SWECO

Strandlodsvej Portal Study

Noise report

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Introduction

This report has been prepared on the basis of an ongoing investigation into the possibilities for reducing noise from the metro trains as they pass through the trough at Strandlodsvej. The noise-related challenges are partly caused by operation through turnouts and partly by operation in a sharp curve. Based on general considerations, the report describes the noise-related factors that turnouts and sharp curves may give rise to.

In addition to the trough's sheet-pile walls, which are approximately 1 m higher than the surrounding terrain, there is currently no further noise shielding. The present study describes the level of noise reduction that can be expected to be achieved by installing shielding along the edge of the trough.

A site plan of the area is shown in Figure 1. There are two turnouts in each track (marked in green), and the track section subject to curve squeal is marked with in red.

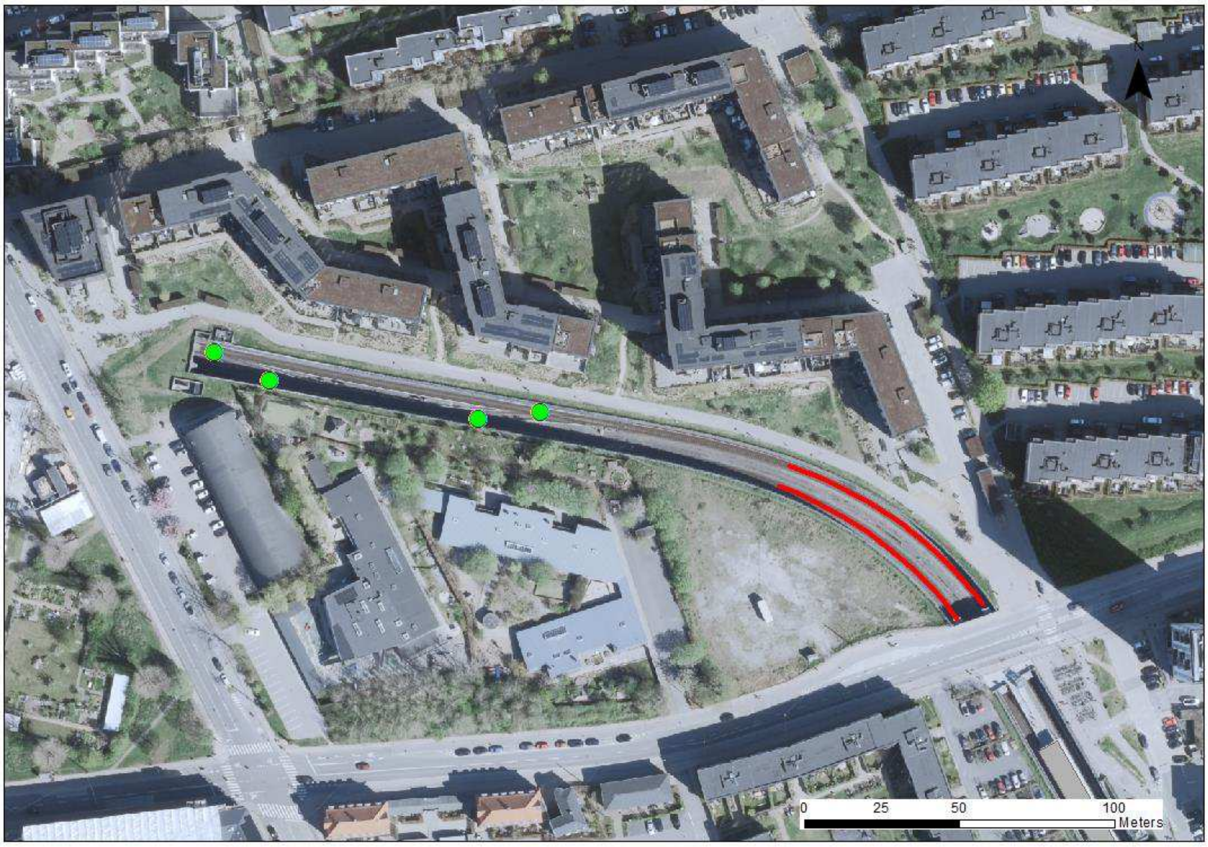

Figure 1 – Site plan of the reilway trough and surrounding area at Strandlodsvej. Turnouts are marked in green

The area was inspected on 24 February 2026, and during the inspection a clearly audible increase in noise from all four turnouts was observed. The curve marked in red in the figure has a radius of approximately 120 m, and an elevated noise level was likewise observed from this track section in both directions.

The trough section is located approximately 30–300 m northeast from Øresund Station. The speed of the metro trains is relatively low and is assessed in all cases to be below 50 km/h.

Noise from turnouts

Turnouts in railway tracks have a significant noise impact compared with ordinary straight track. The primary cause of the increased noise is the geometric irregularity of the turnout, where the wheels, among other things, pass over the turnout frog. This results in impacts and shocks between the wheels and the rails, leading to elevated noise levels and, to some extent, vibrations in the surroundings.

The total noise level at turnouts is typically about 3–6 dB higher than on ordinary straight track, while older or more worn turnouts may cause noise increases of up to 10 dB or more.

In general, turnouts give rise to increased noise over a wide frequency range, but predominantly in frequencies below approximately 2000 Hz, where the increase in individual 1/3-octave frequency bands may be in the order of 10–20 dB.

For slow-moving trains, the dominant frequency range for the overall noise level is typically between approximately 315 Hz and 2000 Hz (1/3-octave bands). At higher speeds, the frequency spectrum typically shifts towards higher frequencies, while the noise generated by the turnout increases.

The human ear is particularly sensitive in the frequency range from 1000 Hz to 5000 Hz, which means that noise from turnouts is often perceived as distinct noise hotspots.

Figure 2 shows the frog of one of the turnouts in the railway trough at Strandlodsvej. Note the large, polished area indicated by the arrow, which suggests a worn frog.

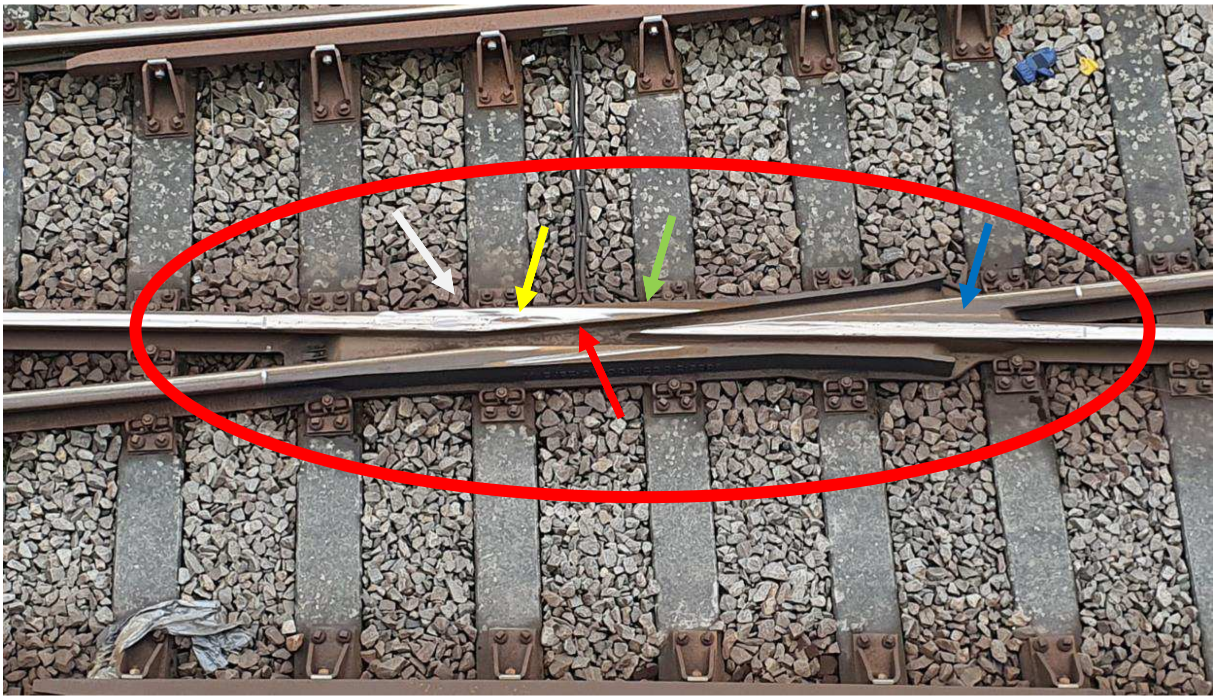

Figure 2 – The frog of one of the turnouts in the railway trough at Strandlodsvej (the turnout closest to Øresund Station).

The image in Figure 2 also suggests other conditions, based on the wear marks, that may have contributed to increased noise. Our interpretation is as follows: The narrow contact band at the nose of the crossing in the through route (blue arrow) is most likely due to a concave wheel profile. The wheel flange keeps the wheel constrained, which is why the wear band appears narrow.

On the wing rail to the left of the crossing nose (green arrow), the hollowness of the wheel profile is still visible as a narrow wear band, although it is wider than at the crossing nose most likely due to a small lateral wheel movement.

At the crossing (red arrow), due to reduced guidance from the wheel flange, the narrow hollow wheel wear band is no longer visible because of a more significant lateral wheel movement.

The unworn areas / dark markings (yellow arrow) on the intermediate piece / wing rail have an irregular pattern and are immediately interpreted as an incipient defect or possibly a shrinkage cavity in the casting.

The contact area at the white arrow is wider than on the railhead before and after the frog and is likewise assessed to be caused by lateral movement.

Noise at the frog is likely to occur at three locations in this turnout:

- Where the back side of the outer surface of the concave wheel impacts the cast crossing nose (blue arrow).
- Where the back side of the outer surface of the concave wheel impacts the wing rail (green arrow).
- Where the load transfer between the crossing nose and the wing rail takes place (red arrow).

Clearly both inadequacies in the track and rolling stock maintenance are major contributory factors in any noise which is generated in the crossing locations.

Based on the site inspection carried out on 24 February 2026, the noise increase from the turnouts in the railway cutting at Strandlodsvej is assessed to be in the order of +10 dB.

In railway noise calculations, the increased noise from turnouts was, until 2023, only included in the calculation of the maximum noise level, where a fixed noise penalty of +6 dB was applied for all train types, while no correction was applied to the equivalent noise level.

Based on new studies carried out by Banedanmark, the railway noise calculation method (NORD2000) has now implemented train-type-dependent corrections for both maximum noise levels and equivalent noise levels when trains pass through turnouts. Depending on the train type, the average noise penalties at turnouts are up to approximately +7 dB. However, these corrections apply only to trains operating on Banedanmark’s infrastructure and are referenced to the track condition level that Banedanmark defines as “well-maintained track”.

Figure 3 shows an example of the average frequency increase in noise for S-trains passing through turnouts at speeds of 60 km/h and 100 km/h, respectively.

Noise from metro trains passing through turnouts has not been investigated, and it is therefore highly likely that the noise from above-ground sections is underestimated at locations where turnouts are present.

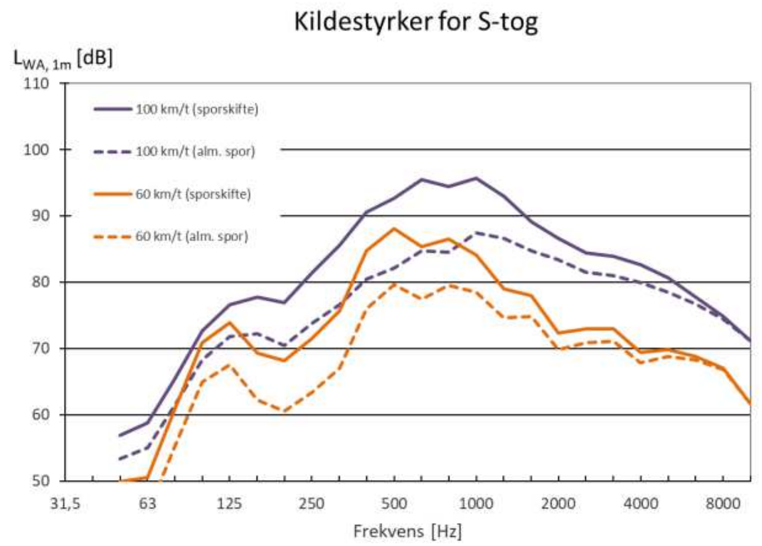

Figure 3 – Comparison of spectral noise levels from S-trains running on well-maintained track (dotted line) and through turnouts (solid line) at speeds of 60 km/h and 100 km/h, respectively. Source: Force Technology, report TC-101656 rev. 1, "Noise from trains passing over turnouts".

Curve squeal noise

Curve squeal on railways occurs when trains operate in curves with small radii.

The curvature forces rigid wheelsets to accommodate different rolling distances for the left and right wheels, resulting in increased lateral creepage and relative sliding at the wheel–rail contact. Noise generation is primarily associated with the contact between the wheel tread and the rail head near the rail crown, where high friction conditions may initiate a self-excited stick–slip mechanism. In addition, noise contributions may occur at the wheel flange–rail gauge face contact, particularly for the leading wheelsets of each bogie as they are guided through the curve.

The stick–slip behaviour is generally more pronounced at the running surface contact than at the flange contact. Repeated dynamic excitation at this location may, over time, lead to the formation of rail corrugation. Insufficient lubrication, elevated friction levels and surface irregularities on wheels and rails can further intensify the phenomenon.

Curve squeal is typically most pronounced on the inner rail of the curve and may result in a significant increase in noise levels compared with ordinary rolling noise, commonly in the order of 10–20 dB or more according to the literature. If corrugation is not mitigated, it may additionally contribute to an increased mid- to high-frequency rolling noise and, depending on corrugation wavelength and track properties, to increased ground-borne vibration.

Different types and degrees of curve squeal are often observed, and the term *curve squeal* can be subdivided into three categories:

- **Wheel squeal** – a highly tonal and intense noise, dominated by a single, typically high-frequency tone (1 kHz–10 kHz), caused by resonance of the wheel itself. Wheel squeal typically occurs due to contact between the wheel and the top of the rail head.

- **Flange noise** – characterized by strong tonal noise consisting of multiple high-frequency (1 kHz–5 kHz) tonal components. It occurs due to contact between the wheel flange and the rail head, typically on the outer rail of the curve.

- **Graunching** – a rubbing or creaking type of noise with a more broadband character (100 Hz–5000 Hz).

Based on the site inspection conducted on 24 February 2026, no distinct tonal components were identified in the curve noise at Strandlodsvej. However, a clear increase in noise level was observed, subjectively assessed to be in the order of 5–10 dB compared with train operation on the section between the turnouts and the curve.

Ambient temperature and humidity conditions may influence the level of curve noise, and variations may also occur between different train sets.

Figure 4 shows northern track in the curve, where corrugations on the surface are clearly visible on the rail head of the inner rail. The wavelength is estimated to be 6–7 cm based on a 60 cm sleeper distance. The outer rail has not the same wear marks.

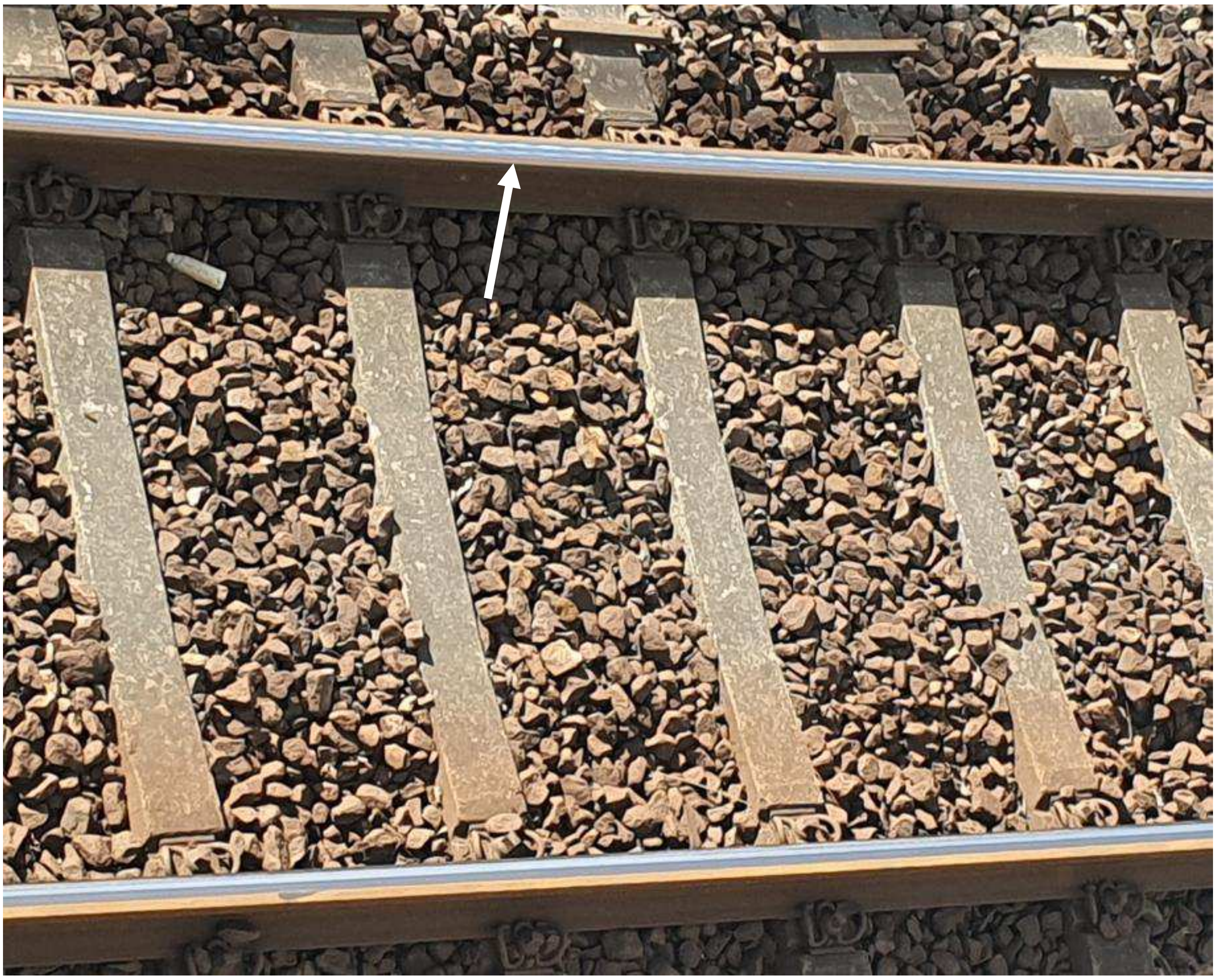

Figure 4 – Corrugation on the rail head of the inner rail in the northbound track because of stick–slip behavior

To reduce curve squeal, rail and/or wheel flange lubrication can be applied. In cases of pronounced wheel squeal, or where lubrication is not desirable for practical reasons, wheel-mounted dampers may be used as an alternative. In addition, rail-mounted dampers are also available.

In the Danish railway noise calculation method, NORD2000, no correction for curve noise is included. However, in the CNOSSOS-EU method, used for EU noise mapping, guidelines are provided for noise penalties based on curve radius (see Table 1).

The curve radius at Strandlodsvej is R = 120 m, which, with reference to Table 1, indicates that an elevated level of curve noise may occur. Although a noise penalty for curve squeal is currently not included in the Danish railway noise calculation method NORD2000. This does not necessarily imply that increased noise levels cannot occur in curved track sections.

Curve radius, R	Noise correction
R > 500 m	0 dB
300 m < R < 500 m	+5 dB
R < 300 m	+8 dB

Table 1 – Noise penalties for curves with different curve radii (CNOSSOS-EU calculation method).

Noise attenuation from the railway trough

The reduction of noise from the railway trough at Strandlodsvej has been assessed using calculation methods.

The calculations were carried out using a 3D noise model based on the NORD2000 method. The calculation model considers all parameters affecting sound propagation, including terrain conditions, shielding effects, reflections, etc.

As a basis for the calculations, the existing noise conditions were calculated for the current situation, but without applying noise penalties for increased noise from turnouts and curve squeal. This situation serves as the reference case and the basis for comparison with five noise mitigation scenarios. The purpose of the calculations is to illustrate the noise attenuation that can be achieved, rather than the absolute noise levels at the surrounding residential buildings. The calculations illustrate the effects on both sides of the railway trough.

Scenario descriptions:

- Scenario 0: Current situation with a reflective sheet-pile wall in the railway trough, extending 1 m above the surrounding terrain.
- Scenario 1: The inner side of the sheet-pile walls in the railway trough is clad with noise-absorbing panels on both sides.
- Scenario 2: The existing northern sheet-pile wall is raised by a 3 m vertical noise-absorbing barrier.
- Scenario 3: The existing sheet-pile wall is raised by a 1 m vertical noise-absorbing barrier, combined with a 2 m noise-absorbing overhang inclined at 45 degrees over the trough.
- Scenario 4: The inner side of the southern sheet-pile wall in the railway trough is clad with noise-absorbing panels. The northern sheet-pile wall is raised by a 3 m vertical noise-absorbing barrier.
- Scenario 5: The inner side of the southern sheet-pile wall in the railway trough is clad with noise-absorbing panels on the upper 4 m. The northern sheet-pile wall is raised by a 2 m vertical noise-absorbing barrier.

Classification of noise barrier

For the scenarios that include sound-absorbing barriers og panels, a reflection loss of 8 dB has been assumed unless otherwise stated, corresponding to a barrier classification of DL_α = 8 dB in accordance with DS/EN 1793-1. Lower values of DL_α will result in an increased proportion of reflected noise on the unshielded side. In situations where the direct noise contribution is effectively screened, such as in the case of the railway trough at Strandlodsvej, it is important that the absorption performance corresponds to a high DL_α value.

In addition, noise barriers must provide sufficient airborne sound insulation. Fundamentally, the sound insulation performance of a noise barrier should be such that the noise transmitted through the barrier is negligible compared to the noise propagating around the barrier. In practice, a surface mass of 15–20 kg/m² is sufficient.

The sound insulation performance is described in DS/EN 1793-2 by the index DL_R, which represents an average value of the barrier's airborne sound insulation in the frequency range 100–5000 Hz. The average value is weighted according to a standardized traffic noise spectrum. In the standard, the parameter DL_R is referred to as the *"single-number rating of airborne sound insulation"* and is expressed in dB. A noise barrier with a surface mass of 15–20 kg/m² typically provides a sound insulation performance corresponding to DL_R = 25–34 dB.

For the classification to be valid, the barrier must be installed with tight joints, both to the supporting structure and to adjacent structures, such as the sheet-pile wall of the railway trough.

Subjective experience of noise change

Noise can generally be defined as unwanted sound and is measured in decibels, abbreviated dB(A).
In relation to railway noise, the unit dB(A) is used, where the "A" indicates that the measurement is A-weighted, taking into account the human ear's perception of sound.

The decibel scale is logarithmic. This means, among other things, that combining the noise from two identical noise sources results in an increase of 3 dB. For example, a doubling of traffic volume leads to an increase in the noise level of 3 dB.

However, this does not imply a corresponding doubling of the perceived noise level. Regarding the perception of changes in noise levels, the following rules of thumb may be applied:

- 1 dB is the smallest change that the human ear can perceive instantaneously.
- 3 dB is perceived as a small change.
- 6 dB is perceived as a significant change.
- 8–10 dB is perceived as a large change and is commonly understood as a doubling or halving of the noise level

In this context, the target for noise reduction at the residential buildings north of the railway cutting has been set at approximately 6 dB or more, corresponding to a clearly noticeable and significant reduction in noise.

Scenario 0 – Current situation

The railway trough between Strandlodsvej and Øresundsvej is an open cutting with sheet-pile walls on both sides.
The sheet-pile walls extend approximately 1 m above the surrounding terrain. North of the trough, the nearest buildings consist of 5–7-storey residential buildings. From the upper floors, there is unobstructed line of sight to the tracks. The shortest horizontal distance between the residential buildings and the railway cutting is approximately 16 m.

South of the railway trough, the nearest buildings consist of two childcare institutions and a sports hall.

Figure 5 – Current situation. Open railway cutting with sheet-pile walls. Residential buildings north of the railway cutting.

The noise propagation to the surrounding area under current conditions is used as the reference for the assessed noise mitigation scenarios. The calculations have been carried out partly as facade noise calculations at the residential buildings north of the railway and partly as a cross-section calculation at the property Strandlodsvej 67A, located approximately at the midpoint of the section.

The results of the calculations are shown in Figure 6 (facade levels) and Figure 7 (cross-section). It should be noted that the facade levels shown in Figure 6 are free-field values, meaning that reflections from the building's own facade are not included. The levels can therefore be directly compared with the Danish Environmental Protection Agency's limit value for railway noise (L_{den} = 64 dB).

In the cross-section calculation, however, facade reflections are included in order to illustrate the sound propagation within the cross-section.

In addition, calculations of noise propagation on both sides of the trough have been carried out at a standard height of 1.5 m above ground level, in order to assess the impact and attenuation on outdoor recreational areas at ground level.

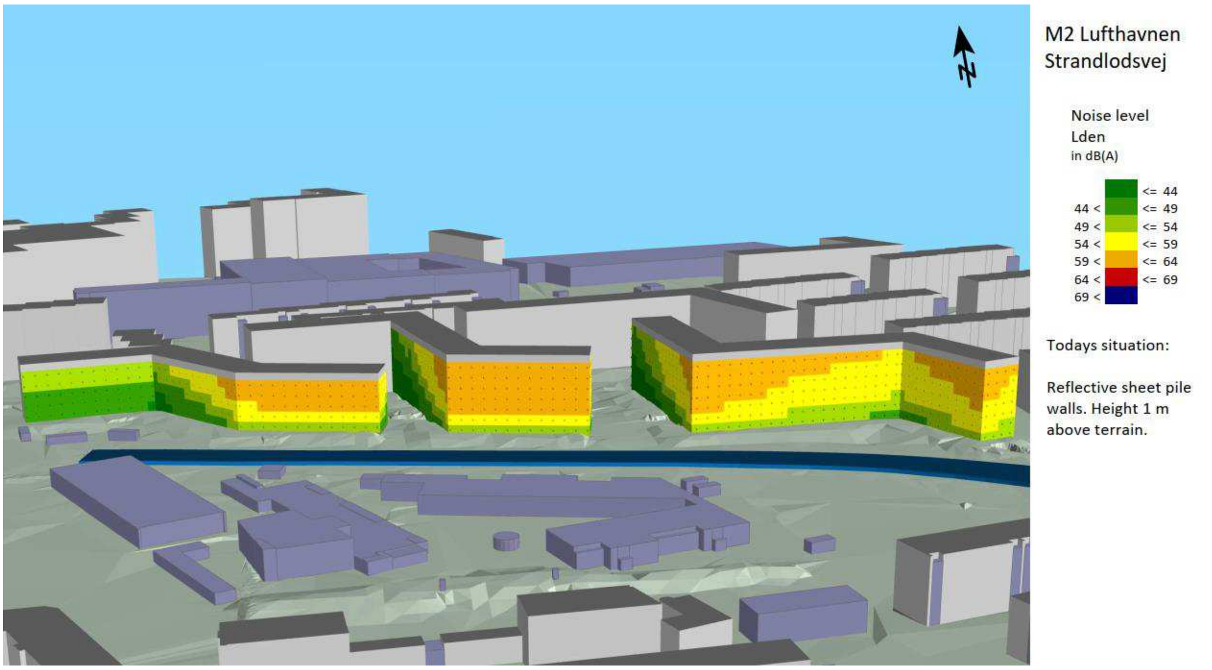

Figure 6 – Current situation. Facade noise calculation

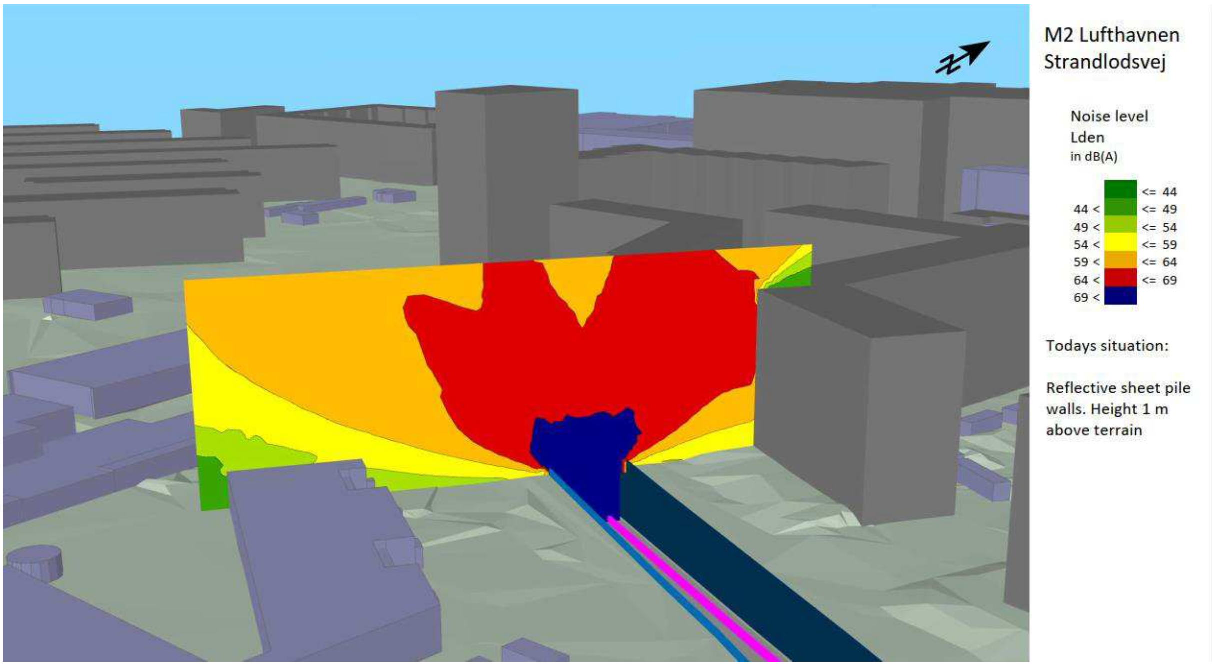

Figure 7 – Current situation. Cross-section calculation at Strandlodsvej 67A.

Figure 8 – Current situation. Noise propagation at ground-level height (1.5 m)

Scenario 1 – Noise absorbing railway trough

The inner side of the railway trough's sheet-pile walls (and concrete wall) is clad with sound-absorbing panels. In the calculation scenario, an absorption classification of DL_α = 8 dB has been assumed. The noise reduction achieved by installing absorptive panels in the trough from bottom to top is illustrated in Figure 9, Figure 10 and Figure 11.

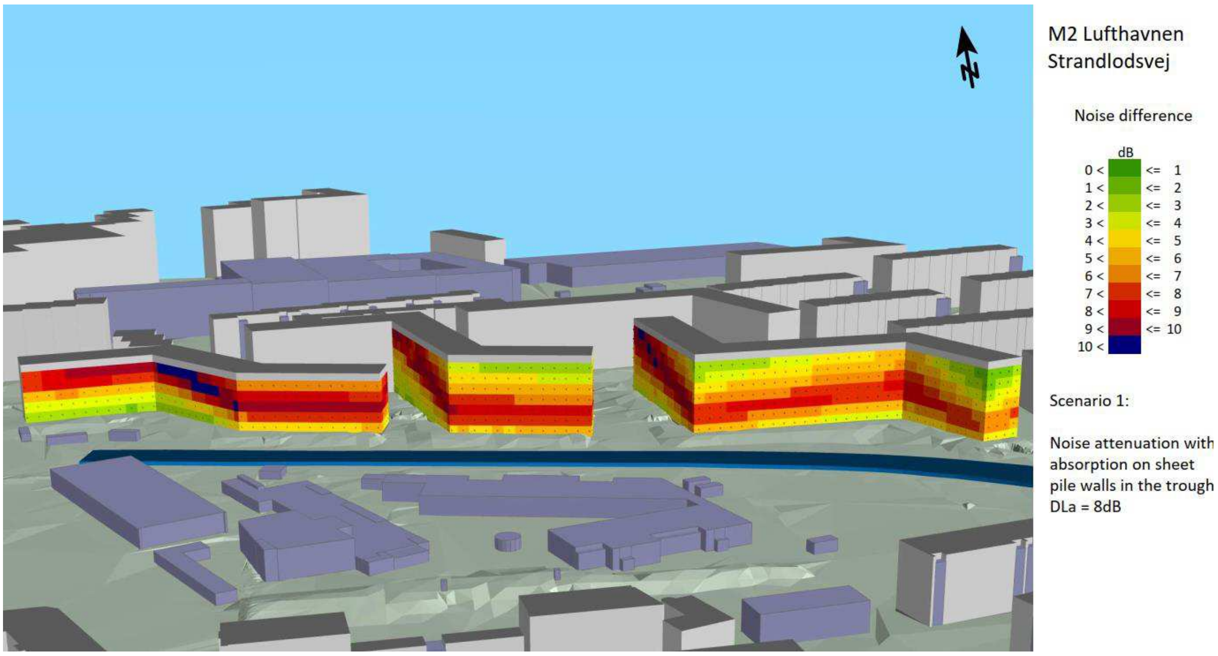

Figure 9 – Scenario 1. Noise reduction at residential façades due to installation of absorption on the railway cutting's sheet-pile walls.

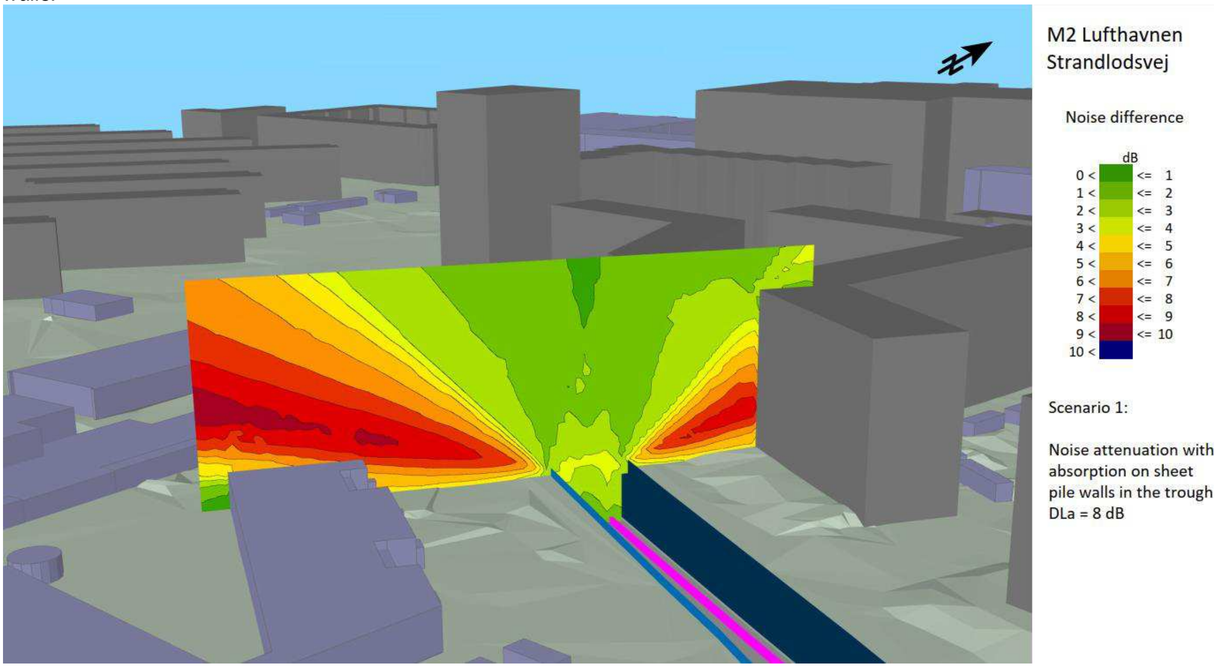

Figure 10 – Scenario 1. Noise reduction illustrated by a cross-section calculation at Strandlodsvej 67A.

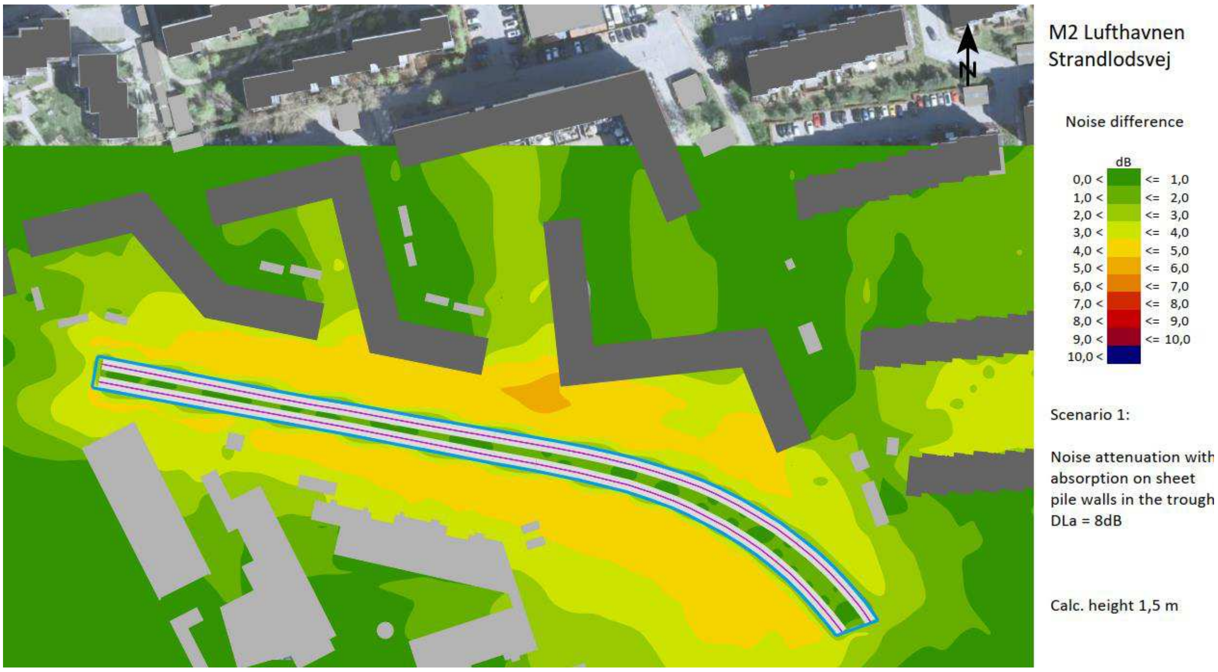

Figure 11 – Scenario 1. Reduction of noise propagation at 1.5 m above ground level

By installing sound-absorbing panels on both walls of the railway trough over the entire wall height, a noise reduction in the order of 7–8 dB can be achieved at floors 1–4 of the property at Strandlodsvej 67, which is the central of the three properties closest to the trough. Similar reductions are observed for the two neighboring properties at Øresundsvej 145–155 and Strandlodsvej 63.

The upper floors generally experience a smaller noise reduction than the mid-level floors. At Strandlodsvej 67, the reduction at the upper floors is approximately 2–3 dB, corresponding to a minor change in noise levels.

At ground-floor level, the reduction is generally smaller than at floors 1–4, as the ground floor is already better shielded from both direct and reflected noise.

For outdoor areas along both sides of the railway trough, including the kindergarten's outdoor playground south of the trough, the noise level is reduced by 4–5 dB (see Figure 11).

If panels with an absorption classification of DL_α = 10 dB are selected instead of DL_α = 8 dB, the facade noise reduction at floors 1–4 can be further improved by 1–2 dB. However, the upper floors (5th and 6th floors) at Strandlodsvej 67 and Øresundsvej 145–155 will overall continue to experience reductions below the design criterion of 6 dB.

Scenario 2 – 3 m high vertical sound-absorbing noise barrier

A 3 m high vertical sound-absorbing barrier is installed on the northern sheet pile wall of the railway trough between Øresundsvej and the tunnel portal. The barrier is assumed to have an absorption classification of $DL_α$ = 8 dB. No absorption is applied to the sheet pile walls in the trough.

The noise reduction provided by the barrier is illustrated in Figure 12, Figure 13 and Figure 14.

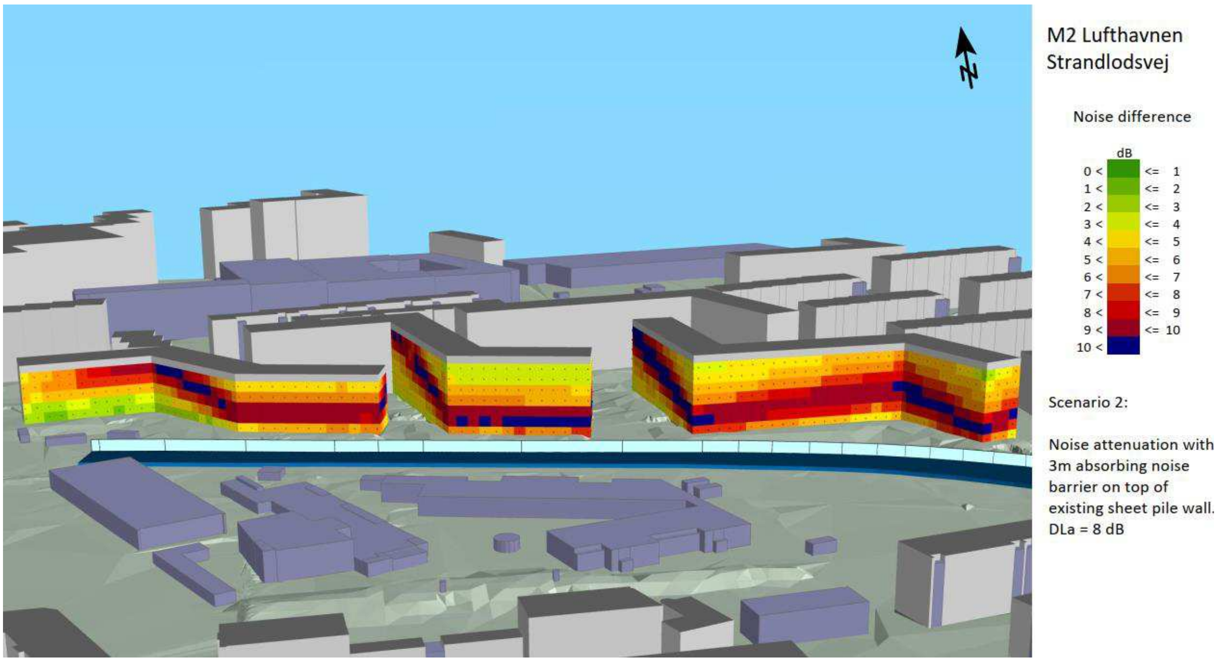

Figure 12 – Scenario 2. Noise reduction at residential facades due to installation of a 3 m high absorptive barrier on top of the northern sheet pile wall.

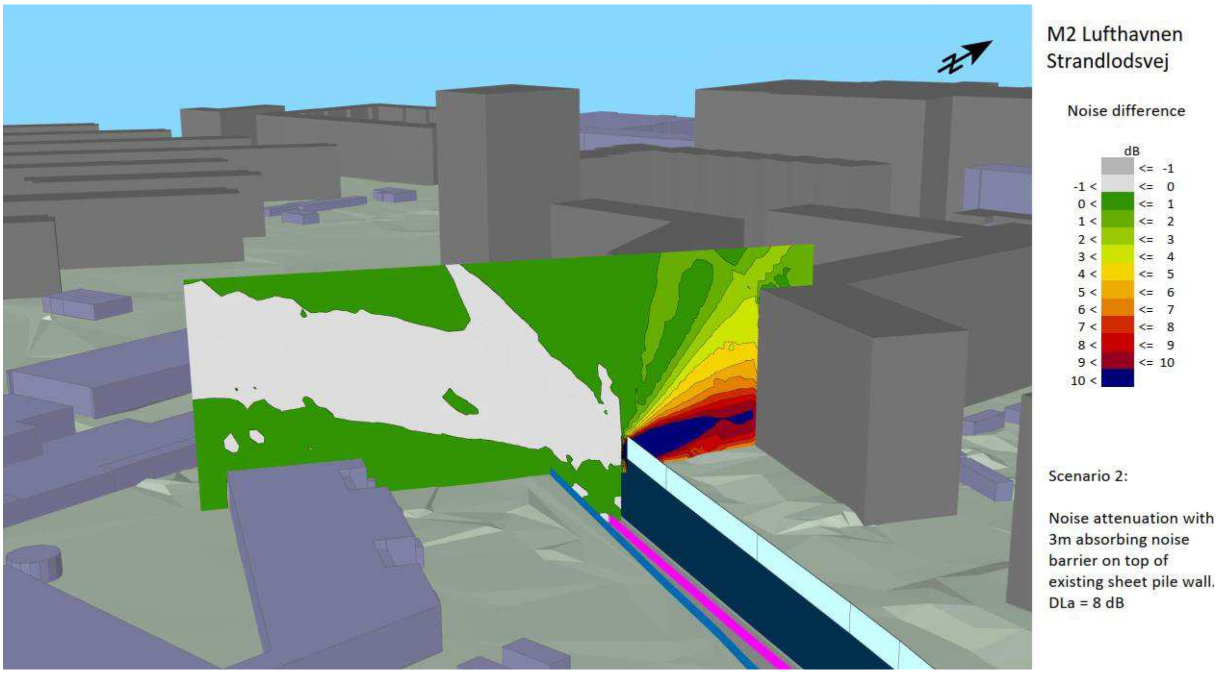

Figure 13 – Scenario 2. Noise reduction illustrated by a cross-section calculation at Strandlodsvej 67A.

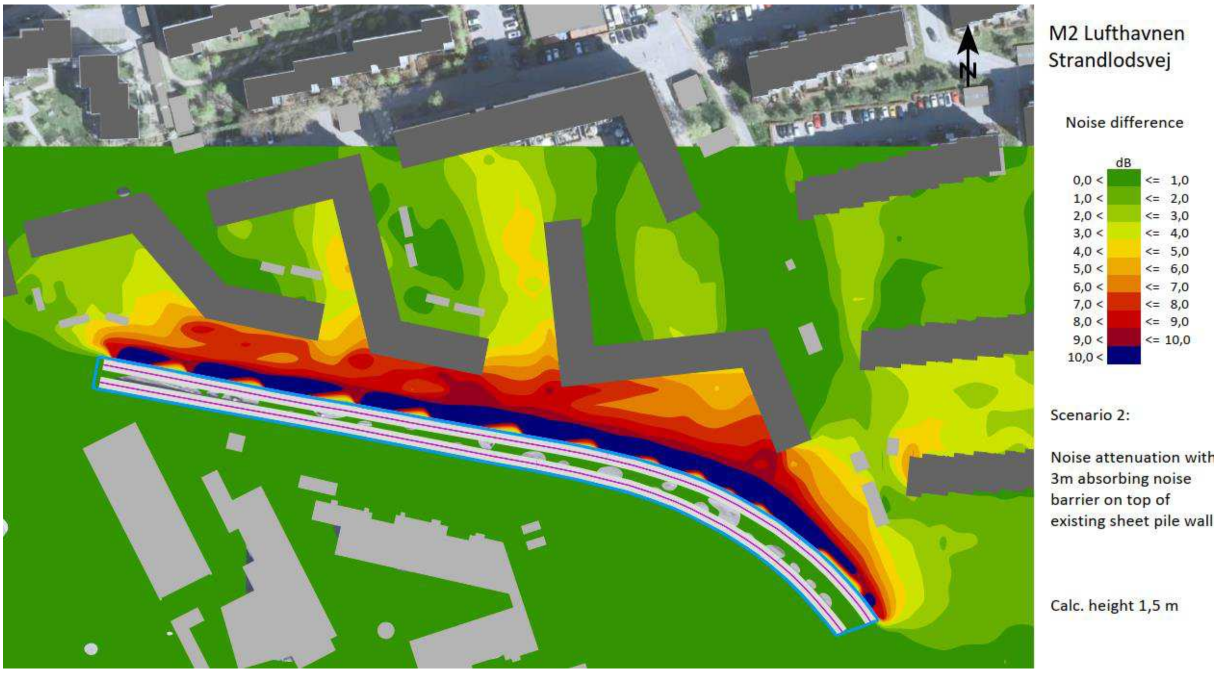

Figure 14 – Scenario 2. Reduction of noise propagation at 1.5 m above ground level

With a 3 m high vertical sound-absorbing noise barrier on top of the existing screening edge along the entire section from Øresundsvej to the tunnel portal, a noise reduction in the order of 6–10 dB can be achieved at floors 1–3 of the property at Strandlodsvej 67 (the central property). At the upper floors, the reduction is limited to approximately 3–4 dB, and at ground-floor level to approximately 5 dB.

Figure 13 shows a minor increase in noise levels south of the trough in the range of 0–1 dB. A detailed analysis indicates that the increase is approximately 0.2 dB, which is not perceptible. The increase is caused by the assumed absorption classification of DL_{α} = 8 dB for the noise barrier, resulting in a small reflection of sound towards the south. The use of a barrier with an absorption classification of DL_{α} = 10 dB may be considered; however, it is not assessed to be necessary.

For outdoor areas south of the railway trough, a marginal noise reduction in the range of 0–1 dB is observed, confirming that reflections from the barrier will not adversely affect noise conditions at the calculation height of 1.5 m above ground level, which is the standard height for noise mapping of outdoor areas.

North of the railway trough, in the area between the railway and the residential buildings, noise reductions of approximately 7–10 dB are observed, though slightly lower at the eastern property, Øresundsvej 145–155.

A sketch with dimensions of the barrier is provided in Appendix 2.

Scenario 3 – 1 m high vertical sound-absorbing barrier with overhang

A 1 m high vertical sound-absorbing barrier with a 2 m long overhang is installed on the northern sheet pile wall of trough between Øresundsvej and the tunnel portal. The angle of the overhang relative to vertical is 45 degrees. The total vertical extension above the existing edge is approximately 2.4 m. The vertical part of the barrier is assumed to have an absorption classification of DL_{α} = 8 dB, while the absorption classification of the overhang is assumed to be “infinite”, due to a model limitation. No absorptive panels is applied to the inner walls of the railway trough.

The noise reduction provided by the barrier is illustrated in Figure 15, Figure 16 and Figure 17.

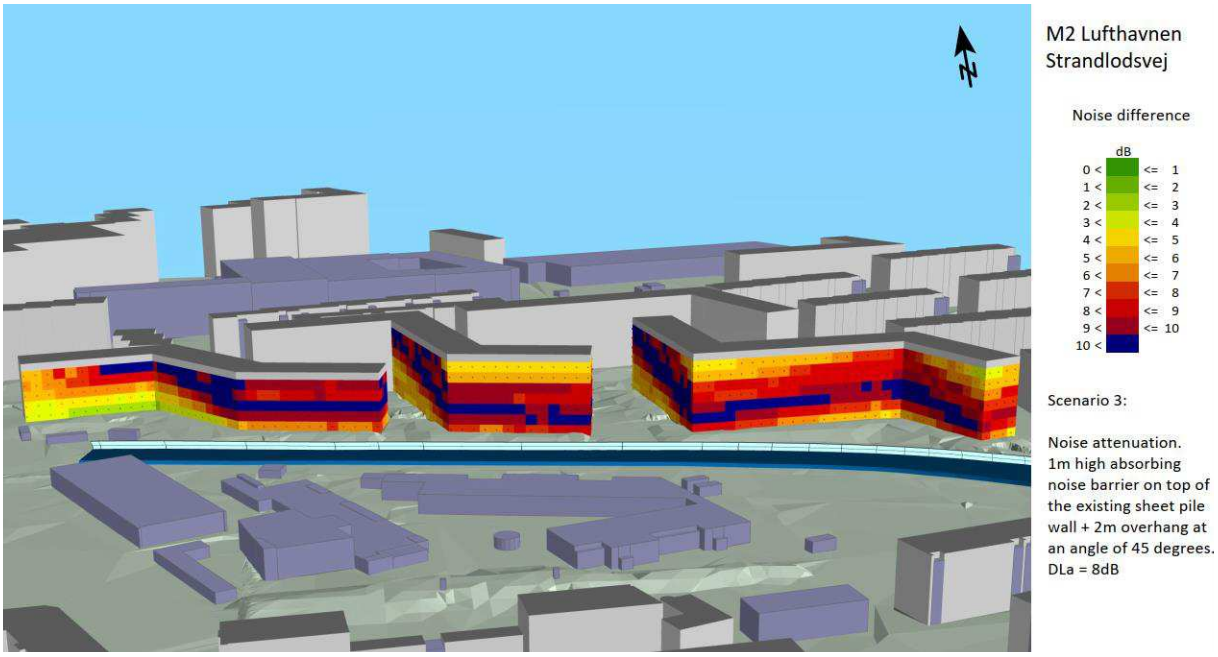

Figure 15 – Scenario 3. Noise reduction at facades. Absorptive barrier with overhang on top of the northern wall.

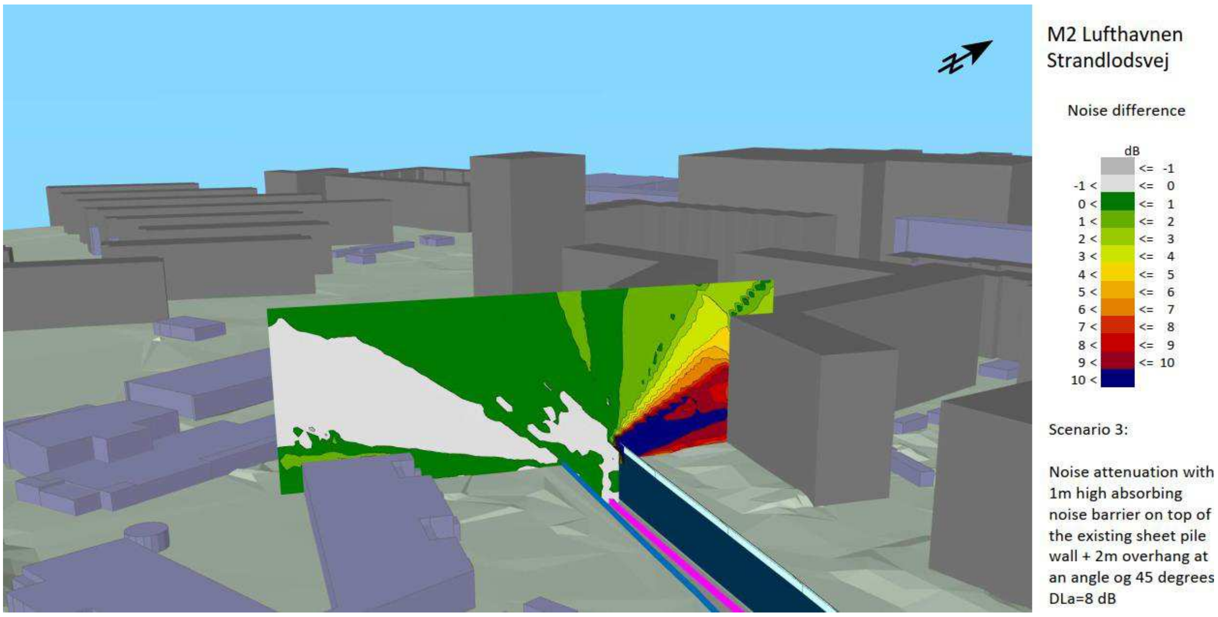

Figure 16 – Scenario 3. Noise reduction shown by a cross-sectional calculation at Strandlodsvej 67A.

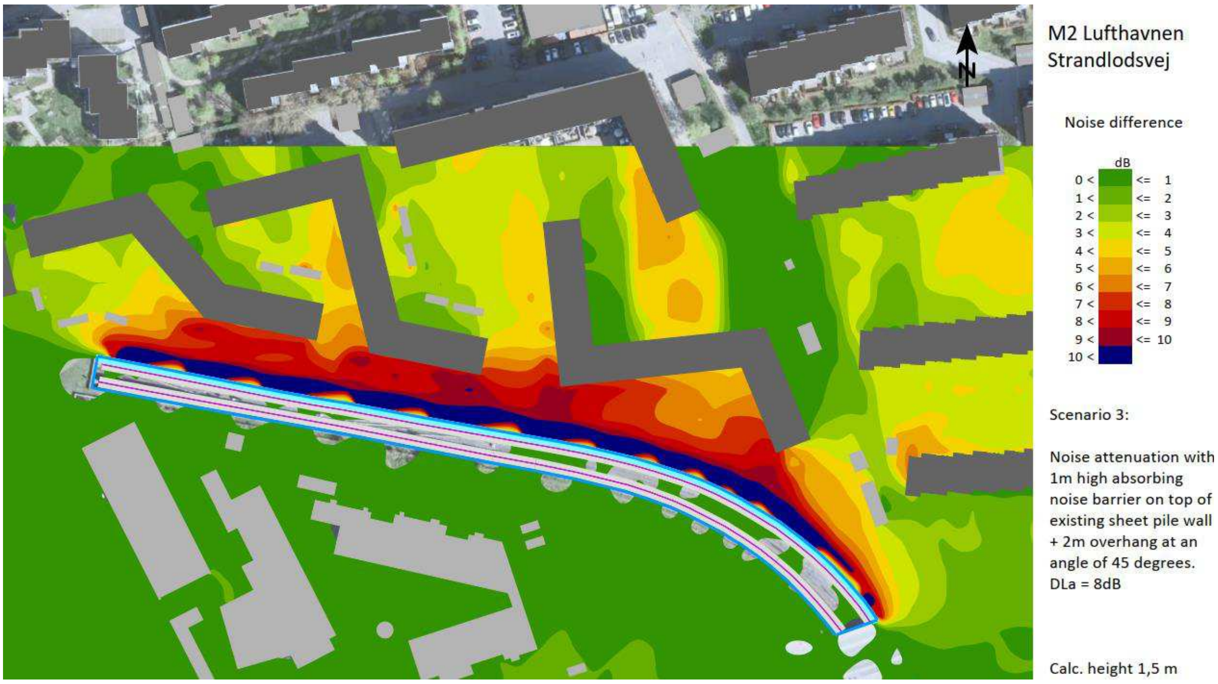

Figure 17 – Scenario 3. Noise reduction of sound propagation at 1.5 m above ground level.

With a 1 m high vertical sound-absorbing noise barrier equipped with a 2 m overhang inclined at 45 degrees relative to vertical, on top of the existing screening edge, a noise reduction in the order of 7–10 dB can be achieved at floors from ground level to the 4th floor of the property at Strandlodsvej 67 (the central property). At the uppermost floors, the reduction is limited to approximately 4–6 dB.

Figure 16 shows a minor increase in noise levels south of the trough in the range of 0–1 dB. A detailed analysis indicates that the increase is approximately 0.5 dB at heights above 5 m. This increase is not perceptible. The noise increase is caused by the assumed absorption classification of DL_α = 8 dB for the vertical noise barrier section, which results in a small reflection of sound.

For outdoor areas south of the trough, a marginal noise reduction in the range of 0–1 dB is observed, confirming that reflections from the barrier will not adversely affect noise conditions at the calculation height of 1.5 m above ground level. North of the trough, in the area between the trough and the residential buildings, noise reductions of approximately 7–10 dB are observed.

A sketch with dimensions of the barrier with overhang is provided in Appendix 3.

Scenario 4 – 3 m high vertical noise barrier and absorbing panels on the southern wall of the railway trough

A 3 m high vertical sound-absorbing barrier is installed on top of the existing northern sheet-pile wall. In addition, sound-absorbing panels are installed along the southern wall of the railway cutting over its full height. The absorption classification of both the barrier and the panels is assumed to be DL_α = 8 dB. The noise reduction provided by the barrier is illustrated in Figure 18, Figure 19 and Figure 20.

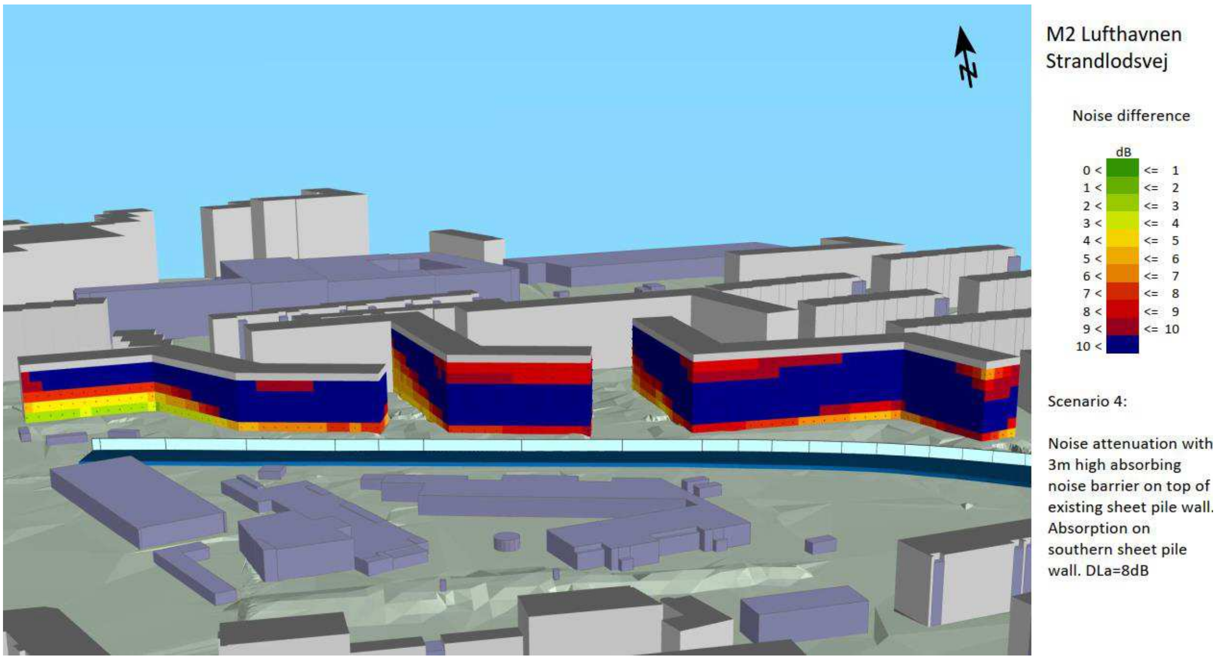

Figure 18 – Scenario 4. Noise reduction at residential facades with a 3 m high vertical absorptive noise barrier on the northern sheet-pile wall and absorptive panels installed on the southern sheet-pile wall.

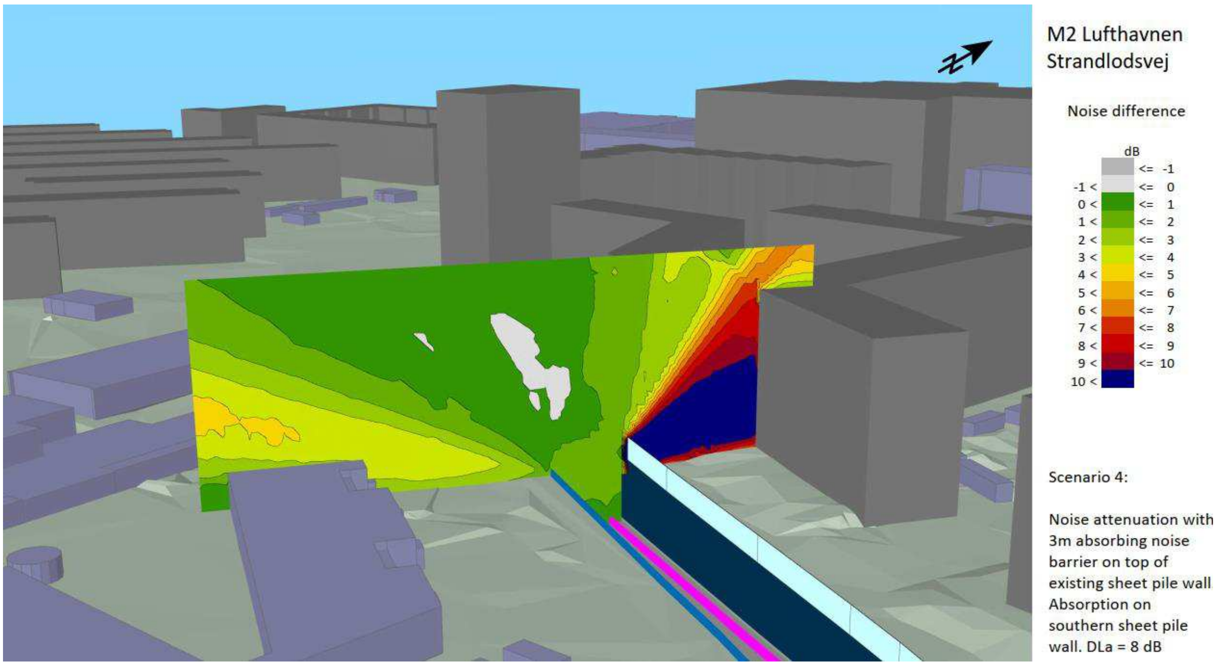

Figure 19 – Scenario 4. Noise reduction shown by a cross-sectional calculation at Strandlodsvej 67A.

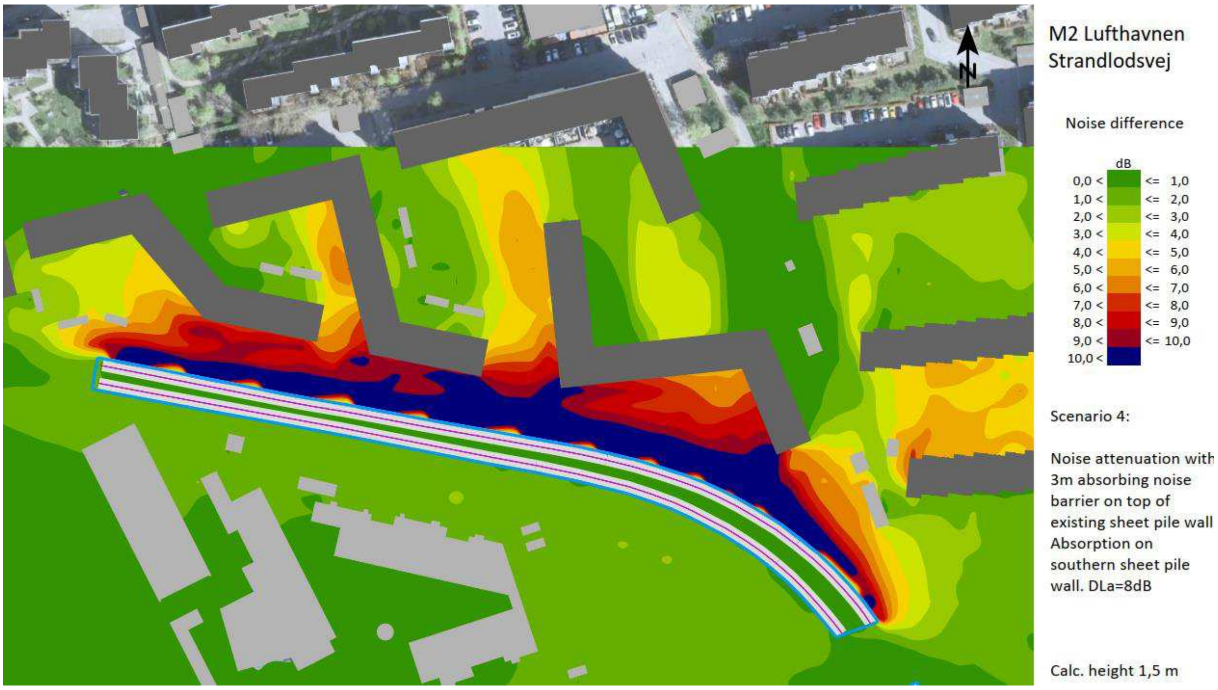

Figure 20 – Scenario 4. Noise reduction of sound propagation at 1.5 m above ground level.

With a 3 m high vertical sound-absorbing barrier on top of the northern sheet-pile wall, combined with a fully absorptive southern wall of the railway trough, a noise reduction in the order of 7–10 dB can be achieved at all floors of the residential buildings north of the railway cutting. The solution meets the objective of achieving at least 6 dB noise reduction at all floors.

At the outdoor areas south of the railway trough, a noise reduction of 1–2 dB is observed. The limited reduction is due to the fact that no absorptive panels have been included on the northern sheet pile wall. North of the trough, in the area between the trough and the residential buildings, noise reductions of approximately 6–10 dB are achieved.

Supplementary calculations, in which absorptive panels are installed only on the upper 4 m of the southern sheet-pile wall of the trough, show that approximately the same noise reduction can be achieved as with full-height panels of the entire wall. The results of the supplementary calculation are shown in Figure 21, which, when compared with Figure 18, are seen to be almost identical. The minor differences are insignificant.

A sketch with dimensions of the barrier is provided in Appendix 4.

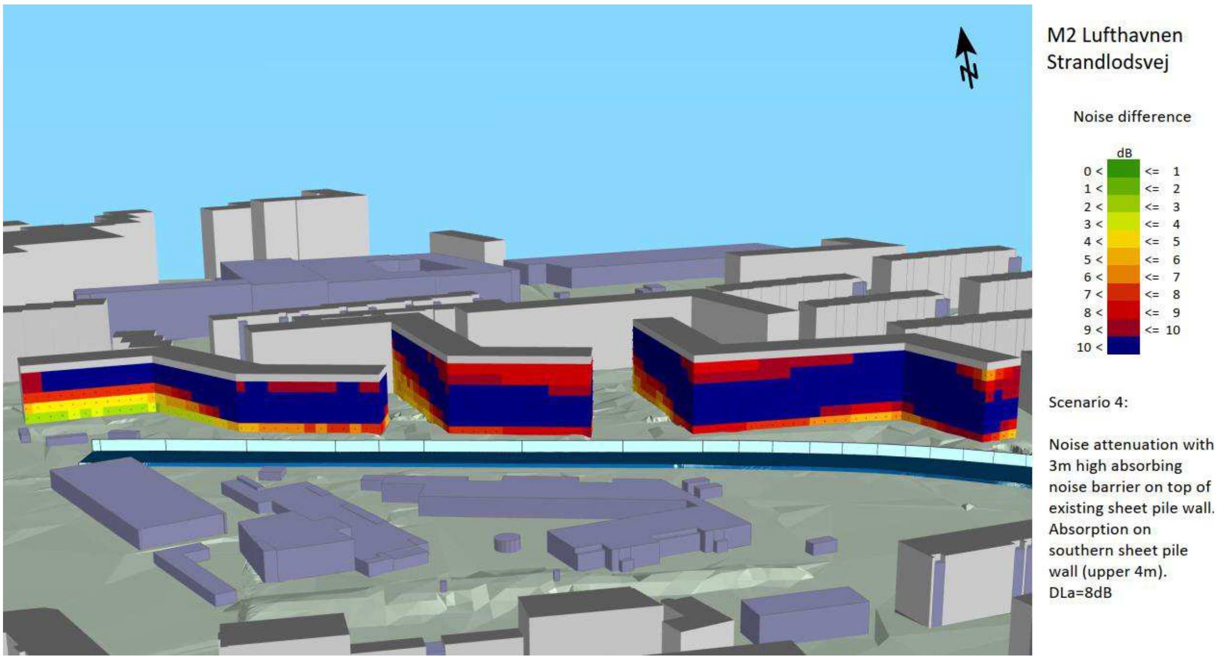

Figure 21 – Scenario 4. Noise reduction at residential façades with a 3 m high vertical absorptive barrier on the northern sheet-pile wall and absorptive elements installed on the upper 4 m of the southern sheet-pile wall.

Scenario 5 – 2 m vertical barrier and absorption on the southern wall of the railway trough

A 2 m high vertical sound-absorbing barrier is installed on top of the existing sheet-pile wall. In addition, absorptive panels are installed on the upper 4 m of the southern sheet-pile wall.
The absorption class of both the barrier and the panels is assumed to be DL_{α} = 8 dB.
The noise reduction provided by the barrier is illustrated in Figures 22, 23 and 24.

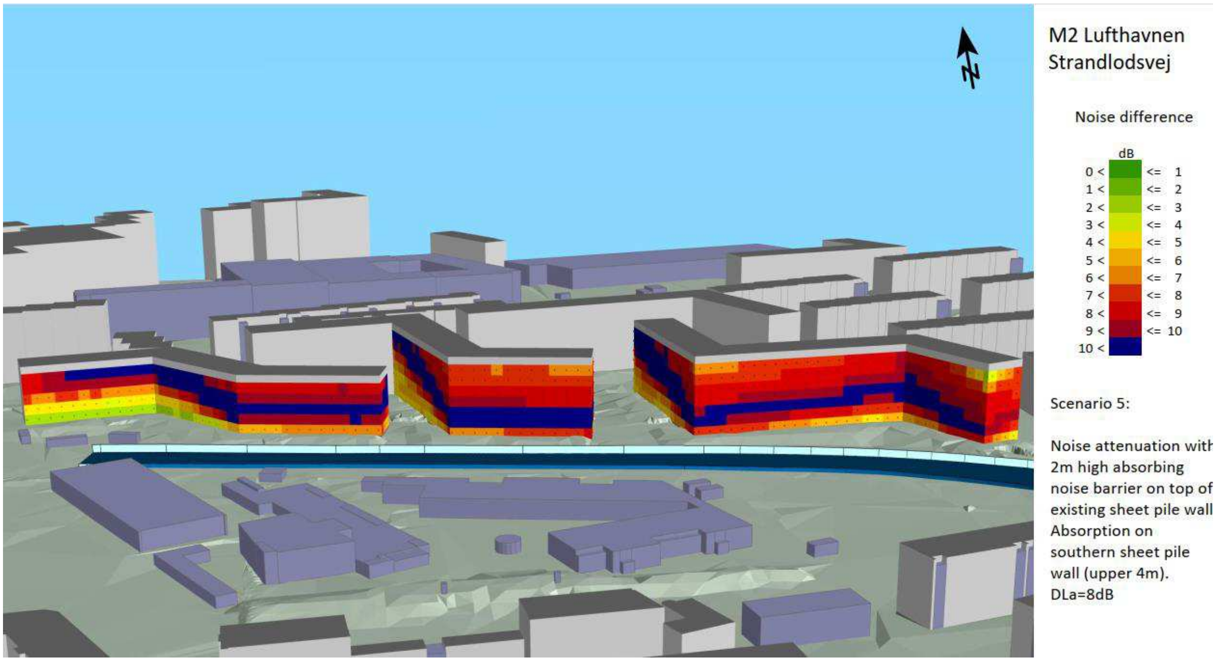

Figure 22 – Scenario 5. Noise reduction at residential facades with a 2 m high vertical absorptive barrier on the northern sheet-pile wall and absorptive panels installed on the upper 4 m of the southern sheet-pile wall..

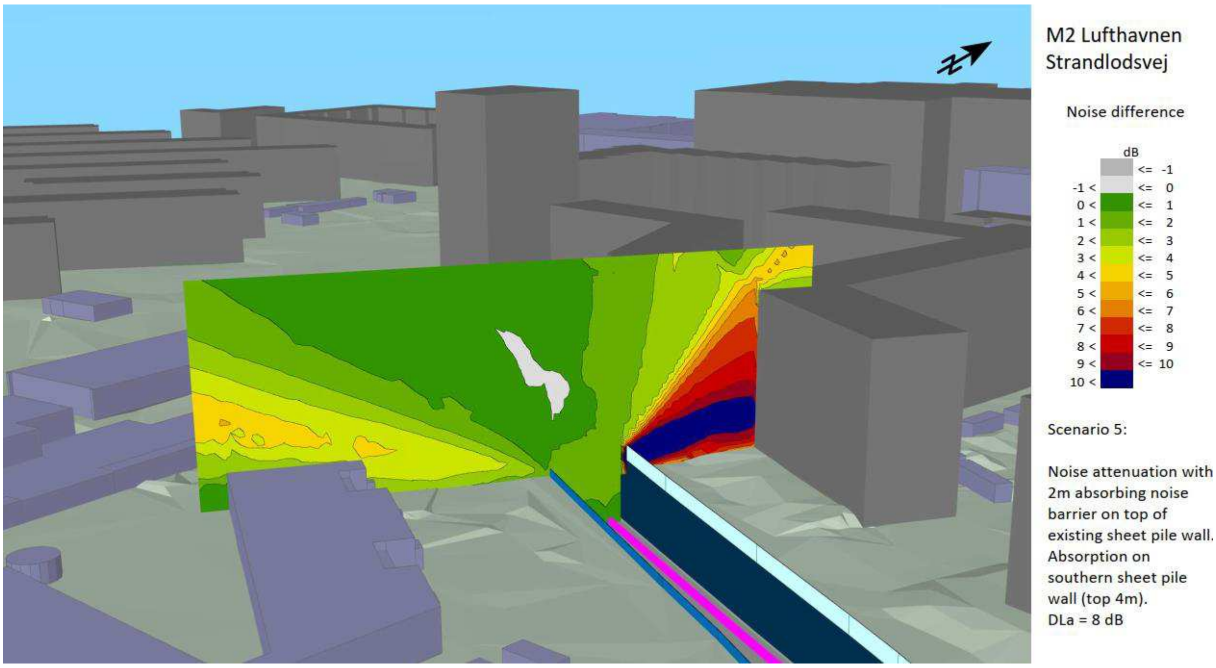

Figure 23 – Scenario 5. Noise reduction shown by a cross-section calculation at Strandlodsvej 67A.

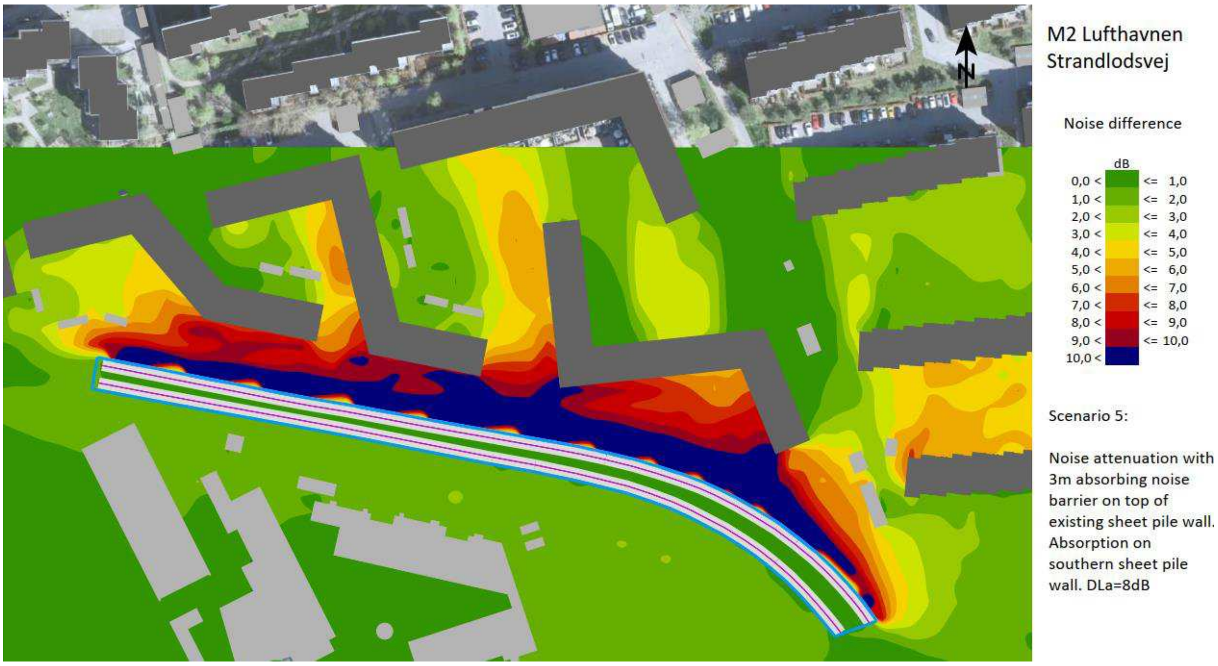

Figure 24 – Scenario 5. Noise reduction of sound propagation at 1.5 m above ground level.

With a 2 m high vertical sound-absorbing noise barrier installed on top of the northern sheet-pile wall, combined with absorptive panels on the upper 4 m of the southern sheet pile wall, a noise reduction in the order of 5–10 dB can be achieved at all storeys of the residential buildings north of the trough. With a few exceptions on the lowest storey, the target of at least 6 dB noise reduction is met.

At outdoor areas south of the trough, a noise reduction of 1–2 dB is observed. The limited reduction is because no absorptive panels are included on the northern wall of the trough.

North of the trough, in the area between the trough and the residential buildings noise reductions of approximately 6–10 dB is achieved.

A sketch with dimensions of the barrier is provided in Appendix 5.

Limitations of the study

The reduction of noise from the railway trough at Strandlodsvej has been assessed by calculation using a 3D noise model. The calculation model accounts for all parameters influencing sound propagation, including terrain conditions, screening effects, reflections, and diffraction. The calculations are based on the current daily distribution of metro train operations, but do not include additional noise contributions from switches and curve squeal. The results therefore illustrate the screening effect that the investigated mitigation measures can provide.

Noise from turnouts and curve squeal results in a different spectral noise content compared with the calculation basis, which represents metro train operation on straight track sections without turnouts or curve squeal. The actual spectral distribution of the noise in the trough has not been measured or compared with the calculated spectrum. It is likely that differences in the spectral content may occur depending on whether the eastern curved section or the western area near the turnouts is considered.

Such nuances are not included in the present assessment, which is solely calculation-based and does not reflect the exact noise characteristics.

A significant change in the frequency content of the noise may influence the calculated noise reductions, particularly if the noise impact is substantially more low-frequent than assumed, which may be the case in the vicinity of the turnouts. If the noise contains a significant low-frequency component, the absorptive panels and/or barrier will provide less absorption than assumed, resulting in somewhat lower noise reduction. If, on the other hand, the spectral content is more dominated by higher frequencies, this is of less concern, as sound absorption generally improves at higher frequencies and is therefore less sensitive to such changes.

Absorptive panels and barriers are expected to reduce noise from the railway trough to some extent, but curve squeal and turnout noise are likely to remain audible, although at a lower level compared with the existing situation. Noise mitigation by absorptive panels and/or barriers should therefore be regarded as a supplementary measure, to be implemented in combination with measures addressing the underlying causes of curve squeal and elevated turnout noise.

When installing a barrier on top of the existing sheet-pile wall, it is essential that the transition between the barrier and the sheet piles is executed with airtight joints, as openings will reduce the screening effect. A noise barrier functions by forcing the sound path to deviate around the barrier, thereby increasing the transmission path length. Any gaps in the screening will reduce the effectiveness of the barrier.

Conclusion

In the railway trough between Øresundsvej and Strandlodsvej, increased noise levels occur due to the presence of four turnouts and a sharp curve. This increased noise is not reflected in standard noise mapping, as noise from curve squeal is not included, and because no correction factor has been established for metro train operations through turnouts.

Based on site inspections, it can be established that there is a clear increase in noise from both the turnouts and curve squeal; however, the noise increase cannot be quantified in detail, as no measurements have been carried out. Studies from Banedanmark among others show that a worn turnout can locally result in an increased noise level of 10 dB or more. Curve squeal can likewise lead to an increase in noise levels of 10–20 dB or more compared with a well-maintained straight track.

The attenuation of noise from the railway trough has been assessed by calculation. Among the five investigated scenarios, the most effective solution consists of a 3 m high vertical sound-absorbing barrier installed on top of the northern sheet-pile wall of the trough, combined with sound-absorbing elements on the upper 4 m of the southern wall of the trough. This solution provides a noise reduction of 8–10 dB at all storeys of the nearest residential buildings along Øresundsvej and Strandlodsvej, which subjectively corresponds to a halving of the perceived noise. The criterion of at least 6 dB noise reduction is met. Extending the absorptive elements to the entire southern sheet-pile wall, rather than only the upper 4 m, would result in a marginal and insignificant improvement.

If the height of the vertical sound-absorbing barrier is reduced to 2 m, the noise reduction is decreased by 1–2 dB compared with a 3 m barrier. With a few exceptions at ground-floor level, the 6 dB noise reduction target can still be achieved (see Figure 22).

Although the propagation of noise from the railway trough is reduced, it must be expected that both curve squeal and turnout noise will remain audible. Consequently, measures addressing the underlying causes of curve squeal and turnout noise should also be pursued.

Appendix 1 – Scenario 1

On both walls of the railway trough, sound-absorbing panels is installed from top to bottom on the inner side between Øresundsvej and the tunnel portal. The sound absorption is assumed to be classified as DL_{α} = 8 dB.

The area of the northern wall of the cutting is approximately 2,215 m², and the southern wall approximately 2,085 m². The height of the trough varies from approximately 7 m above top of rail at Øresundsvej to approximately 10 m above top of rail at the tunnel portal to the west.

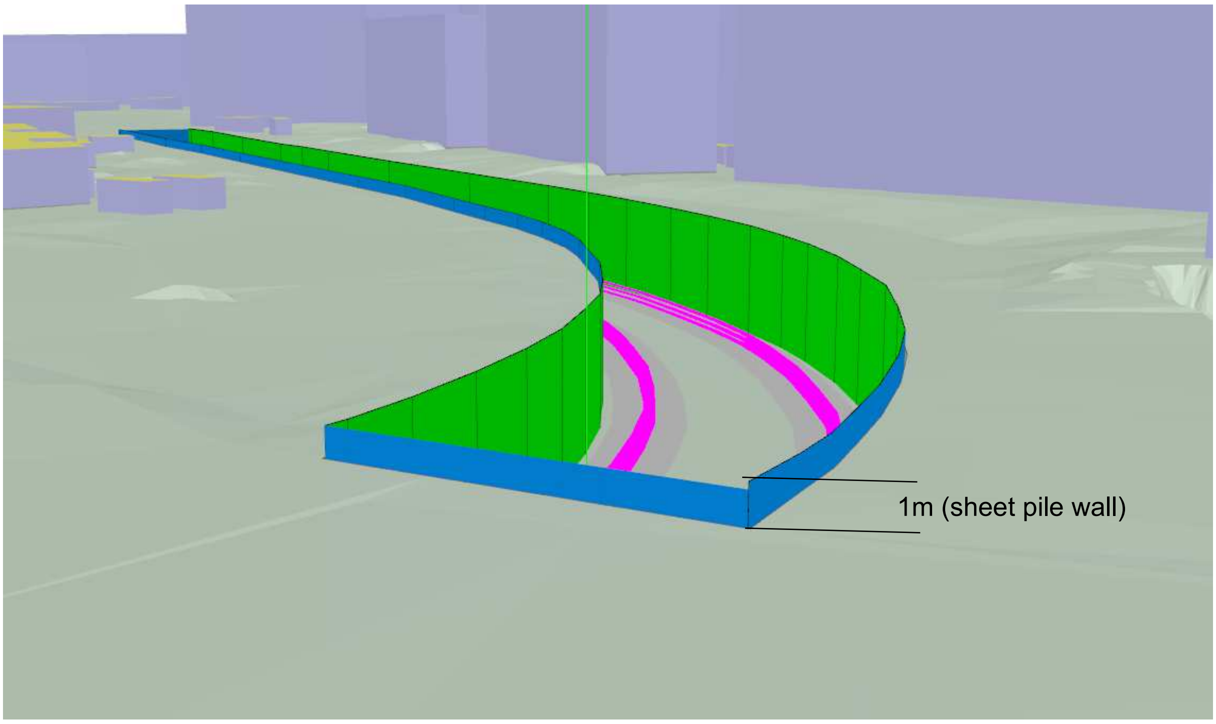

Figure A1-1: Scenario 1. Sketch of sound-absorbing elements (green shading) installed on the inner side of the sheet-pile walls of the railway cutting, covering the full height from the tracks to the top of the walls.

Appendix 2 – Scenario 2

On the northern wall of the railway trough, a 3 m high vertical sound-absorbing barrier is installed. The barrier is assumed to be sound-absorbing on both sides in order to minimize the risk of multiple reflections between the barrier and the residential buildings north of the railway. The total length of the barrier is approximately 278 m.

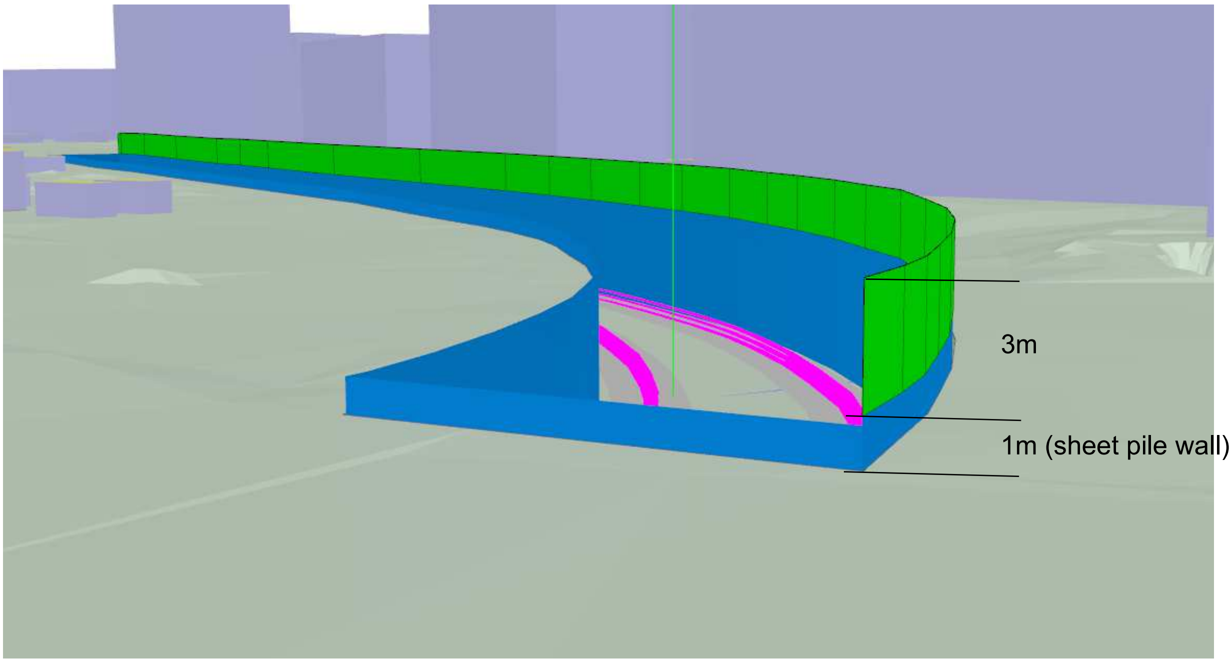

Figure A2-1: Scenario 3. Sketch of a new 3 m high barrier (green shading) installed on top of the edge of the existing sheet-pile wall (blue shading).

Appendix 3 – Scenario 3

On the northern wall of the railway trough, a 1 m high vertical sound-absorbing barrier is installed with a 2 m long overhang extending over the trough. The angle of the overhang relative to the vertical/horizontal is 45 degrees. The total vertical height of the new barrier is approximately 2.4 m, and the overall length is approximately 278 m.

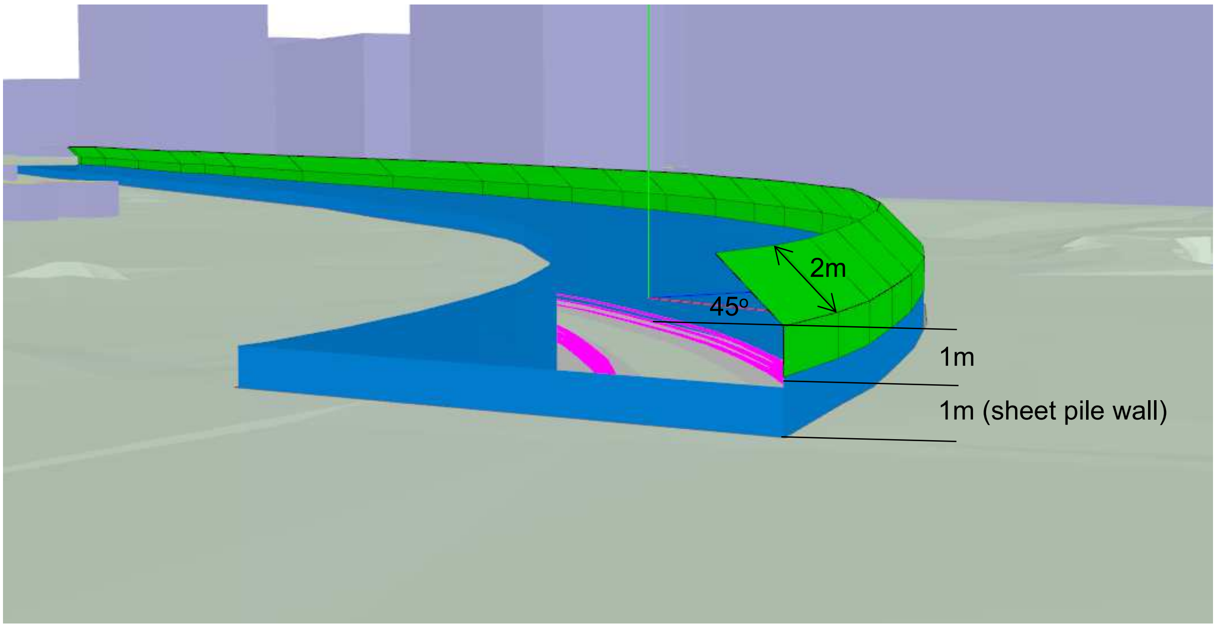

Figure A3-1: Scenario 3. Sketch of a new barrier with overhang (green shading) installed on top of the existing shielding edge (blue shading).

Appendix 4 – Scenario 4

On the northern wall of the railway trough, a 3 m high vertical sound-absorbing barrier is installed. The barrier is assumed to be sound-absorbing on both sides in order to minimize the risk of multiple reflections between the barrier and the residential buildings north of the railway. On the southern wall, sound-absorbing panels are installed from top to bottom. In Figure A4-1 (upper), the absorbing elements are installed on the southern wall over the full height of the cutting. In Figure A4-2 (lower), the sound-absorbing cladding is limited to the upper 4 m.

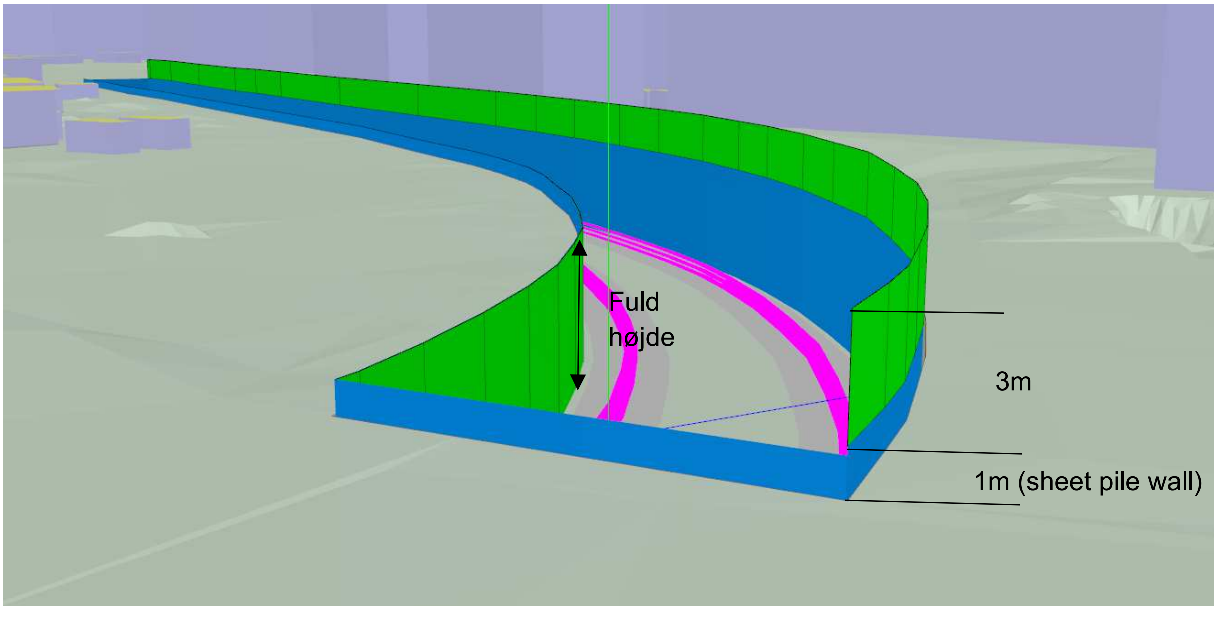

Figure A4-1: Scenario 4. 3 m high vertical sound-absorbing barrier on the northern sheet-pile wall and a sound-absorbing southern sheet-pile wall over the full height.

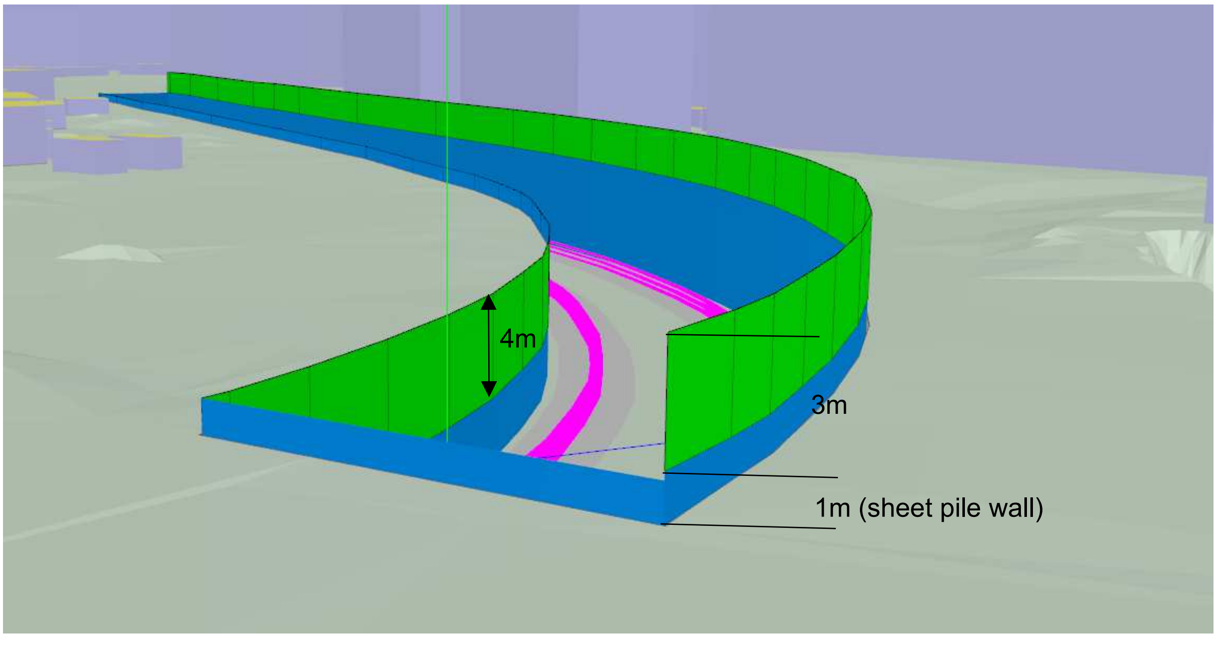

Figure A4-2: Scenario 4. 3 m high vertical sound-absorbing barrier on the northern sheet-pile wall, with the upper 4 m of the southern sheet-pile wall fitted with sound-absorbing panels.

Appendix 5 – Scenario 5

On the northern wall of the railway trough, a 2 m high vertical sound-absorbing barrier is installed. The barrier is assumed to be sound-absorbing on both sides in order to minimize the risk of multiple reflections between the barrier and the residential buildings north of the railway.

On the southern sheet pile wall of the trough, sound-absorbing panels are installed on the upper 4 m.

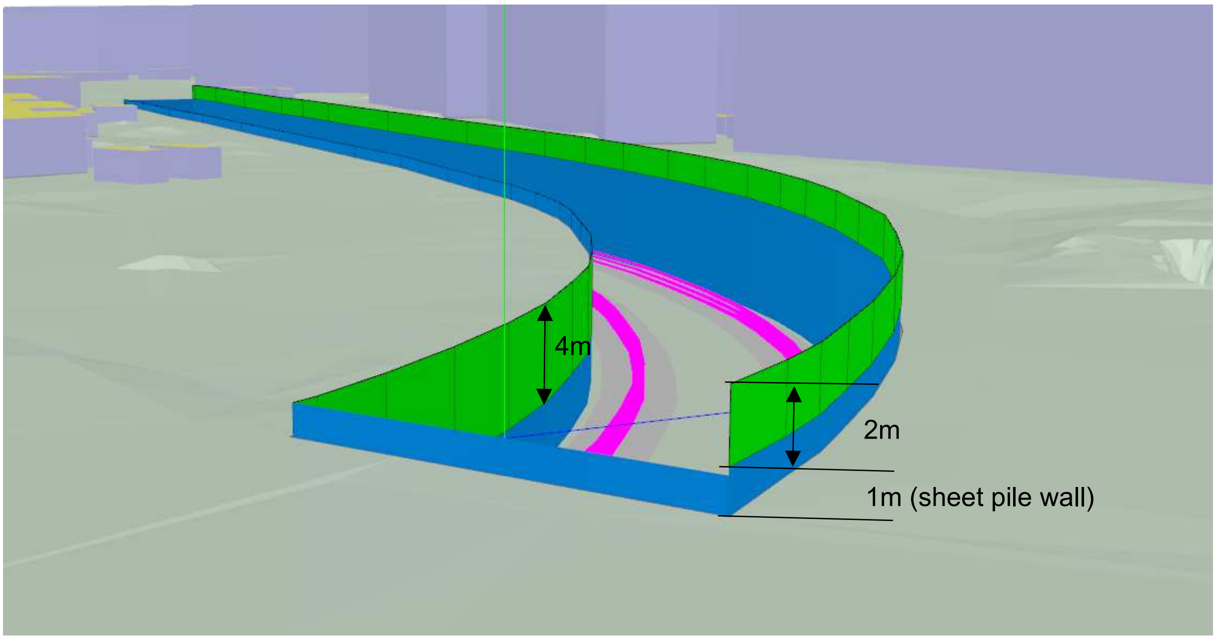

Figure A5-1: Scenario 5. 2 m high vertical sound-absorbing barrier on the northern sheet-pile wall, with the upper 4 m of the southern sheet-pile wall fitted with sound-absorbing material.