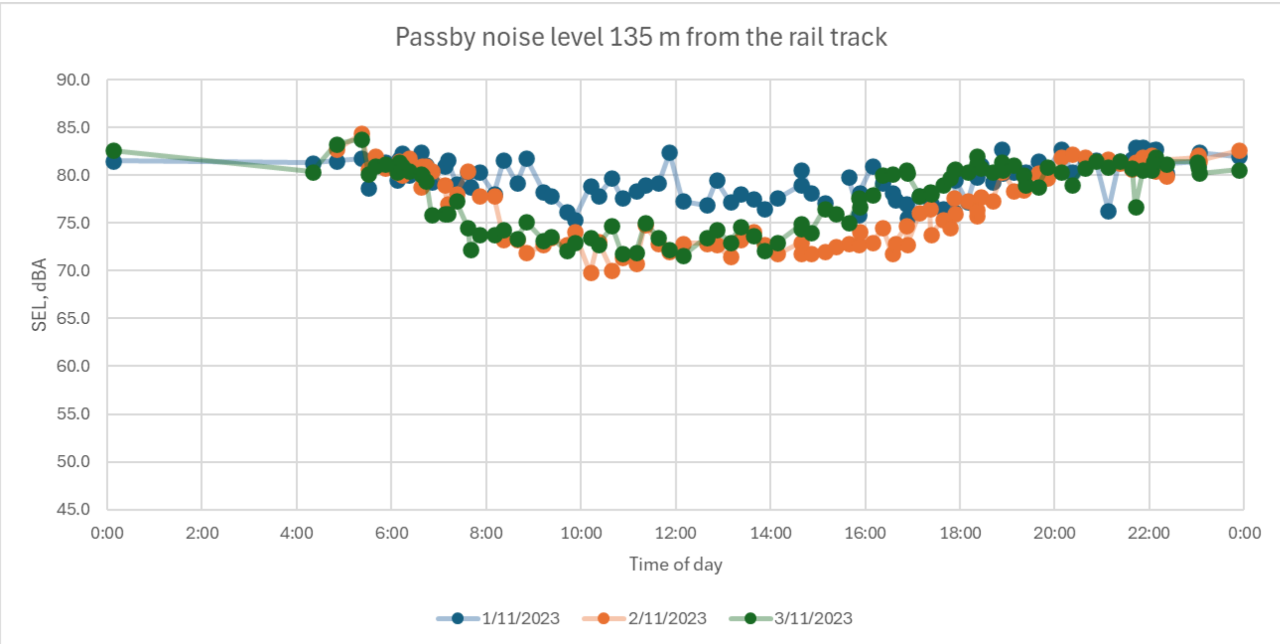

Figure 12: Measured noise levels 135 m from the rail track

Both Figure 11 and Figure 12 shows that the measured noise levels generally are higher for day 1 compared to the following two days. The difference is more pronounced during the daytime period and more noticeable for the location furthest away from the track. The figures also show that the highest noise levels generally are measured during the morning period.
The wind speed on day 1 was slightly higher compared to day 2 and 3. The wind direction on day 1 was parallel to the rail track whereas the wind direction on the following two days was in the direction from the receptors towards the rail track.
Figure 13 shows the weather data recorded in the area for the three days.

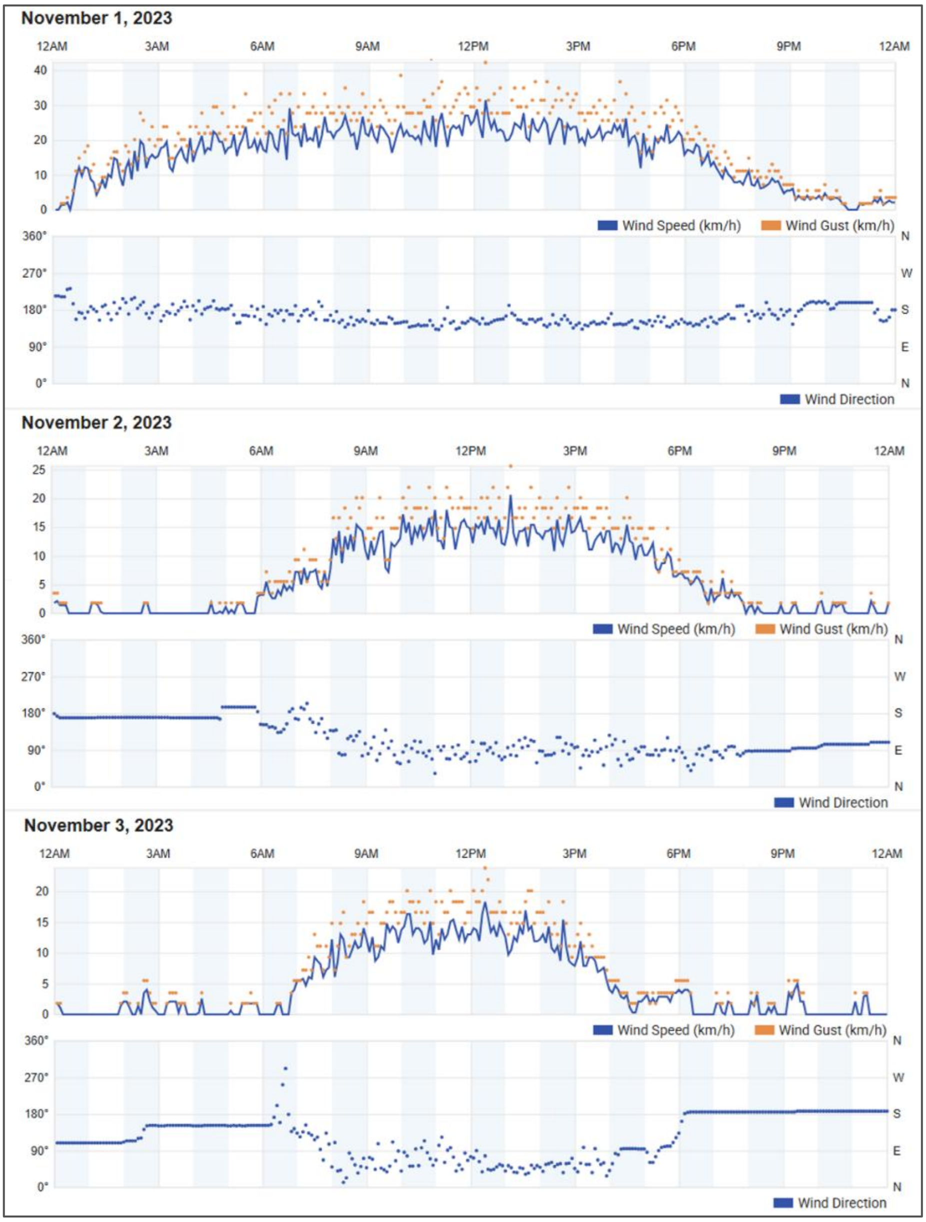

Figure 13: Weather data during the rail monitoring period

The weather data shows more wind on day one compared to the following two days.
The monitoring locations are shown on Figure 14a. The figure also shows the distance between the monitoring location and the rail track. The numbering of the measurement locations are based on distance from the rail track where measurement location 1 is the receptor situated closest to the rail track. Figure 14b shows the measured noise levels at the receptor locations. The measured level on Figure 14b is the average of measured SEL's over the three days of monitoring. Where the variations observed in Figure 11 and Figure 12 are incorporated, the measured noise level could be up to 8 dB higher at location 12 and up to 4 dB higher at location 8.

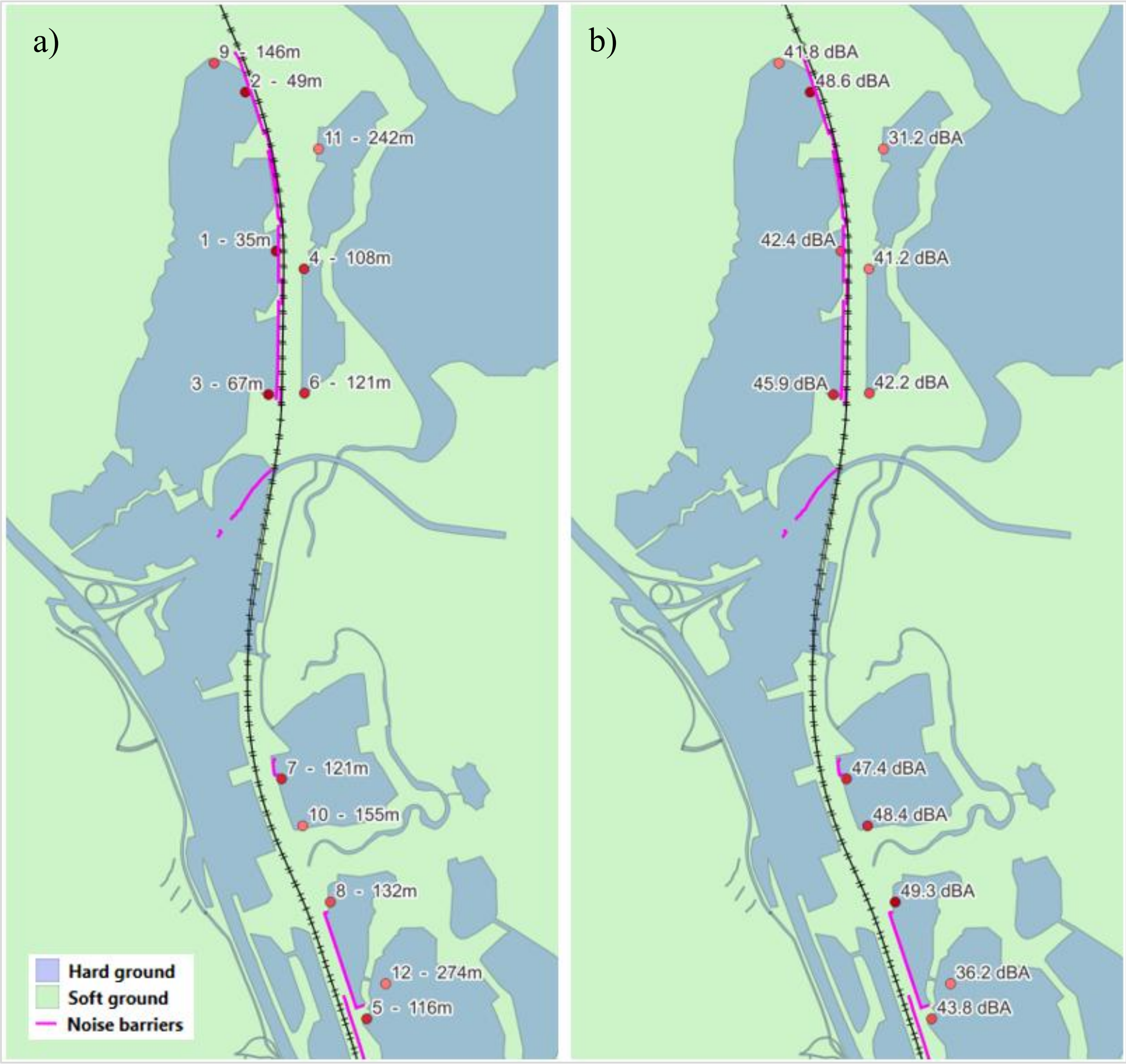

Figure 14: Monitoring locations and measured noise levels

Figure 14 shows that for most of the locations the measured noise level is higher the closer the receptor is located to the rail track.

5. PREDICTED NOISE LEVELS AT DWELLINGS

The noise model created for the large infrastructure project was adopted for the prediction of noise levels using both the Kilde 67/130 method and the Nord2000 method.
The model was set to 98 trains per 24 hours to be consistent with the number of trains passbys measured each day.
The Kilde model used an absorption coefficient of 0 for hard ground and 1 for soft ground.
The Nord2000 model was set to:

- Absorption of 0, Effective flow resistivity Sigma = 2000 kNs/m^4 (N2k: F: compacted dense ground (gravel road, parking lot). Roughness Class: S: Small +/-0.5 m for hard ground
- Absorption of 1, Effective flow resistivity Sigma = 80 kNs/m^4 (N2k: C: uncompacted loose ground (turf, grass, loose soil). Roughness Class: S: Small +/-0.5 m for soft ground.

Figure 15 shows the difference between the predicted noise level and the measured noise level for the Kilde and the Nord2000 prediction algorithms.

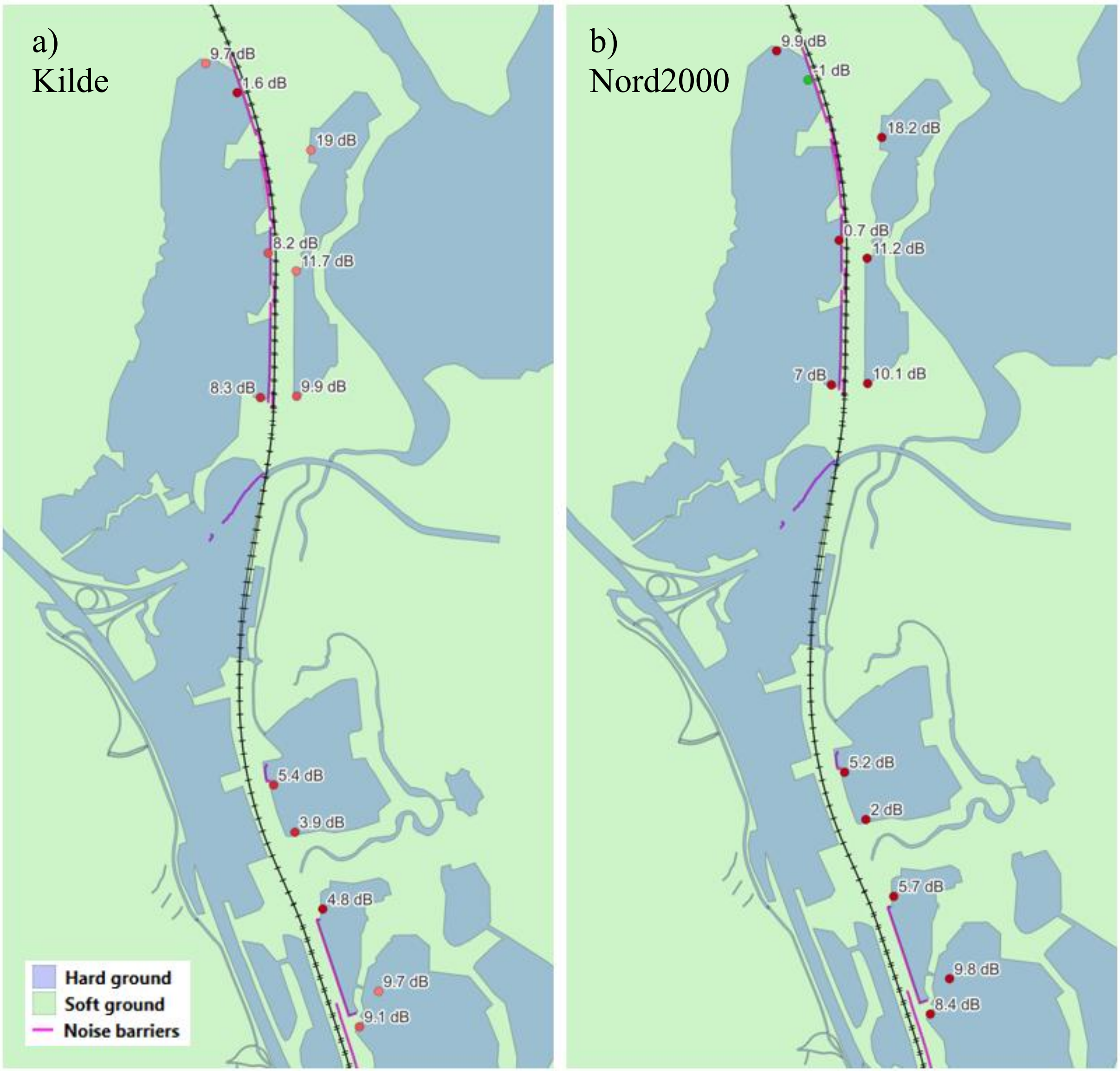

Figure 15: Difference between predicted and measured noise levels

Figure 15 shows that there is not a significant difference in predicted noise levels at most of the receptors. The largest difference is at receptor number 1 where the overprediction has changed from 8.2 dB for the Kilde prediction to 0.7 dB for the Nord2000 prediction. Receptor number 1 is situated behind a large noise barrier and there is no line of sight to the rail track from this monitoring location. Location 2 shows a 1.6 dB overprediction for the Kilde calculations, whereas the Nord2000 method shows an underprediction of 1 dB. This location is the only location where the Nord2000 model underpredicts.

The average overprediction for the two models are as follows:

- 8.4 dB for the Kilde model
- 7.3 dB for the Nord2000 model

Both noise prediction methods show a substantial overprediction at location 11. It should be noted that there is significantly vegetation between the rail tack and location 11. The vegetation was included in both noise models. Table 3 shows the noise model settings for the vegetation included in the noise models.

Table 3: SoundPLAN settings for vegetation

Model	Parameter	Value
Kilde	Amax (dB)	20
Kilde	a(f) (dB/m)	0.05
Kilde & Nord2000	Effective height (m)	10
Nord2000	Mean stem radius (m)	0.15
Nord2000	Mean tree density (1/m^2)	0.25
Nord2000	Mean stem radius (m)	0.15
Nord2000	Factor kp	1.25
Nord2000	Mean absorption coefficient	0.1

Figure 16 shows the difference between the predicted noise level and the measured noise level for the Kilde and the Nord2000 prediction algorithms with vegetation included in the noise model.

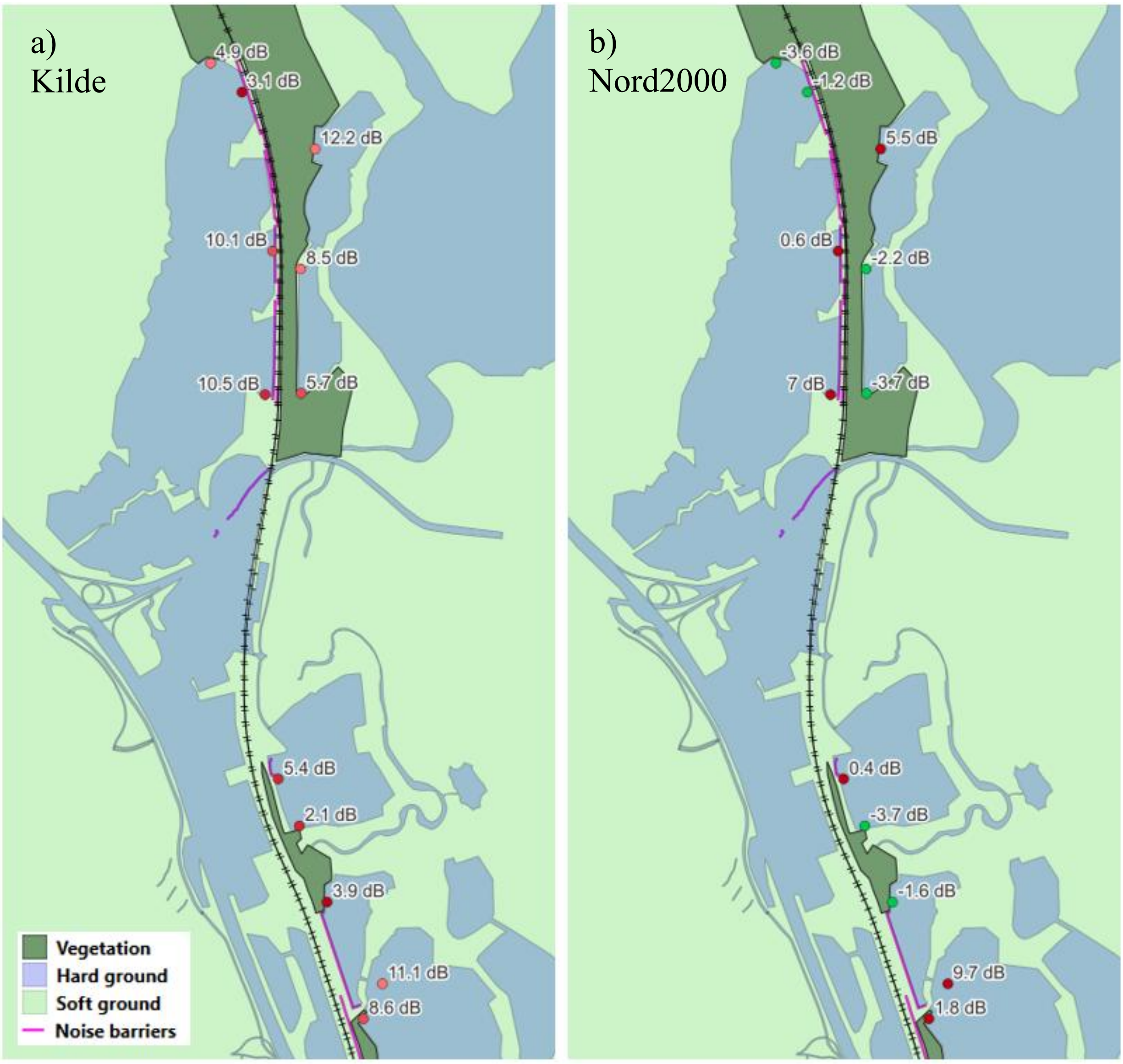

Figure 16: Difference between predicted and measured noise levels with included vegetation

Figure 16a shows that that the overpredictions that were presented in Figure 15a have reduced. It is also interesting to see that the Kilde method predicts a noise increase in areas on the opposite side of vegetated areas.
The Nord2000 method shows that the noise level is underpredicted at half of the measurement locations and overpredicted at the other half.
The average overprediction for the two models are as follows:

- 7.2 dB for the Kilde model
- 0.8 dB for the Nord2000 model

6. DISCUSSION

The Kilde method predict conservative noise levels as the model predictions only are valid for downwind conditions.
Vegetation is often included only for verification purposes, rather than as a reliable input for future predictions. This is because vegetation can change or be removed over time for many reasons, including land clearing, agricultural activity, urban development, road construction, fire, drought, flooding, disease, seasonal dieback, changes in land management, or natural succession. In some cases, vegetation that is present at the time of verification may no longer exist when future conditions are being predicted.
Where vegetation is included in a predictive model, the consultant should be able to clearly justify its inclusion. There may be valid reasons for using vegetation as an input, particularly where it is expected to remain stable, where it is directly relevant to the process being modelled, or where its future condition can be reasonably supported by evidence.
For this reason, vegetation should be treated carefully. It may be useful for checking or validating current observations, but it should generally not be assumed to remain unchanged in predictive modelling unless there is strong evidence that the vegetation will persist over the relevant prediction period.

7. CALCULATION TIME

The time taken for the calculation of 20 receptors for the Kilde model was 2 minutes. The Nord2000 model took 71 minutes to calculate the noise level for the same 20 receptors. It is worth noting that it may take up to 35 times as long to predict noise levels using the Nord2000 algorithm.

8. CONCLUSIONS

The study undertaken for this paper developed and validated Nord2000 emission coefficients for Queensland NGR trains using detailed pre-construction noise measurements. The results demonstrate that both the Kilde and Nord2000 prediction methods tend to overestimate rail noise levels, particularly at receptors located further from the track. Both methods generally provide reasonable agreement with measured data at locations close to the rail corridor where no or very limited screening is situated between the rail track and the monitoring location. The only notable difference between the two prediction algorithms was for a location behind a large noise barrier. At this location the Kilde method showed a significantly overprediction, whereas the Nord2000 method showed good agreement with measured levels.
The modelling further showed that the inclusion of vegetation in the noise model reduced the difference between measured and modelled noise levels.
The calculation time took 35 times longer for the Nord2000 method compared to the Kilde method. This may limit its practicality for large-scale or time-sensitive projects.
Overall, the findings highlight a trade-off between computational efficiency and modelling accuracy. While the Kilde method remains suitable for conservative and rapid assessments, the Nord2000 method offers enhanced frequency dependent detailed noise analysis, particularly in complex environments where shielding and ground effects play a significant role.

9. ADDITIONAL WORK

The analysis of the L_{max} noise descriptor is required for a more comprehensive understanding of the difference between predicted and measured noise levels for the two noise prediction methods. The project did unfortunately not require assessment of the L_{max} descriptor; however, the L_{max} will be extracted from the measurement data for comparison of the modelling methods at some point in the future.
The noise modelling used the weather *DK Weather Statistics suppl. 4 cl* for the noise predictions, additional work needs to be done to understand the effect of changing the weather profile.
Noise analysis has only been undertaken for one type of passenger train. Measurements and analysis of other trains and in particular freight trains should be undertaken to improve the understanding of the Nord2000 prediction method compared to the Kilde prediction method.

ACKNOWLEDGEMENTS

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