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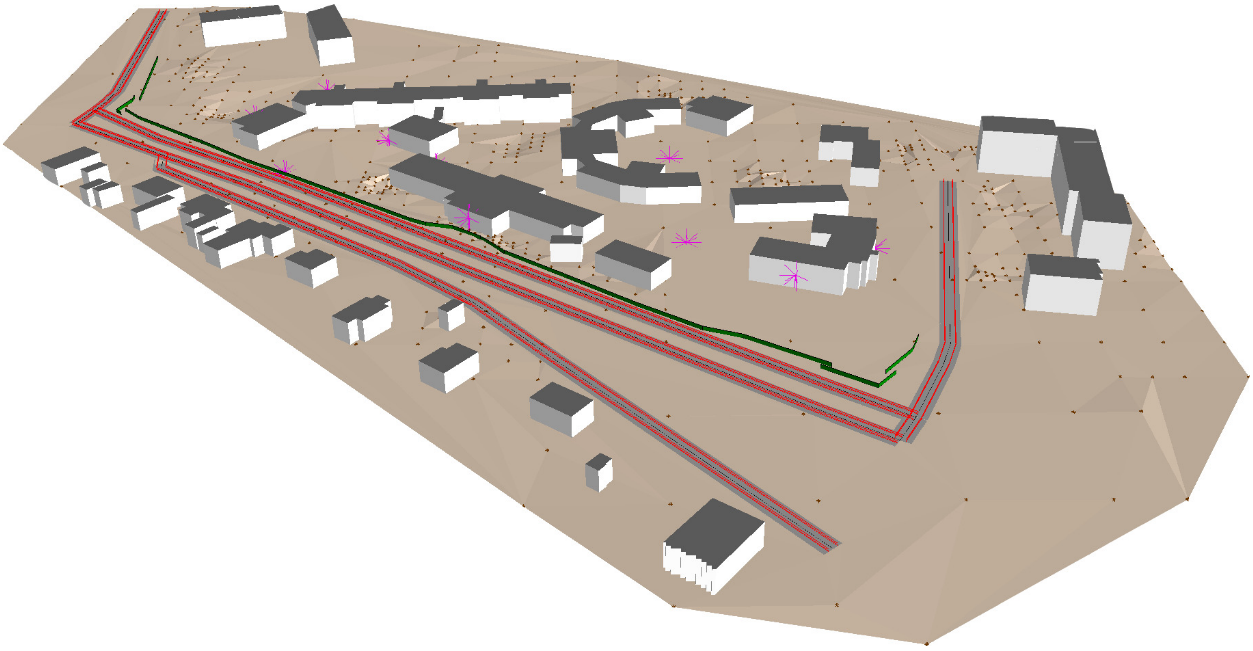

A combination of a road restraint system and a noise reducing device

Master of Science Thesis in Applied Acoustics

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Gothenburg, Sweden, September 2017

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Cover: Overview of Augustenborgsskolan, developed by using SoundPLAN

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Abstract

Based on measurements performed on a low-height noise barrier, an investigation was commenced on where such product could be implemented with respect to both noise reduction and to road restraint requirements, including traffic safety. By using three noise prediction tools, SoundPLAN (version 7.4), a Boundary Element Method (BEM) and an analytic solution, the screen insertion losses could be estimated and compared. The screen heights that were studied were 1.2 m and 1.4 m. The noise reducing effects of these screens were investigated in two real cases that were given by Malmö Stad and in a theoretical case. Standards for both a road restraint system and a noise reducing devise have been studied and summarised to facilitate the development of the combined system. The insertion losses for the two heights were 10 dB(A) and 11 dB(A) respectively when calculating for the theoretical situation. For the real case scenarios, the insertion losses were deteriorated to around 3 dB(A), concluded to be due to reflections in surrounding facades. The deviations in insertion loss between the different calculation methods was at most 2 dB but the results for the increased barrier height showed that a higher insertion loss could be achieved. The use of the BEM results, which were pre-calculated and provided to the project, showed that an absorbing screen should be considered when it comes to a low-height noise barrier, since an even higher reduction could be achieved. A low-height noise barrier should be considered and further investigated since it actually reduces the levels of community noise and has good potential to protect pedestrians from collisions within an urban environment.

Keywords: Noise reducing device, road restraint system, acoustics, collision, low-height noise barrier, community noise, SoundPLAN, Boundary Element Method, Analytic screen diffraction theory.

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Claudia Burgos and Linnéa Wåssén, Gothenburg, Sweden, August 2017

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Glossary

AADT Annual average daily traffic.

ASI Acceleration severity index.

ASJ Concrete,asphalt.

BEM Boundary Element Method.

C structure constant.

c sound speed.

c_0 reference sound speed or mean sound speed.

CE-marking European Conformity marking.

χ grazing angle.

DAC11 Dense Asphalt Concrete with 11 mm maximum aggregate.

DL_α Single-number rating of sound absorption performance expressed as a difference of A-weighted sound pressure level, in decibel.

E_s scattered power.

IL Insertion loss.

k wave number.

NRD Noise reducing device.

p effective sound pressure.

Q spherical reflection factor.

ρ distance to receiver from scattering position.

RISE Research Institutes of Sweden.

SALAR Swedish Association of Local Authorities and Regions.

σ scattering cross-section.

SPC Statistical Process Control.

SPL Sound pressure level.

STA Swedish Transport Administration.

$t_{0,K}$ **or** $T_{0,K}$ reference temperature or mean temperature.

θ scattering angle.

THIV Theoretical head impact velocity.

U flow speed.

V scattering volume.

VGU Krav för vägars och gators utformning.

VTI The Swedish National Road and Transport Research Institute.

z height above ground.

1 Introduction

Through a collaboration between the Swedish Transport Administration (STA) and Z-bloc Norden AB a desire to use a low-height noise barrier for roads has emerged. This sort of noise barrier has already been made and used for railways around Sweden with big success and now the question remains if it is possible to implement this technique on roads.

To be able to reduce the noise from cars, a low-height noise barrier can be quite effective since they can be placed closer to the sound source. This, however, leads to that the barriers must be able to handle vehicle impacts. Having this in mind, a conversation started between STA and Z-bloc Norden AB, and the idea of combining a low-height noise barrier with a road restraint systems was brought up. Both the Noise reducing device (NRD) and the road restraint system have strict and specific regulations which leads to that a low-height noise barrier must be seen as a combination of these two. Therefore a combined product must meet both a NRD and the road restraint systems requirements.

Previous measurements have been carried out in Stockholm on an area called Holmiaparken. For these measurements, low-height noise barriers used for the train tracks were temporary placed along the road only to investigate if they actually reduced the traffic noise in this situation. The results showed that the barrier had a reducing effect on the community noise [8]. These measurements are one of the main reasons behind this thesis, namely in what sort of situation a low-height noise barrier is of interest to use.

1.1 Aim

The purpose of the master thesis is to investigate if a low-height noise barrier is applicable in a road environment and to produce a basis for the development of this sort of barriers. The longterm goal is to reduce the the road traffic noise which will contribute with to a more sustainable urban development.

1.2 Scope

This thesis will focus more on the influence that a low-height noise barrier will have on the road traffic noise than the economical part and the mechanical structure of the NRD. The aim is not to present a fully developed product, but to set a basis that future suppliers can lean on. Different types of material will not be investigated for the combined product. Neither will the strength be calculated, but only the acoustical part of the construction. Only Swedish regulations will be brought up in this report.

The project corresponds for 30 credits ECTS at Chalmers University of Technology from the division of Applied Acoustics, Department of Civil and Environment Engineering.

When developing a new product there is a lot of aspects that has to be taken into account. The barrier has to be as effective (or more) as the products that are already on the market. Therefore it is important to state some questions that should be answered in this thesis:

- How close to the sound source is it possible to mount the barrier?
- What is required in order to put this product into use?
- How does the barrier work acoustically?
- How much noise should the barrier transmission be in decibels according to standards?
- What are the other requirements on the NRD?
- What are the requirements on the road restraint systems?
- What is the purpose with combining road restraint systems and low-height noise barriers?
- On what type of road can this barrier be implemented, is it multifunctional?
- How high is the present noise level on the road that is of interest?
- Why should this product be used instead of the present products that are available?

1.3 Thesis structure

The thesis project will be started by looking into different standards for both a road restraint system and a NRD to see what regulations must be fulfilled. By interviewing STA and the Traffic Office of Malmö stad it will be possible to investigate if they have any requirements on a specific area which could be of interest for this thesis. A theoretical case will also be implemented and worked with.

To be able to carry out calculations on the barrier, input data is necessary. By applying traffic data and the topography over Malmö stad, conclusive calculations could be achieved. These noise calculations will be based on two given situations that are of interest to investigate when it comes to applying low-height noise barriers, as well as on a theoretical case.

An investigation if an impact test is necessary when developing this sort of product will be presented.

2

Community noise

2.1 Noise related impact on human health and how to prevent it

It has been shown that environmental noise, especially road traffic noise, is affecting the human health and well-being negatively in many ways and is therefore of big importance to reduce [9]. Nowadays traffic noise is a well known social problem which has bad influence on the sleep- and rest-level and the ability to perform and learn. It will also increase the stress level. [7]. This environmental noise is increasing in the urban areas when the cities are growing in population.

A person is more sensitive to background noise when preforming different tasks. Especially, during night time as it can lead to sleep disturbance. During sleep, humans can react on sound and is able to evaluate both sounds and impacts that are well known. This leads to that the sleep gets very sensitive and easily influenced by the surrounding sound environment. Not only the sleep pattern and the sleep quality is affected by background noise. During awake time a person's flexibility and ability to focus on different subjects at the same time can be disturbed if the sleep has been impinged by noise. In addition to this, humans also might feel less productive and concentrated which can lead to that the stress level is increased as well as the tiredness [10].

Due to these reasons, it is of big importance to prevent or reduce the sound emission and the exposure to community noise. By spreading and reducing the noise between the source, the emission can be limited. The most common object that is used are noise barriers and noise banks. It is also possible to reduce the exposure by changing windows on buildings that are affected by community noise. Lowering the speed on the roads, using a quiet side on the building (meaning putting the bedroom and the living room on the opposite side of the road), putting certain rules on roads (for example that the road can only be used during certain hours etc.) are also actions that can be implemented to help reducing the noise [7].

2.2 Outdoor sound propagation

Noise is unwanted sound which can emerge for different sound sources such as vehicles, wind turbines and machines. The most common noise that humans are affected by on a daily basis is community noise which is particularly prominent in urban areas due to the amount of traffic found in these environments.

Traffic noise arises due to many reasons as it depends on different factors which are audible throughout the entire audible range, 20 Hz - 20 000 Hz. Factors that contribute to the noise are speed, vehicle weight, engine noise and the contact between the tires and the road. The factor that is most prominent and grants the bigger part to the noise depends on the situation, for example if the car is idling, driving, rolling down a slope or travelling in high speed. In addition, the size of the vehicle will be of importance. Heavy vehicles, where trucks and busses fall within the category, have been found to be 10 dBA louder than private cars. Tire noise for the two vehicle categories also differentiate from each other as the rolling noise becomes more pronounced above 40 km/h and 70 km/h for private and heavy cars respectively. [7]

Since noise spreading is affected by wind, temperature, topography, ground relation and the shape of the surroundings, it is sometimes a complex problem to prevent and decrease the noise.

The output power level will not only depend on the speed and vehicle category but also on the amount of traffic and the type of material that has been used for the road. It is for example possible to assume an increase of 3 dB when the traffic load is doubled while the driving speed is unchanged, since doubling or halving sound energy gives a 3 dB change in SPL. The noise level will also be altered when a vehicle is driving on a slope as the sound pressure increases by approximately 0.5 dB for each percent slope increase. There are roads where a certain type of asphalt has been used which is able to reduce the noise level by up to 6 dB. This sort of noise damping asphalt is quite effective since one of the abilities the asphalt has is that the noise is absorbed in the porous material. However, this effect is decreased with time when the asphalt is worn out as the holes are filled with dirt and dust. This leads to that the sound is partly reflected instead of being absorbed.

The surroundings, close to or around the road, will also have an impact on the noise as the topography will either protect or expose the receiver to the noise [7]. When a road is located on a bank the noise from the road is able to travel longer than when it is placed in a valley. This is due to that the walls surrounding the valley will work as screens or absorbers depending on what material they are made out of. Another factor which affects the noise level due to the material is the ground. It can be seen as either hard or soft where the first mentioned will reflect the sound and the second will act as an absorber. Snow and grass are for example seen as soft while water and dense asphalt are categorised as hard ground.

Since noise can have a bad impact on health, which is mentioned in Section 2.1, certain guidelines have been set for the environmental noise indoors and outdoors which can be seen in Table 2.1. In the table both equivalent SPL and maximum SPL are presented. These are the two types of noise levels that are considered within the community noise area. These two types of noise levels are also illustrated in Figure 2.1. The first mentioned looks at the average SPL during 24 hours while the latter is used for identifying the highest SPL with a certain time-weighting that can occur due to a single vehicle. This time-weighting will be further explained in this chapter.

On the 11th of May 2017 new regulations were set, where the environmental noise outdoors by the facade was changed to 60 dB. However, these regulations concerns new constructions and since in this thesis old buildings are investigated the old guidelines will be followed.

Table 2.1: Swedish guidelines for community noise exposure, indoors and outdoors [7].

Environment	Equivalent SPL (dBAeq)	Maximum SPL (dBA)
Indoors	30	45 (Night time)
Outdoors by the facade	55	-
Patio by the building	55	70

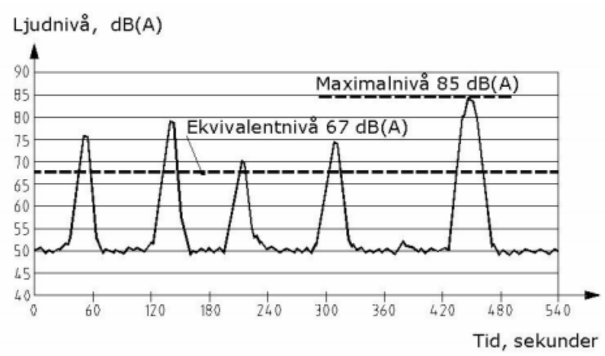


Figure 2.1: A representation of the equivalent and the maximum SPL[1].

A decrease of the SPL will occur and be noticeable as the distance increases between the sound source and the receiver. A rule of thumb is that the equivalent SPL in free field is lowered by 3 dB for each distance doubling (or rising with the same amount if the distance is halved). For the maximum SPL for one vehicle a decrease of 6 dB will emerge.

The requirements illustrated in Table 2.1 are in some cases hard to meet. For example, if the ground between the road and a building is soft and there are no obstacles in between, the equivalent noise requirement can easily be breached. This might occur in this case if the amount of vehicles per 24 hours and the speed lies around 4000 v/d and 90 km/h. Another example is to exchange the ground to a hard ground which will result in that the requirements will be breached at a vehicle amount of 1000 v/d [7].

2.2.1 Noise propagation factors

In this section, further information about factors affecting the outdoor noise propagation is presented. Factors that were mentioned earlier, such as the equivalent level, maximum level, meteorological aspects and choice of ground material (ground effect), will be further explained.

Equivalent noise level. The equivalent noise level, $L_{Aeq,24h}$, can be seen as a sum of various incoherent sources that are lined close to each other. By correcting the sum of the sources to the actual mean distance that vehicles have, $L_{Aeq,24h}$ is achieved [4].

Maximum noise level. The maximum level, L_{max}, is not modelled as "easily" as the equivalent level since only one point source is used along the length of all the vehicles [4]. L_{max} will for example be overestimated with this model when a receiver point is located close to the road. The maximum level always have a time weighting which is of big importance. It is either marked with a S or F which stands for slow and fast respectively. The first mentioned has the time constant 1/8 s and the latter 1 s. Further in this report the maximum level will be expressed as L_{AFmax} where A indicates that the value is A-weighted. The limit of 70 dB(A) for the maximum noise level outside, presented in Table 2.1, are correlated to a maximum amount of event. During an average night (22.00 - 06.00 for Swedish regulation) L_{AFmax} is not allowed to be exceeded more than 5 times within an hour.

Refraction. When the speed of sound is changing in the vertical direction, the sound path will change direction forming a curve, also known as refraction [4]. Since this curvature can change the direction of the sound path it is important to have refraction in mind when for example a noisy environment is to be rectified. The speed of sound changes with varying air temperature and the relationship can be written as:

$$c = c_0\sqrt{t_K/t_{0,K} or T_{0,K}} + U \tag{2.1}$$

The calculated c is called the effective speed of sound. In Equation 2.1 c_0 is the reference speed of sound, t_K is the temperature of interest in K, $t_{0,K}$ or $T_{0,K}$ is the reference temperature which is correlated to the reference speed of sound and U is the flow speed.

The flow speed is changing logarithmic with height and will dominate the effective speed of sound in windy situations. In lighter wind situations the temperature contribution will play an important role which has a more linear shape when changing with height. This linear sound speed profile will lead to a circular shape of the sound path due to Snell's law, Equation 2.2, which has a great impact on the sound travelling distance. The linear contribution is especially high during clear nights where the temperature of the ground and the sky deviates more.

$$\frac{cos_{\chi}(z)}{c(z)} = \frac{cos_{\chi 0}}{c_0} = const. \tag{2.2}$$

Where χ is the grazing angle and z is the height above ground. The derivation of the curved sound path can be further studied in *Building acoustics and community noise (BAC)* by Forssén [4] in chapter 7.1. In Figure 2.2 it is visual how different temperatures is affecting the sound path from a source to a receiver.

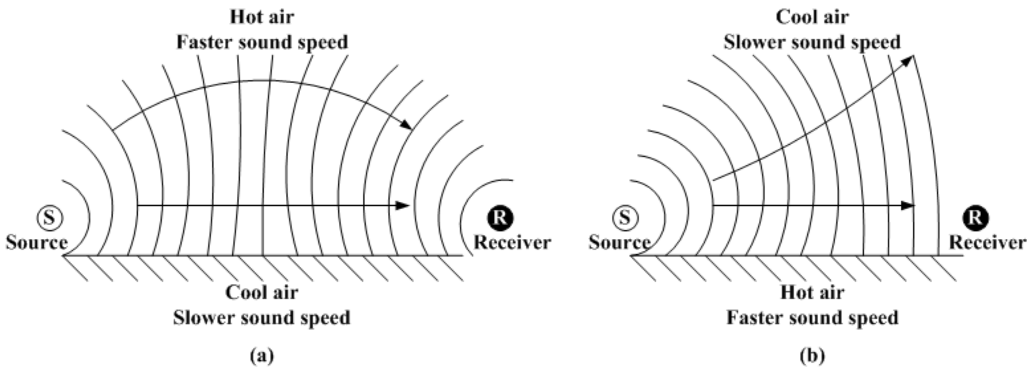


Figure 2.2: Sound paths for two different temperature situations. Figure a) describes a situation with cooler air closer to the ground than at higher altitudes. Figure b) describes a situation with hotter air closer to the ground than at higher altitudes [2].

Ground effect. The ground between a source and a receiver is of importance when it comes to the sound propagation. Ground qualities that produce the most effect is the impedance and the topography which is highly frequency dependent [4]. There are two sound waves travelling between the source and the receiver, a direct sound wave and a reflected sound wave. These two waves create reducing effects on the frequency response at a distance difference between the two waves as following:

$$n\lambda + \frac{\lambda}{2} \quad n = 0, 1, 2... \tag{2.3}$$

In which frequency range the damping will occur depends on the reflected wave, which in turn is influenced by the *specific acoustic impedance* of the ground. This impedance is defined as the effective pressure p at a certain point on the ground divided by the effective velocity v_n which has the direction normal to the ground surface.

When the source and the receiver is placed closer to the ground the width of the affected frequency range will increase. This is due to that the relation showed in Equation 2.3 will occur much more often when the travelling distances becomes more alike. This wide damped frequency range is more commonly called the *ground effect* and is favourable to implement to reduce community noise.

For a sound source that is placed close to the ground compared to the wavelength, spherical waves will emerge. This is usually the case and therefore a spherical reflection factor expressed as Q has to be assumed when calculating the contribution from the ground. This reflection factor can be derived by Green's function which has the following expression:

$$G = \frac{e^{jkR_1}}{4\pi R_1} + Q\frac{e^{-jkR_2}}{4\pi R_2} \tag{2.4}$$

Where k is the wave number and R_1 and R_2 is the direct and reflected travel distance separately. The exact approach of the derivation will not be further discussed in this report but can be studied in *Predicting Outdoor Sound* by Attenborough

[11]. The final expression for Q, implemented in the calculation of the total sound pressure at a receiver position, is described below:

$$Q = R_{pl} + (1 - R_{pl})F(w) \tag{2.5}$$

Here R_{pl} is the contribution of a plane wave reflection factor while $F(w)$ is a factor to adjust the expression to a spherical situation.

Diffraction The sound path can be affected by a barrier placed between the source and the receiver position. This sort of obstruction will create a diffraction of the propagating sound which in turn leads to a decreased sound pressure level. In the urban areas a noise barrier is the most common man build diffracting obstruction to reduce community noise [11]. The simplest model which the diffraction theory is based upon is a thin hard screen which is the model that will be used in the following theory.

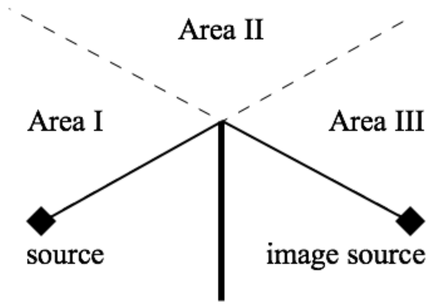


Figure 2.3: Different diffraction areas for a thin hard screen between a source and a receiver.

In Figure 2.3 it is visible how a thin hard screen is affecting an incoming sound wave. The area around the screen can be divided into three regions. Within these regions the received sound will be different. Area three is determined by the direct sound path from the source (dashed line between area two and three in the figure). In this area, also called the shadow zone, only diffracted wave created by the screen can be reached. The dashed line between area one and two in the figure is representing the the limit of a reflected wave from the screen, meaning that a reflected sound wave can only be reached in area one. This boundary is defined by an image source on the opposite side of the screen. A summary of the sound types in the different areas is listed below:

Area I: reflected sound, direct sound and diffracted sound
Area II: direct sound and diffracted sound
Area III: only diffracted sound

There are different methods to use when modelling a screen. In this report an analytical method by Pierce, BEM and a screen model implemented in the acoustical software SoundPLAN will be explained later in Chapter 3.

Combination of diffraction and ground effect Since the screen is placed on a surface, it is important to take the ground material into account [11]. When considering a receiver position in area III there are four ways the sound path can differ which is shown in Figure 2.4 where ground reflection is included.

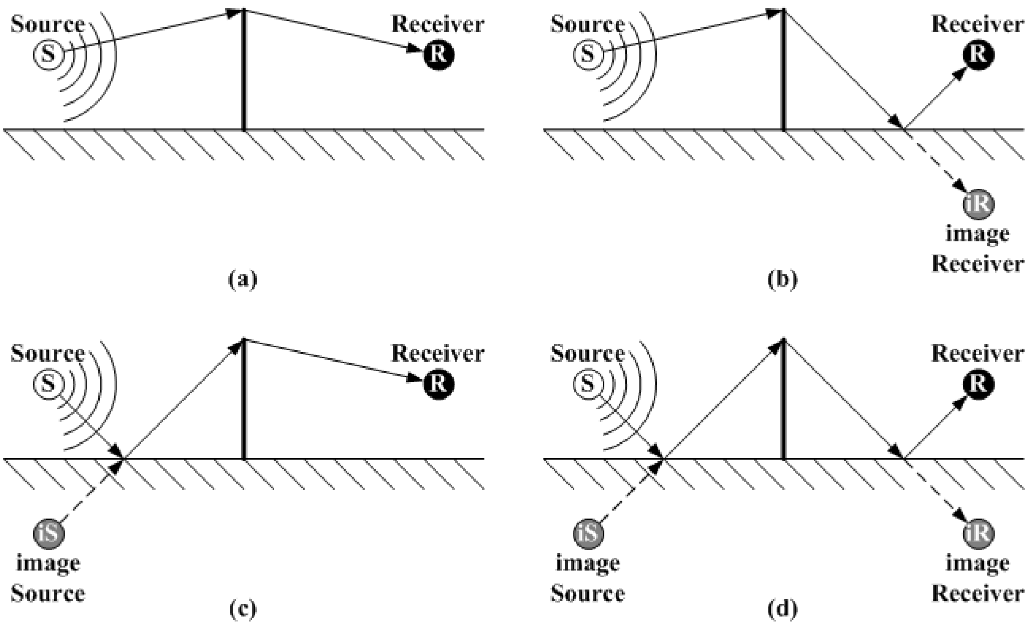


Figure 2.4: Different sound paths for a sound propagation case with a noise barrier. The receiver position is in receiver area III [3].

The figure is illustrating a method called the image method which consider an image source as well as an image receiver. With the help of the image points on both sides of the barrier the reflection points on the ground can be estimated. The sound pressure at the receiver position is then a sum of all the sound paths' pressure fields over the barrier which will have the following expression:

$$p_t = p_1 + p_2 + p_3 + p_4 \tag{2.6}$$

For most cases the ground impedance is anything but infinite which results in that the *spherical reflection factor* Q, explained earlier in this section, must be included in Equation 2.6. Since there are two ground sides, two reflection factors have to be included. This leads to that the final expression of the sound pressure looks as following:

$$p_t = p_1 + Q_2 p_2 + Q_1 p_3 + Q_1 Q_2 p_4 \tag{2.7}$$

Where p_n represents the sound paths in the four situations in Figure 2.4, Q_1 is the reflection factor at the source side and Q_2 is the reflection factor at the receiver side. However, this sort of method is a simplified model and there are some assumptions made that can cause errors, especially in the lower frequency range [4]:

- ⋆ Multiple orders of diffraction between the ground and the screen, which is very important when it comes to calculation of lower frequencies.
- ⋆ When it comes to calculating with an image source (shown in part c and d in Figure 2.4), the distance between the image source and the screen edge is only true if the receiver was placed on the screen edge and not otherwise.

Air attenuation and turbulence Outdoor sound propagation is influenced by the surrounding air. The sound can both be damped or amplified by the air depending on the outdoor condition. Two cases due to air will be described here which is air attenuation and turbulence.

Air attenuation is another word for when the air is damping the propagated sound, also called air absorption. This effect will increase with frequency since humidity, temperature and travelling distance affects the air absorption [4]. The vibrating and rotating energy that the sound wave is producing will be stored in the air molecules and further be lost as heat.

The turbulence effect is created by wind shearing, heat differences and obstacles in the air. There are two ways the sound wave can be distorted by turbulence which is by decorrelation or scattering. Decorrelation emerges in a non-screened situation where the frequency pattern created between the direct wave and the reflected wave, e.g ground effect, will be smeared out and cover a greater spectra. The decorrelation can be described with the following equation where Γ is representing the amount of turbulence. 1 indicates no turbulence which increases when the value goes towards 0:

$$\left|\frac{p}{p_0}\right|^2 = 1 + |Q|^2 \frac{R_1^2}{R_2^2} + 2|Q| \frac{R_1}{R_2} \cos[k(R_2 - R_1) - \phi]\Gamma \tag{2.8}$$

For a situation including a screen the sound path will be scattered and occur in the shadow area behind the screen, area III shown in Figure 2.3, which leads to that the screen will have a reduced efficiency. A scattered wave that goes from an object to a receiver without encountering with another object is called a single-scattering approximation. This approximation suits well for a case with steep geometry or short distances between the scattering object and the receiver [4]. The expression for calculating the amount of the sound wave that is scattered is called a scattering cross-section, σ and look as follows:

$$\sigma(\theta) = 0.03k^{1/3} \frac{\cos^2\theta}{\sin(\theta/2)^{11/3}} \left[0.14 \frac{C_T^2}{T_0^2} + \frac{C_v^2}{c_0^2} \cos^2 \frac{\theta}{2}\right] \tag{2.9}$$

Where θ is the angle of the scattered wave to the receiver, C is a structure constant where the index T stand for the temperature fluctuations and v stands for the velocity fluctuations. From this scattering cross-section, the scattered power E_s can be estimated with Equation 2.10 which will tell how much of the sound power that will be scattered away from the receiver.

$$E_s = \int_V p_0^2 \frac{\sigma(\theta)}{\rho^2} dV \tag{2.10}$$

Where V is the scattering volume and ρ is the distance to the receiver from the scattering position. By studying Equation 2.9 and Equation 2.10 it is plausible to see that the scattering power will get stronger if the scattering angle gets smaller [4]. This is also the case when the frequency is increasing and when the geometry of the situation gets scaled up.

The single scattering approximation expression is only valid for a single scattered wave and to estimate the limit of this method all the possible scattered waves have to be summed up. This method is called the total scattering cross-section. This derivation can be further studied in *Building acoustics and community noise (BAC)* [4].

3
Noise prediction methods

When new buildings, areas or constructions are planned the community noise has to be looked over. By predicting the noise, acousticians and engineers are able to see how the noise can be reduced and stopped before the actual building is in place. In Sweden there are two prediction methods that are used, namely *Nordisk Beräkningsmodell, reviderad 1996* and *Nord2000*. In this section both of the methods will be described. However, the first mentioned method will not be as profound as the second method as only the maximum SPL will be covered.

3.1 Road traffic noise - Nordic prediction method revised 1996

The road traffic noise - Nordic prediction method was produced by members of the Nordic environmental and road authorities in 1996 and is meant to be used for noise protection measures. Within this method the maximum and equivalent levels can be predicted.

In this section only the maximum level will be explained. The entire method will therefore not be as profound as Section 3.2. More information on how the method can be implemented and works can be found in *Vägtrafikbuller - Nordisk beräkningsmodell, reviderad 1996 - Del 1* [12].

As mentioned in paragraph *Maximum noise level* Section 2.2.1 the maximum level, L_{AFmax}, is the maximum sound pressure level that has an A-weighted sound frequency response and a time-weighting which is used for measuring the highest sound pressure level that a vehicle can emit. In this prediction model there are important parameters which are in need of consideration so that the maximum value can be achieved from its average and standard deviation. The parameters needed are the vehicle type, speed, the position and dimensions for a noise barriers among other [12].

L_{AFmax} is calculated in five steps where in the first an initial value is obtained under certain prerequisites. The remaining steps are corrections for different cases which then are added to the first step. Equation 3.1 shows how the different steps achieve the maximum level.

$$L_{AFmax} = L_{1max} + \Delta L_{2max} + \Delta L_{3max} + \Delta L_{4max} + \Delta L_{5max} \tag{3.1}$$

In the first step the initial value, L_{1max}, is achieved by knowing the vehicle category and speed. With these variables the value $L_{1max} = L_{AFmax5\%,10m}$ can be determined. $L_{AFmax5\%,10m}$ is the undamped maximum level at a distance of 10 m from the road centre, where the noise level has been overstepped by 5% of the vehicles. Based on this value it is then possible to add the corrections which will lead to L_{AFmax} [13].

The second term in Equation 3.1 is a correction which deals with attenuation due to distance. Equation 3.2 calculates the correction where the the shortest distance between the receiver and the road centre a is included. In addition, the difference between the heights placed receiver, h_m, and the road, h_b, is needed. It is also assumed that the sound source is positioned 0.5 m above the road surface.

$$\Delta L_{AV} = -20lg\left[\frac{\sqrt{a^2 + (h_m - h_b - 0,5)^2}}{10}\right] \tag{3.2}$$

The correction for the ground and barriers are taken care of in the third term in Equation 3.1.

All attenuation, except the distance attenuation has been defined as ground attenuation. However, in this prediction model it has been restricted to only calculate the correction based on certain parameters. They are the height of the receiver, dimension and positioning of the barrier, the ground condition and the road surface's height above the ground [13].

As the topography varies for different situations the height for the receiver and the road surface will not always be measured from the ground that is closest to them. Instead, in this prediction model, reflection planes are used, which are determined from where on the ground the sound is reflected between the road and the receiver. There are different ways to determine where the reflection plane should be depending on the situation further explained in *Nordisk beräkningsmodell, Del 1* [12]. Once the reflection plane has been set the receiver height and the road surface height can be achieved.

The remaining factor which is important for obtaining the ground attenuation is the shortest distance between road centre and the receiver, a. Having all the parameters the ground attenuation is produced by using equation (2.36) and (2.37) found in *Nordisk beräkningsmodell, Del 2* [13].

When a barrier is used, two reflection planes are required; one between the road and the barrier and one between the barrier and the receiver. For a situation where a barrier is present the shortest distance becomes the sum of the distance between the road centre to the barrier and the distance between the barrier and the receiver. The barrier correction is easiest calculated in two steps, since more parameters are needed it is easier to divide it up. First the screening is achieved without taking the ground into account then the grounds influence is added and corrected for.

The remaining corrections L_{4max} and L_{5max} are corrections for other parameters such as for example reflections from buildings and facade isolation that will not be further discussed here. More information can be found in *Nordisk beräkningsmodell* [12].

Worth to mention is that in this method the sound source is always assumed to be 0,5 m above the ground surface.

3.2 Nord2000

The development of Nord2000 started in 1996 where a general sound propagation model and a specific sound source model for different types of environmental noise sources where in mind [14]. The reason to why a new prediction method was started was partly due to that there was a desire for developing a propagation model. This model could then be implemented with different types of source models such as road noise, rail noise, industrial and aircraft noise. In this section the source model for road traffic noise and the general sound propagation model will be treated.

With the new prediction method it is possible to calculate equivalent and maximum sound pressure levels in 1/3-octave band with centre frequencies from 25 - 10,000 Hz. Many aspects can be included such as the different types of ground impedances, more than one barrier can used in the calculations and meteorological conditions are also now considered [15]. For the evaluation of the ground effect a geometrical ray theory is implemented where also the spherical wave reflection coefficient is involved. When it comes to barriers, combinations between different theories are implemented. The ones that are used to evaluate the screening are the diffraction theory which is used with geometrical theory and the reflections that can occur on obstacles. In the last mentioned, mirrored sources are included. Lastly, the Fresnel zone approach is also implemented to achieve the screening. For the atmospheric reflection effect a heuristic model is used. This model is also based on the geometric ray theory. Further information and derivation of the different theories can be found in *Predicting Outdoor Sound* [11].

When the noise levels from community noise are to be predicted, sound sources are needed in noise prediction methods that emits noise and expose receivers to it. In the newer prediction method the outdoor noise, which emerges due to vehicles, are modelled as uncorrelated moving point sound sources. They have been divided into sub sources which can emit noise within a relatively large frequency range and can either be seen as omni-directional or be assigned a directivity if needed. Their strength depends on many factors for example the speed, type of vehicle and the surface of the road just to mention a few and are normally shown as sound power levels [15].

The vehicle type is of big importance since the noise that emerges from it will vary as it originates from different parts on the vehicle. The parts that mostly are looked upon are the engine, the exhaust pipes and the tyres (which produce noise when they are in connection to the road surface). There are five categories where different types of vehicles are categorised within and the ones that are mostly used are the first three. In these categories passenger cars and larger vehicles such as busses or trucks are found. For all the three categories mentioned the tyre noise is represented by a point source located at a height of 0.01 m. For the passenger cars the propulsion noise, which is also represented by a point source, is placed at a height of 0.3 m. For the heavier vehicles the latter mentioned is found at 0.75 m. The propulsion noise consist most of lower frequencies, while frequencies in the higher range are found in the rolling noise (tyre noise) [4] [16].

When it comes to barriers, Nord2000 is able to handle any number of barriers in combination with different types of ground conditions. However, due to practical reasons a limitation has been set so the prediction model only deals with two barriers. The barriers that can be used for calculations can have various dimension, meaning both thick and thin barriers can be used. Barriers with wedge shape can also be implemented. For low-height noise barriers, reflections are obtained according to the so called Fresnel-zone correction [15]. The concept of the Fresnel zones correction is used for including small variations which can be found in terrains that are seemed to be flat. In real cases, a terrain can never be completely flat. The ground will have small variations or other properties that are range-varying and this is covered by the correction in Nord2000. The ground in between the source and the receiver is more thoroughly looked at as more reflections within this area are considered and taken into account [4].

The sound propagation from a sound source will be affected by many factors before it reaches a sound receiver. As mentioned in Section 2.2.1 scattering, air attenuation, ground reflection just to mention a few will decrease the sound energy. In this prediction model the attenuation, due to these factors, is calculated for all the individual point sources mentioned earlier [15].

To achieve the equivalent sound pressure level, L_{eq}, all the contributions from one vehicle, or one sound source, have to be summed up. This is done by adding the sound exposure levels during pass-by. Since the road, where all of the vehicles are present, is divided into segments, the sound exposure of the individual vehicle must be calculated for each road segment. Once all the segments and the vehicles are added together, L_{eq} is found. It is possible to achieve the equivalent sound pressure level for any type of combinations between the vehicle type, traffic flow and the meteorological conditions. The maximum sound pressure level is obtained from the sound power levels.

$L_{eq,T}$, L_{den} and L_{Fmax}

The sound power level is determined from the sound exposure level that has been normalised to 10 m with an angle of integration of 2.75 rad by equation (2.1) in *Nord2000. New Nordic Prediction Method for Road Traffic Noise* [15]. After some modifications the sound power level L_W is achieved with Equation 3.3, more detailed information on how to reach L_W can be found in *Nord2000* [15].

$$L_W = L_{E,10m} + 10lg(\frac{v}{50}) \tag{3.3}$$

Knowing the sound power level of a point source, it is possible to obtain the equivalent sound pressure level from a vehicle flow for an entire road during a specified time period T. All the source contributions within a vehicle category are also included in Equation 3.4 to obtain the sound pressure level.

$$L_{eq,T} = 10lg\left[\sum_{vc=1}^{N_{cat}} 10^{(\frac{L_{eq,T,vc}}{10})}\right] \tag{3.4}$$

Further derivations on how the sound exposure level leads to the sound power level, which in turn gives the equivalent level for one vehicle can be found in chapter

2, 3 and 4 in *Nord2000* [15]. Once all the factors are in place, Equation 3.4 can be put into use.

In Nord2000, L_{den}, which is the equivalent sound pressure level during 24h, is achieved with Equation 3.5 where the movements for the vehicles during the day, evening and night are considered.

$$L_{den} = 10lg\left[\frac{1}{T_{day} + T_{evening} + T_{night}}\right] + \\ 10lg[T_{day}10^{(L_{eq,day}/10} + T_{evening}10^{(L_{eq,evening}+5)/10} + T_{night}10^{(L_{eq,night}+10)/10}] \tag{3.5}$$

In the equation it is possible to see that 5 and 10 dB has been added to the equivalent level during the evening and night. These decibels are penalties that the European union has proposed to use when L_{den} is looked upon. In Sweden the three time intervals are 06.00-18.00, 18.00-22.00 and 22.00-06.00 for day, evening and night respectively [17].

The maximum sound pressure level is relatively complicated to obtain theoretically. This is due to that different frequencies during varying time will have different maxima. However, it has been observed that by using different heights for the point sources on a vehicle, $j = 1 : n$, and combining them with the sound propagating theory it is possible to achieve reasonable values for L_{Fmax}. By summing up all the point sources height at different positions i and then taking the maximum value of all the positions the vehicle has during a complete pass by gives L_{Fmax} as Equation 3.6 shows.

$$L_{Fmax} = max(L_{Fmax}(i)) = max\left[10log\sum_{j=1}^{n}10^{(L_{W,ij}+\Delta L(\phi)+\Delta L(\psi)+\Delta L_{ij})/10}\right] \tag{3.6}$$

A horizontal directivity occurs around the contact point between a vehicles tyre and the road surface. This is due to the so called horn effect which is not of importance when $L_{eq,T}$ is calculated. However, it should be considered when the maximum level is calculated since it can lead to that the maximum levels become overestimated. Correction for this has been included in Equation 3.6 where $\Delta L(\phi)$ and $\Delta L(\psi)$ are the horizontal and vertical directivity respectively [15].

3.3 Comparison between Nord2000 and Nordic prediction method revised 1996

It has been seen that the two methods differ from each other when looking at for example the sound pressure levels and the air attenuation. For the last mentioned the old method only uses the same spectrum for both the ground effect and attenuation due to barriers. In Nord2000 the air attenuation will vary when it is expressed in A-weighted levels. The reason is, that in the newer model real spectrum for different speeds are implemented. A profound comparison where the emission and the excess attenuation has been made can be found in chapter 7 in *Nord2000. New Nordic Prediction Method for Road Traffic Noise* [15]

4

Barrier modelling

In a previous study called *A low-height acoustic barrier in a setting with urban road: measured and predicted insertion loss* [8] where a low-height barrier was investigated, the prediction method Nord2000 was combined with a numerical technique called the Boundary Element Method (BEM). How this method works will be described in the following section. In addition, an analytical solution by Pierce will be described as it can be combined with Nord2000 to predict the pressure which is diffracted from a hard thin barrier.

4.1 The Boundary Element Method

The BEM is a numerical method which can be used to understand how a structure radiates sound. The approach is from the beginning derived from the Rayleigh's integral that enables a structure to be divided into several surfaces. The new surfaces will then more or less follow the shape of the structure and will all have a certain volume flow. The volume flow for all the surfaces depend on their velocities normal to the surface and their size. Meaning that every new surface on the structure has a monopole situated in the middle. If the body of the structure is removed and only the monopoles are left it is possible to achieve the sound pressure of the structure in free field when all the monopoles pressure are summed up. However, it is not sufficient to describe the structure radiation with just the Rayleigh integral since the scattering on the structures body is ignored. The boundary conditions on the structure is simply not met mathematically [18].

To obtain the radiated sound pressure, dipoles need to be added to each monopole. With a dipole it is possible to see changes in both amplitude and direction for the pressure, where as for a monopole only the amplitude is achieved. The pressure of the structure at a position in free field can be reached by adding the sum of the monopoles to the sum of the dipoles and then compare the pressure of each individual surface on the structure to each other. A large linear equation system is used for all the calculations. Comparison of the elements, where also the problem of the contribution from the element itself is taken into account and solved for. Once all of this has been completed the radiated sound pressure of the entire structure in free field is obtained with Equation 4.1 when using BEM.

$$P(M) = P_{inc}(M) + \int_S P(Q)(\rho w^2 Y(Q) G(M,Q) - \frac{\delta G(M,Q)}{\delta n}) ds(Q) \tag{4.1}$$

M represent the position, at any place on a infinite flat ground, of the radiated sound pressure. $G(M, Q)$ is the Green's function representation of the pressure field the structure is producing at M due to Q, which are the unit sources in the structure mentioned earlier. The real body of the structure is not present as the unit sources are used instead, however the ground is included. P_{inc} is the pressure at position M from a real source such as a vehicle. This variable does not include the contribution of an acoustic barrier. Y is a mobility that changes positions and frequency along a boundary S of an acoustical barrier.

It is possible to use Equation 4.1 and apply it to a Software that enables 2.5D geometries in the x-z plane. In this software the sound source is represented by several uncorrelated point source locations placed along the traffic direction (y-axis), while an acoustic barrier is represented by a contour. The receiver that can be placed at different position along the axis are not able to vary once its position has been set. The sound source is also invariant and both the source and the receiver are extended infinitely along the y-axis [8].

By adding a source model to this setup, such as Nord2000, it is possible to predict how much a barrier can decrease noise at any receiver point. As long as all the needed data is inputted it is possible to predict maximum and equivalent levels. Information that is needed is for example the barriers dimensions and positioning, the receivers height and position, the ground type and the all the sound source information. Reflections from buildings and topography are however not considered in this method.

It is also possible to add absorption to the barrier in this setup. The so-called slit-pore model which is based on the relationship that is used between porosity and tortuosity for stacked spheres can be implemented. Within this model parameters such as thickness, porosity and effective flow resistivity can be varied. More on how the model works can be found in *Outdoor ground impedance models* [19].

4.2 Analysed solution by Pierce

Another method which can be implemented to predict how much a barrier can decrease community noise is to use the analysed solution by Pierce. This approach describes how a pressure is diffracted from a thin and hard barrier in a relatively simple way. The approximation that is made is restricted to that the sound source and the receiver position are not positioned too close to the barrier. About one wavelength of the lowest frequency of interest should be used.

The pressure can be obtained by using Equation 4.2.

$$p_{Pierce} = \frac{e^{-jkL}}{L} \frac{e^{-jkL/4}}{\sqrt{2}} [A_D(X_+) + A_D(X_-)] \tag{4.2}$$

Where $A_D(X_+)$ is the diffracted integral which the analysed solution by Pierce is based on. L is the total distance where the length is measured between the sound source and the receiver where the barrier is not included. r_0 and r are distances where the first motioned is the distance between the source and the barrier and the second mentioned is the distance between the barrier edge and the receiver.

The angles θ_0 and θ, which are visual in Figure 4.1, are taken into account as they define the input X_+ and X_- which are used in the diffracted integral $A_D(X_+)$. The

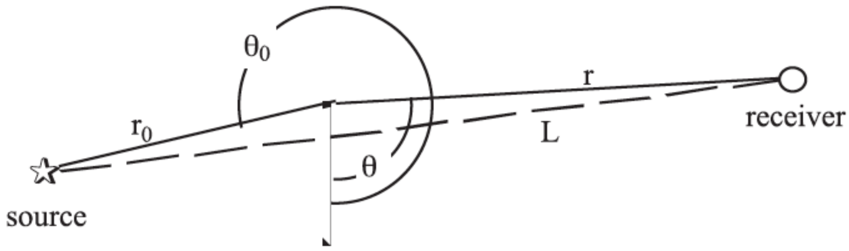


Figure 4.1: Pressure that is diffracted from a barrier [4].

last mentioned is quite a messy integral that is simplified by using so called auxiliary Fresnel-functions which are further described in *Building acoustics and community noise (BAC)* [4].

5

Road environment requirements

Barriers that are constructed to be used close to the roads have to fulfil certain requirements to avoid interference and have to prevent problems that may occur in this sort of environment. The requirements differ depending on the products that are used and can be found in many standards. In this report road traffic reducing devises and road restraint systems are investigated. Therefore, the requirements that are presented will apply to these sorts of products.

5.1 Road traffic noise reducing devices

A NRD placed in a road environment has to fulfil both guidelines and requirements stated in Krav för vägars och gators utformning (VGU) (*Requirements for road and street design*) and European standards. Both requirements for acoustical performances and non-acoustical performances of the NRD has to be taken into account where the non-acoustical performances presented here are, according to SS-EN 1794-1 [20] and SS-EN 1794-2 [21], resistance to load, residence to brush fire, shatter properties, light reflectivity, durability, impact of stones, safety in collision, environmental protection and transparency.

5.1.1 Acoustical performance

The requirements on the acoustical performance stated in VGU [22] is that the NRD has to be completely sealed both between different parts of the device and to the ground underneath. The NRD must also fulfil sound absorption category A4 according to SS-EN 1793-1:2012 [23] which states that the DL_α has to be between 12 dB and 15 dB. This value is produced by executing laboratory measurements where the traffic noise spectrum is defined by the *normalised traffic noise spectrum* in SS-EN 1793-3:1997 [24].

The measurement should be carried out according to EN ISO 354 and will measure the absorption coefficients for each one-third octave band. This test will not be further explained here but can be studied in EN ISO 354:2003 [25].

It is of important to have in mind that this measurement is preformed under laboratory conditions and is only used to indicate in which absorption category the NRD falls within. This value should therefore not be confused with the barriers insertion loss.

Suggestions on acoustical performances For the noise barrier to be useful for reducing the traffic noise it has to break the line of sight. This has to be fulfilled both in the length direction and in the height direction. To avoid a too high or too long barrier the NRD can be placed closed to the road, be bent on the top or combined with existing buildings or terrain that does not need to be protected by the barrier. There are both advantages and disadvantages placing the barrier closer to the road or closer to the desired shielded objects. The placement of the barrier depends on the situation and the most important point is that it is not placed in the middle between the noise source and the shielded object. The barrier can be more efficient if it is placed closer to the road as it will come closer to the low height sound source. When it comes to isolated houses it can be an advantage to place the barrier closer to the buildings since a barrier closer to the road needs to be longer to be able to shield the whole sight [26].

A barrier is not always a good solution for reducing road traffic noise. If the NRD does not have any absorptive side towards the road the reflections from the barrier can result in increased noise level on the other side of the road [26]. The barrier can also create unwanted reflections between barriers or between barrier and vehicle shown in Figure 5.1. The diffraction angle for a sound wave will vary depending on how absorptive a barrier is. If the barrier is of the non-absorbing type, the sound will due to the diffraction angle reach the sound receiver as the sound will be multiple reflected between the barrier and the vehicle. This problem is most prominent density populated areas and if the barrier is placed close to the road.

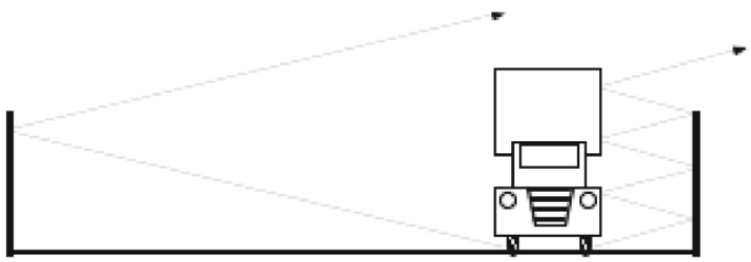


Figure 5.1: Multiple reflection between barriers or between barrier and vehicle [4].

Another situation that can make the barrier less effective is when it is placed near areas with soft ground where the ground effect can occur. This situation is further explained in Section 2.2.1.

In an urban environment NRD must interact with the structure of the city which can lead to that gaps in the barrier must occur. To avoid poor noise performances in these situations, the barriers on both sides of the gap, must imbricate with each other and have absorptive material on the sides [7].

5.1.2 Barrier design

Many aspects have to be considered before a new barrier can be implemented next to a road. Many requirements have to be met and the barrier should blend in where it is mounted. The aesthetics of a barrier for example cannot be neglected since it is crucial to not destroy and interrupt an ambience complexion. It has to be adapted in such a way to the road and the environment so that it does not become an obstacle instead of a feasibility. In Figure 5.2 it is possible to see how a barrier should be placed by crossings to avoid losing the noise barriers effect [22].

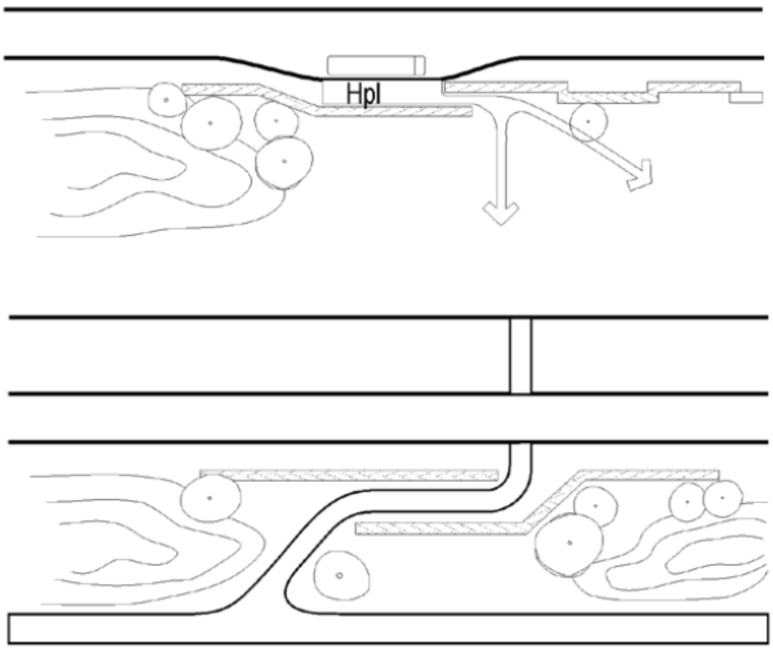


Figure 5.2: Example on how a barrier should be placed by crossing [5].

Except for this, it is important to make the NRD varying, as monotonic barriers can lead to that the road user become fatigue. Variation can be achieved by using different types of colours and material. The barriers height and formation is also possible to change. If barriers cannot be varied due to some reason, plantation can be used to diminish the monotonic experience. The "easiest" solution to this problem could be to use transparent barriers where landscapes and plantation would not be hided [26]. As mentioned earlier the barrier must look natural in the environment it has been mounted [22]. For urban areas it becomes more aesthetic if a noise barrier is used instead of a noise bank, which natural fits better in green areas such as park or on the country side [26]. However, for low-height noise barriers many of these aspects are not as crucial as it is for higher barriers.

5.1.3 Technical performance

Apart from protecting against noise the noise barriers have to be able to withstand certain weather conditions. Since it will be exposed to different seasons, engineers have to for example estimate the load from snow and wind in the construction calculations. In addition, it must not block the water drainage from the road during for example rainy days. This problem is most likely to occur when a barrier is placed close to a road. For these cases it is important to include some kind of drainage in the connection between the barrier and the ground [7].

The surrounding environment where the barrier is placed will be affected by the barrier. This is due to that there are great chances that snow drifts, sharp winds and shadowing creating patches of ice emerges. Snow drifts are dependent on the noise barriers placement and the sharp winds are found at the barriers endings where there is a risk that road users are exposed to it. When the height of a barrier is decreased this effect will not be as prominent, but should still be considered. To avoid these issues the barrier should be placed away from the road with a minimum distance of four times its height. Unfortunately this distance will impoverish the acoustic characteristics of the barrier. However, by using vegetation around the barrier it is possible to decrease the distance as the vegetation can help to prevent snowdrifts and sharp winds [7].

The road traffic noise reducing devices will as mentioned earlier be exposed to many tings since they are placed within a road environment. Except from the different weather conditions the NRD will be subjected to the dynamic air pressure the passing traffic causes. Shocks due to pebbles and other debris which the vehicles tyre tosses up, or the dynamic force that ejected snow causes from snow removal equipment are other factors that the barriers can be exposed to. All of these factors have to be considered when a barrier is being developed as they should not reduce the barrier's effectiveness [20].

There are requirements that have been set for sound barriers where its elements are not allowed to detach during the exposures just mentioned. In addition, the elements are not allowed to fall off due to its self weight, collisions, vibrations and fatigue effects. In the standard, Road traffic noise reducing devices - non-acoustic performance Part 1: Mechanical performance and stability requirements [20], there are guidelines on how to prevent the barriers structural performance from deteriorating due to mentioned reasons which will not be further discussed here.

5.1.4 Road safety according to NRD

Since a NRD is placed in a traffic situation it can impinge on the traffic safety for the road users. The requirement stated in VGU says that the barrier should not cover the sight triangle for the drivers, further explained in Section 5.2.1. It should also be placed outside the roads safety zone where the dimensions depend on the speed on the road [22]. Within urban areas where the speed usually does not exceed 50 km/h the safety zone outside the carriageway can be between 0.5 m and 1 m. However, these dimensions are only applicable around a road environment that due to its character produces short crossings, low speeds and low traffic flows [26]. If the barrier is placed within the safety zone it can be combined with a restraint system which means that it has to fulfil the requirements for both a NRD and a road restraint system. The requirements for the restraint system will be explained in Section 5.2.

The NRD can also have a favourable affect on the road users behind it since the barrier can guide them to specific traffic safety cross-overs [7].

For a NRD to be implemented in the road traffic area it has to fulfil general safety and environment performances which is: brush fire, secondary safety: danger of falling debris, environmental protection, means of escape in emergency, reflection of light and transparency. It is of importance to consider all different plausible situations the barrier can be subjected to when implementing these performances and all of them have to be tested and documented on the NRD before the product is put into use. More detailed information about how these different performances are tested and furthermore classified can be read in SS-EN1794-2 from 2011 [21].

5.1.5 Road traffic noise reducing devices and long term performances

A NRD can be constructed in many different ways. Barriers might contain different elements that also have to meet their own requirements for the entire construction to be approved. Cladding is, among other applicable elements, one type of element that can be attached to noise barriers. The description of cladding is according to SS-EN14388 (2015)(p. 5) [27] "A noise-reducing device which is attached to a wall or other structure and reduces the amount of sound reflected".

For a noise barrier to be covered by the standard, certain tests must be accomplished. These required tests are presented in Annex A [27] by **table 1 and 2** where the first table is for the noise barrier and the second is for the cladding. The test categories of interest in this report are: sound absorption, resistance to load, residence to brush fire, shatter properties, light reflectivity, durability, impact of stones, safety in collision, environmental protection and transparency. All of these tests have to be performed and the products' different elements have to be well documented as the first step of the European Conformity marking (CE-marking). Notes and further requirements to fulfil the CE-marking can be found in SS-EN 14388 Annex ZA [27].

Except from the CE-marking, a product, consisting of an element which is attached to a barrier, has to be tested in accordance to SS-EN 12767 [28] where a test for passive safety of support structures for road equipment is described. More information can be found in Section 5.2.3.

When investigating a NRD with purpose to use it at the road side, it is of importance to consider its function during its whole working life. The performance has to maintain and not only be fulfilled in the development. If the NRD is designed with several elements these have to be tested under the same exposure conditions when studying the ageing. How this procedure is carried out is further described in SS-EN 14389-1 [29] and SS-EN 14389-2 [30] where the fist one considers the acoustical long term performance while the second one considers the non-acoustical long term performance.

5.2 Road restraint systems

When road restraint systems are to be used there are certain regulations that have to be met so that the system can be implemented in a road environment. These regulations can be found in VGU and the standard SS-EN 1317.

5.2.1 Requirements in accordance with VGU

In Sweden there are certain rules and regulations that need to be met when it comes to placing objects, such as a low-height noise barrier, close to a road. In the publication by the STA *VGU* [22] it is possible to find part of these criteria.

To understand how the requirement and guidelines should be implemented some notations terms need to be explained. There are two main areas namely the working width and the support strip that affect for example a railing's placement, especially the working width, W. The working width, W, talks about how much a railing bends out or moves when it is hit by a vehicle while the support strip is used for supporting either the roadway's shoulder or a barrier's supporting structure [31]. The working width is determined on a basis of a crash test which is explained in Section 5.2.2.

Within a road environment it is also important to follow the regulations and dimensions that are set so that installations, road signs, special constructions etc. are not destroyed by a passing vehicle. The so called free room is a guideline that talks about free height and free width on a traffic road or a cycle track. When talking about the free width both the right and the left verge, that is the space between the roadway edge and the barrier, should not be narrower than 0.2 m in urban environments. However, since maintenance has to be performed at times this spacing usually needs to be larger. Larger spacing is also needed if a cycle track is placed next to the road. In Figure 5.3 it possible to see the minimum requirements on the free widths for both urban environments and countryside areas.

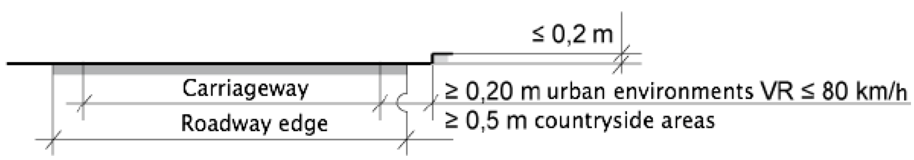


Figure 5.3: Guidelines for the free width [5].

It is important to keep unprotected road-users, such as pedestrians and cyclist, safe from accidents which can occur close to a road. By putting a barrier between the road and the cycle track it is possible to protect the road-users and prevent collisions from taking place. To be able to put such an obstacle close to a road it has to fulfil requirements that can be found in VGU section 1.3.4.2 which talks about smoothness. On both sides of the barrier it is not allowed to be any protruding parts that interfere into the road and the cycle track. The barrier has to be plain and smooth on the sides and cannot have any sharp edges. In addition, barriers made out of concrete should have edges that are bevelled [22].

Since the low-height barrier in this thesis is planned to be used close to a driving lane it has to be able to protect pedestrians, from not only community noise but also from collisions with vehicles as mentioned earlier. The low-height barrier is therefore a certain type of restrain system. In VGU it is stated that this sort of system should be able to stop pedestrians from entering the road, this can be reached by meeting the requirement that states that the barrier has to have a minimum height of 1.1 m. It is also pointed out that the barrier should be able to subdue the injury consequences. This can occur when a vehicle drives off the road and to stop the off driving vehicle from causing damage on nearby facilities, just to mention a few. The barriers placement and shape should in addition not be positioned and constructed in such way so that it does not harmonise with the road and its alignments [22].

Depending on what type of railing that is used there are different guidelines that must be followed. In VGU there are eight ways on how a railing should be placed. For the low-height barrier that is discussed in this thesis the railing brought up in VGU section 1.3.2.2.4 is the most appropriate guideline which can be followed.

Figure 5.4 shows dimensions for a barrier that is placed next to a road. The type of barrier that is shown is a so-called gliding barrier, meaning a barrier that glides along the ground when it is hit by a vehicle. For this type of railing the ground surface of the supporting strip has to be paved, have the same slope as the roadway both under and behind the railing. It should also have the width of the railings working width. Within this area it is not allowed to have any obstacles, however in VGU it is stated that a barrier placed between a cycle track and a road is allowed to interfere with the cycle track's free width. The barrier's deformation is allowed to enter the cycle track's free width by 1 m but should not exceed this measure.

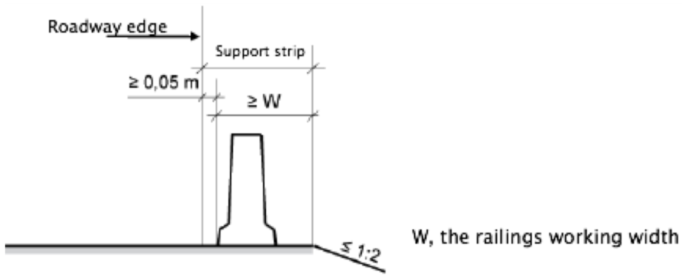


Figure 5.4: An example of the dimensions and guidelines for a railing that glides when in collision with a vehicle [5].

All of the guidelines for differently placed railings which are not mentioned in this report can be found in VGU [22].

A railing's properties is another factor that should not be forgotten. Depending on the barrier's capacity, there are different classes which it can be classified under. To figure out how much the railing can withstand a crash, an impact test is usually performed and this is done in accordance to the standard SS-EN 1317-2. For the labels of the functional characteristics of the railing the standard SS-EN 1317-5 should be followed. A railing placed next to a road has to at least fulfil the requirements which the containment level N2 states. There is a way to enable the mounting of a railing on the side of a road which falls under a lower containment level, N1. For this to be approved the speed on the road has to be below 80 km/h and the Annual average daily traffic (AADT) has to be less then 1500. However, the implementation of a lower containment level railing has to be approved by the road authorities. On a road where a barrier of the containment level N1 is placed, it is possible to replace it with a barrier that falls within the containment level N2. The reason why such barrier should be replaced with a barrier of containment level N2 is that a smaller working width can be achieved. In urban environments small working widths are of interest due to the density of populated areas within a city. With a N2 barrier on a road that only requires N1 barriers the working width can be decreased to the sum of the barriers own width and its dynamic deflection. The last mentioned is measured through a crash test, so called TB11 which is in accordance to SS-EN 1317-2. However, for this to be implemented it has to also be approved by the road authorities [22].

Around crossings in urban environments it is important for drivers to have a clear sight to avoid accidents from occurring. In other words, there cannot be any obstacles that are in the way of the drivers sight that disturbs. The drivers eyes height has been measured to be 1.1 m above the road so a barrier placed close to a crossing should not be higher than this height [22]. The visibility range for the driver varies depending on what type of road the driver is driving on and what speed the vehicle has. On a road where the vehicle speed is 40 km/h the barrier should be placed so that the driver has a visibility range of 35 m. In addition to this, the barrier should not shatter when in collision with a car, especially if the barrier is placed close to a cycle track.

Figure 5.5 shows the area where a driver has to have free sight around a crossing. The primary roads length LP is decided depending on the roads vehicle speed. The length becomes longer as the speed is increased and for a road with the speed 40 km/h LP needs to be 85 m long. It is possible to shorten this length by 25 m if the road authorities confirms it. LS that is the secondary road has to be larger or equal to 5 m but can in certain circumstances be 3 m (as long as the road authorities have given their permission).

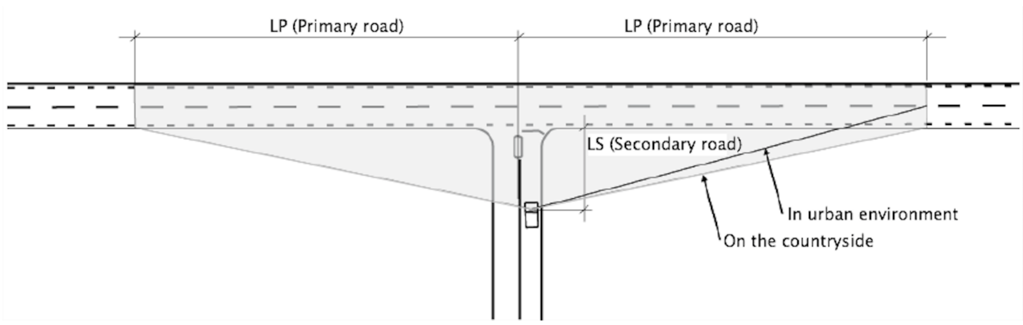


Figure 5.5: Guidelines for the free width [5].

Since the barrier cannot block the drivers view around crossings it has to be adjusted so that it does not disturb in the environment while at the same time it lives up to the requirements that the situation and the environment requires. In addition to this, the railing has to live up to the regulations that are set for its beginnings and endings. In VGU section 1.3.5 these requirements are mentioned. It is stated that a barrier's ending and beginning (the terminals) has to be anchored so that their function is reached and so that they begin and end in a traffic safe way. The terminals of a barrier usually starts in a certain angle and at times this angle can be relatively large, so the terminals of the barrier will of course look differently depending on the environment it is placed in. For roads with a vehicle speed below 80 km/h a barrier can have three different types of terminals. One is a terminal that is angled with a small angle facing away from the road, the second is a terminal that immerses into the ground and the last one is an energy absorbing terminal or alternatively a crash cushion. The immersing terminal is only to be used if the road authorities have given their approval while the last mentioned is only to be implemented if there is not enough space or possibility to use an angled terminal. More specified dimensions and guidelines can be found in VGU as it will not be further discussed here [22].

In urban environments the roads usually end by a curbside. When a railing is implemented by a curbside it has to be placed according to fixed dimensions. The railing's front side has to be placed 0.05 m behind the front side of the curbside as it is shown in Figure 5.6. However, the railing can be mounted further away if the road authorities give their approval. This case in other hand can only be used with a curbside that is either 0.12 m tall or more. If the railing is placed between 0.05 m and 0.5 m from the front side of the curbside, the height of the railing is measured from the road. For distances larger then 0.5 m the height is measured from the street instead of the road [22].

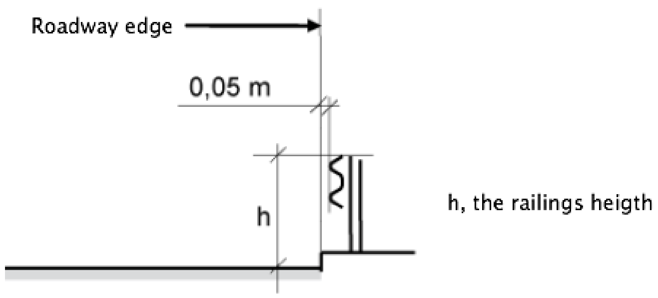


Figure 5.6: Dimensions for placement of a railing close to a curbside [5].

Since the barrier discussed in this thesis will most likely be seen as a combined device due to its characteristics, regulations for this sort of system has to be met. According to VGU section 1.3.11.1 a combined device can be a protective device that is combined with for example a noise protection or road sign just to mention a few. It is possible to use this type of system as long as it does not disturb and interrupt the free width within the free room mentioned earlier. The device connections and terminals should in addition be connected and secured in such a manner that they are road safe. Parts from the device are also not allowed to come off when in a collision with a vehicle, this concerns parts that are heavier than the ones stated in the class determining protocol. It is important for the combined device to pass all the requirements within the capacity and safety classes for it to be put into use [22].

5.2.2 Requirements in accordance to SS-EN 1317

Around road environment maintenance and improvements should be accomplished without endangering people that are present on the road. For sections or locations on and along the road that are categorised as more dangerous, installations of restraint systems are usually seen. These types of systems can both avoid and reduce the incidents which might follow after an impact. As mentioned earlier in Section 5.2.1 the restraint systems are used to either redirect an errant vehicle back into the road or stop it depending on what type of system that is used. The restraint systems are namely categorised into different categories depending on their performance level [32].

The performance level is determined by an impact test which is in accordance to the standard SS-EN 1317 [32] [33] [34], where basically a restraint system is hit by a moving vehicle. The test is performed under controlled circumstances within a special area, which is constructed after the requirements found in the standard *Road restraint systems - Part 1: Terminology and general criteria for test methods* [32].

To determine a restraint system performance class, several systems has to be considered such as the containment level, impact severity and the systems deformation. These requirements are tested in accordance to different impact test that can be found in table 1 in *Road restraint systems - Part 2: Performance classes, impact test acceptance criteria and test methods for safety barriers including vehicle parapets* [33]. There are eleven types of impact tests where the difference is found in the impact speed, the impact angle, the vehicles total mass and the vehicle type. The most common test that always is included during impact tests is the so called TB11 which uses a light car of 900 kg. The speed used within TB11 is 100 km/h and the impact angle is 20°.

The containment levels is a category for how well a railing can absorb energy as well as it can be used as guideline for dimension of a railing both on bridges and roads. These levels are divided into low angle-, normal-, high- and very high containment. Within the normal containment it is possible to either follow the containment level N1 or N2, where the latter uses both the tests TB32 and TB11. TB32 is similar to TB11 aside from that the impact speed is 110km/h and the cars total weight is 1500kg.

The second requirement mentioned earlier, impact severity, evaluates the Theoretical head impact velocity (THIV) and the Acceleration severity index (ASI) of the cars. The impact severity is divided into three levels, A-C. For higher safety levels A should be aimed for as this level is greater then B, and B greater then C. Values for the impact severity levels can be found in table 3 in Road restraint systems - Part 2 [33]. The procedure to achieve THIV and ASI can be found in Road restraint systems - Part 1 [32] as it will not be further discussed here.

To define the deformation of a restraint system during an impact three factors are considered namely the dynamic deflection, the working width and the vehicle intrusion. The first mentioned is the maximum displacement of the restraint system in the lateral direction and the last mentioned is a measure for heavy vehicles and their dynamic lateral position during an impact. The working width is categorised into eighth normalised working width levels while the normalised vehicle intrusion is divided into nine. The levels values can be found in table 4 and 5 in Road restraint systems - Part 2 [33] where also the procedure to achieve the normalised values are presented.

The safety barrier should aside from all of this also be able to detain a vehicle without breaking. However, if the barrier has a part that detaches due to a collision and it weights more than 2 kg the producer must indicate this in the test report. The classified part and its location has to be recorded to avoid using that area to protect for example pedestrians behind the barrier. In addition, parts from the barrier is not allowed to penetrate the vehicle, especially the passenger compartment [33].

The vehicles used in the impact tests are production models and has to fulfil the requirements set in Road restraint systems - Part 2 [33] to reach the impact acceptance criteria, this will however not be further explained here.

For an object to be placed on a road environment it has to have the CE-marking. To get CE-marking the barrier has to pass all the test mentioned earlier, where the containment level, impact severity, working width, the dynamic deflection and the durability are essential characteristics [34].

5.2.3 Requirements in accordance to SS-EN 12767

For road restraint systems that consist of for example a barrier that has an attached element, requirements are found in SS-EN 12767:2007 Passive safety of support structures for road equipment – Requirements, classification and test methods [28]. In this standard there are three categories that are considered: high energy, low energy and non-energy absorbing barriers. The barriers that are energy absorbing slow down the vehicles that have driven of the road by absorbing the kinetic energy of the cars. By slowing the cars down, secondary accidents are prevented such as impacts with pedestrians, bicycles and obstacles close to the road. The difference from the barrier mentioned earlier is that a non-energy absorbing barrier allows the vehicles to continue even after the impact. However, the cars are still slowed down but not as much as they would have been with an energy absorbing barrier.

There are four levels of occupant safety that also are taken into account in this standard. The three first levels are used to increase the safety by reducing the severity the impact may cause. The higher the level the higher the safety. The fourth level implies that the structure is very safe. To be able to class a structure in the three first levels it has to go through two sorts of tests namely according to table 1 and the test at 35 km/h described in SS-EN 12767 [28]. The forth level can be achieved by performing a more simplified test (class impact speed also found in SS-EN 12767). In all the tests a light vehicle is used.

By performing these test and classifying road items the road authorities are given information about the product and how well it is able to perform during an impact with a vehicle. Factor such as for example the cost benefit and the roads geometrical layout are also taken into consideration. More factors can be found in SS-EN12767:2007 [28] as it will not be further discussed in this section. The objects performing class is shown by combining the vehicle speed, the energy absorbing class and the safety level for occupants.

The restraint system has to meet the basic requirements to qualify within a performance class. For the pedestrian restraint system, or other certain types of restraint systems, to be used, it has to meet all the requirements for both high and low speeds. Within the basic requirements the predictable behaviour and road user/vehicle occupant risk is overseen [28]. For new products, for example when acoustical objects are attached, tests have to be performed so that the requirement that fragments or detached elements do not penetrate the compartment where the occupant is sitting is achieved.

5.3 Winter road maintenance

One of the most important aspects to consider when implementing an object, such as a railing, in a road environment is the safety aspect. For a country like Sweden where the road conditions changes a lot during a year, from hot and dry summers to cold and wet winters, the road maintenance is very crucial. A railing close to the road lane, as it is investigated here, will obviously influence the road maintenance during the winter. This is due to that the snow can camouflage the railings and that the railings can be damaged by snow removing vehicles. Therefore, this section will briefly enlighten how the winter road maintenance is conducted and what requirements are applied.

In the literature *Vitt på svart* by Malmberg and Sandberg [35] investigations were made 2010 and 2013 to enlighten what people thought about the winter road maintenance in their municipality. The investigation in 2010 was a bit simpler with a fewer amount of questions compared to the investigation done in 2013 where more question about cycle tracks were asked. Still the result did not differ that much between the two investigations and the main conclusions were as follows:

- In general people want the winter road maintenance to be focused on or chiefly begin with the main roads towards the city centre.
- The people who walks or travel by public transport to daily activities such as work/school/store prefer the focus to be on the main cycle tracks towards the city centre as well as the main roads.

The study showed that the overall impression of the present winter road maintenance in the investigated municipality is good. However, older people in general would like the maintenance to be better, especially on the walking paths.

5.3.1 Requirements for the winter road maintenance

The winter road maintenance has a great influence on the road safety and the surrounding environment. Therefore it is of importance to plan the operation before the snow season begins. The road lane is of higher priority than the verge and there are two ways to reposition the snow from the road. Either the snow can be removed and disposed by the verge or the snow can be removed and disposed at a specific disposing area. Where the snow should be placed depends on two factors. The view of sight cannot be blocked by the snow and the passability on the road is not allowed to be interfered. This means that the snow can be placed at the verge as long as the road safety and the surrounding environment is not affected negatively. Places where the snow might affect the road environment the least is where the speed is low, for example around crossings and turnarounds. Although in crossings it is important to have in mind that the crosswalks should not be confined by disposed snow [36] [35].

To make the snow removal as workable as possible the focus of the organisation should be to identify potential places where unprotected road-users and drivers meet and where a conflict can occur. It is often that the vehicles for snow removal move more slowly than the rest of the traffic and therefore create a bottleneck. Another problem that also occurs due to the winter road maintenance is the usage of salt, an often used method in many urban environments. The regular salting, which is road salt in its regular form, is damaging the vegetation since the soil is absorbing the salt and dries out the surrounding vegetation. In some areas the salt is replaced with sand and gravel but there are problems regarding this method as well. Compared with salt, the sand and gravel have to be removed when the winter season is over which requires some additional maintenance of the roads and ditches. Although, the sand and gravel does not make such a harm to the vegetation at the road sides as the salt does [35].

Requirements for the road In the Standard Description for Basic Maintenance Road by Swedish Association of Local Authorities and Regions (SALAR) [36] requirements regarding winter road maintenance are stated. The requirements treat the dimensions on how much snow that is allowed on the road and the amount of disposed snow allowed along the side of the road. When ploughing is executed on a road with a railing at the verge, the width of the disposed snow beside the railing towards the road lane should not exceed 0.4 m. There is also a height requirement that the snow bank should not be higher than 0.9 m. This requirement is also applied to roads without any railing. If this height is exceeded the disposed snow has to be cut and dismissed from the verge. After the cutting, the snow is allowed to be 0.3 m high beside a road with no railing and 0.7 m if a railing is present. As for the road with a railing, there is a requirement for how broad the snow bank can be for a road without railings before it has to be cut, which is 1.5 m. This distance is measured form the road lane and out while the width against the railing is measured from the railing and towards the road lane.

There are also some regulations according winter road maintenance at crossings. These regulations are depending on what sort of roads the crossing is between. The main requirement is the the sight should not be disturbed by disposed snow where the sight is based on the sight triangle explained in Section 5.2.1. This sight triangle is varying in height for different roads. If the crossing is between national cycle tracks the uncovered height should start at 0.8 m while national roads should have an uncovered height starting at 1.1 m. It is also important to have in mind that snow marking poles have to be placed at the railing edges (e.g. near crossings) to be able to navigate the vehicles for winter road maintenance when a snowfall has been present [36].

During a snowfall requirements state how much snow is it allowed to be on the road, which depend on the road classing. This road classing is based on the AADT where a bigger AADT results in a higher road class where best class has the rank one. Roads with road class between one and three have a requirement of a maximum snow height of 1 cm during a snowfall while roads with road class four, five and cycle tracks have requirement of 2 cm. This requirements applies both for the road lane and the verge [36].

Requirements for winter road maintenance equipment's It is not only important to adjust the road to the winter road maintenance, but type of equipments used is also important to consider during the planning. The literature *Vitt på svart* [35], mentioned earlier in Section 5.3, brings up a tool to adapt when deciding what sort of vehicle that will be used. The tool is a technical needs' analysis which will result in information about the vehicle that fits into a specific situation. This analysis is divided into seven parts, as seen in Figure 5.7.

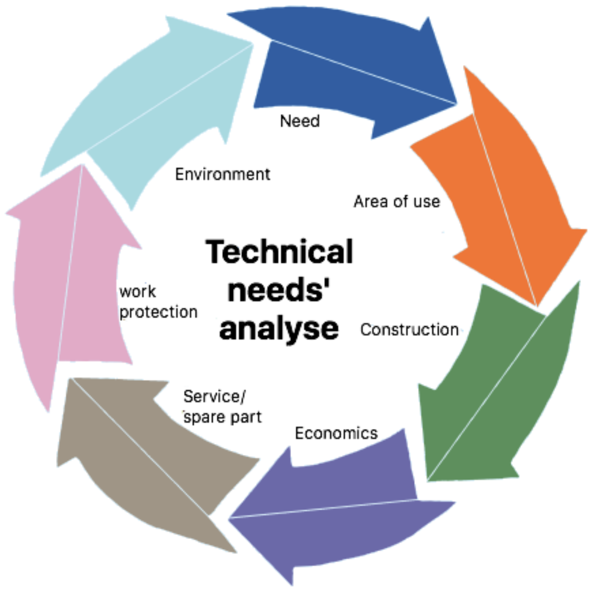


Figure 5.7: Technical needs' analyse of vehicles containing need, area of use, construction, economics, service/spare part, work protection and environment.

This technical needs' analysis is of big importance when planning the winter road maintenance and further explanation of the analysis different parts can be further read in *Vitt på svart* [35].

5.3.2 The progress of winter road maintenance

If the winter road maintenance gets more efficient it can result in increased safety for all road-users, less disturbance in the traffic, decreasing costs and less damaging effect on the environment. This section will bring up some of the progress work done in this area.

Nowadays the most used equipments for winter road maintenance in Sweden is the loading machine and the tractor. However the trend is going towards smaller vehicles with smaller turning radius since the cities are becoming more narrow and densely populated. The consequence of this is that the traditional tractor becomes less common and is more often replaced by a modern loading machine [35].

When a small amount of snow has fallen, snow removal vehicles using a rotating broom can be used as well as a plough. This sort of equipment is usable up to when 50 cm snow has fallen. A plough creates snow valleys along the side of the road. To avoid snow valleys a snow thrower can be used instead. They are also more sufficient when a bigger amount of snow has fallen, which the plough cannot handle. One requirement that must be fulfilled when using a snow thrower is that there is space along the road to store the snow [35].

Two improvements that is brought up in *Vitt på svart* [35] that could increase the efficiency of the winter road maintenance is to focus more on both the meteorologic data, to be more prepared, and develop better sensors to be able to measure for instance the amount of salt the road contains or the dew point temperature. The new sensors can result in that the spreading of the salt will be dependent on different road surface types and therefore it is also better for the surrounding vegetation and for the vehicles on the road. This is further investigated in a study called *Measurements for winter road maintenance* by Riehm [37].

Another measurement tool that can be used better for the same purpose is the GPS which easier can tell where to prioritise the maintenance [38].

6

Method

6.1 Real cases in Malmö

After a conversation with the Traffic office of Malmö stad two cases were provided where a low-height noise barrier could be of interest to implement. Both cases are placed in Malmö where one area is a park called Magistratsparken and the second area is a school ground called Augustenborgsskolan. In Figure 6.1 it is possible to see the position of the two cases.

Figure 6.1: The position of the two cases within Malmö.

Magistratsparken is surrounded by three roads known as Pildammsvägen, Östra Rönneholmsvägen and Borgmästaregatan. The community noise from these roads does not just affect the sound environment inside the park, their noise also expose pedestrians/cyclists to high sound pressure levels that are present on the bicycle paths that goes along the roads.

The second case, Augustenborgsskolan, is surrounded by three busy roads whose community noise pollutes large areas within the schoolyard and the school buildings facades. The roads are called Ystadvägen, Lantmannagatan and Södra Gränges-bergsgatan.

In Table 6.1 the total amount of traffic and the distribution between light and heavy traffic on all the roads mentioned are shown. Table 6.2 holds the distribution of the traffic during 24 hour for all the roads where the distribution is: day (73%), evening (18.5%) and night (8.5%).

Table 6.1: Traffic flow and velocity.

Road	Total Traffic [veh/24h]	Light Traffic [veh/24h]	Heavy Traffic [veh/24h]	Velocity [km/h]
Ö Rönneholmsvägen	13500	13230	270	40
Pildammsvägen	18000	17460	540	40
Ystadsvägen	24400	23180	1220	40
Borgmästaregatan	400	396	4	40
Lantmannagatan	15800	15168	632	40
S Grängesbergsgatan 1	4300	4257	43	40
S Grängesbergsgatan 2	300	297	3	40

Table 6.2: Traffic flow (Day/Evening/Night)

Road	Day [veh/24h]	Evening [veh/24h]	Night [veh/24h]
Ö Rönneholmsvägen (Ö R.v.)			
Light	804,8	611,9	140,6
Heavy	16,4	12,5	2,9
Pildammsvägen (P.v.)			
Light	1062,2	807,5	185,5
Heavy	32,9	24,9	5,7
Ystadsvägen (Y.v.)			
Light	1410,1	1072,1	246,3
Heavy	74,2	56,5	12,9
Borgmästaregatan (B.g.)			
Light	24	18,3	4,2
Heavy	0,2	0,2	0,1
Lantmannagatan (L.g.)			
Light	922,7	701,5	161,2
Heavy	38,4	29,2	6,7
S Grängesbergsgatan 1 (S G.g 1)			
Light	259	196,9	45,2
Heavy	2,6	2	0,5
S Grängesbergsgatan 2 (S G.g 2)			
Light	18,1	13,7	3,2
Heavy	0,2	0,1	0

6.2 Earlier preformed measurements

In spring 2016, sound measurements were preformed to investigate how efficient a low-height noise barrier could be in an urban environment. The type of barrier, called Soundblock, used in the measurements has earlier been implemented beside train tracks with good ability to reduce noise from trains and railways. The developer of this type of barrier is called Z-bloc Norden AB [6]. The barrier itself has a height of 1.2 m and a width of 0.3 m, but within the investigation it was placed on a curb which gave the total height from the road lane to the top of the barrier 1.4 m. Both values of $L_{Aeq,24h}$ and L_{AFmax} were estimated from measurements and compared to calculations done with BEM and SoundPLAN. This was carried out to investigate how accurate the calculations were to the real case scenario. To obtain the IL, measurements were made with and without the temporary placed barrier [8].

The test site was located in Stockholm, close to a park called Holmiaparken. Around this area, a two lane road with the speed limit of 50 km/h was present. There was also a pedestrian and a bicycle path beside the park which was placed close by to the road. The maximum noise level was measured at two different distances to the road, 5 m and 20 m at two different receiver heights, 1.2 m and 1.5 m. The equivalent noise level was measured at a distance of 20 m from the road and at three different receiver heights 1.2 m, 1.5 m and 2 m. More about how the measurements were performed can be found in the article *Performance of a low-height acoustic screen in a setting with an urban road: field measurement and numerical study (2016)* [8].

The low-height barrier is constructed as in Figure 6.2 and consists of a concrete foundation with an attached absorptive material at the side facing the noise source. The absorptive material is made out of a glass and flint mixture that is able to be shaped in many different ways to fit certain situations.

Figure 6.2: The type of low-height noise barrier which was implemented in the measurements around Holmiaparken [6].

6.2.1 Result of the measurements

The results for the equivalent level are based on weekly measurements performed with and without a barrier at the distance of 20 m from the road and at the height of 1.5 m above the road. When measuring without the barrier the $L_{Aeq,24h}$ was

67 dB while for the measurement with the low-height noise barrier the value was 63.6 dB, which results in an IL of 3.4 dB. This value corresponds well with the same calculated factor in SoundPLAN [8].

As mentioned in the previous section, Section 6.2, the L_{AFmax} was measured at two different distances to the road and at two receiver heights using controlled single light vehicle pass by. For the closest position, the average IL over the two receiver heights was measured to be 10.9 dB while the IL for the position further away from the road was measured to be 5.7 dB. When comparing these values with the calculated values achieved with BEM, the IL by BEM is a bit overestimated concluded to be mainly due to that these calculations are not including the reflections due to the surroundings [8].

6.3 Calculations made with SoundPLAN 7.4

Calculations were preformed for three different cases in SoundPLAN 7.4. Two of them are the cases Augustenborgsskolan and Magistratsparken explained in the previous section, Section 6.1, with the traffic information from Table 6.1 and Table 6.2. The topography and the building data used for the two cases mentioned was given by Malmö Stad. The third case is a theoretical case including a straight road with traffic information from Ystadvägen, Table 6.1 and Table 6.2, and a low-height noise barrier. All roads in SoundPLAN contains two lanes with the width of 2.75 m which has the road surface of Dense Asphalt Concrete with 11 mm maximum aggregate (DAC11) [17] and the air temperature of 8 °C.

For the grid noise maps, different grid spaces and interpolations where used. The grid noise maps were also calculated for a height of 1.5 m above ground. The reflection order for all the calculations was set to two reflections, the reason being that a higher number of reflections would have led to too long computation times. The noise prediction method used for equivalent levels was Nord2000 and for the maximum levels the Nordic prediction method revised 1996 was implemented. The latter was due to that SoundPLAN is unable to calculate maximum levels with Nord2000 in the version used. The calculations were divided into three time period levels known as L_{DEN} which is further explained in Section 3.2.

For the single point sound calculations, all the receiver points for all three cases were set to 1.5 m.

6.3.1 Settings and calculations for Augustenborgsskolan

Ten different receiver positions of different character were selected for the case Augustenborgsskolan. These positions are shown in Figure 6.3 and the distances are presented in Table 6.3. The ground absorption had a ground factor of 0.5 (in SoundPLAN the scale goes from hard ground to soft where 0 is considered as hard and soft as 1).

For this case, single point sound calculations and grid noise maps for daytime equivalent levels L_D were achieved for all receiver positions where a low-height noise screen was used with two different heights: 1.2 m and 1.4 m. The reason to why only L_D was implemented was due to that the hours included in the daytime were the

Figure 6.3: Receiver positions for Augustenborgsskolan

Table 6.3: Receiver point distances measured from the surrounding roads.

Receiver points	**Distance [m]**			
	Y.v.	L.g.	S G.g. 1	S G.g. 2
School facade 1	27	63	-	-
School facade 2	42	-	-	-
School facade 3	15	-	-	-
Schoolyard 1	40	-	-	-
Schoolyard 2	90	-	-	93
Schoolyard 3	44	-	86	76
Agustenborgsgården 1	40	-	47	42
Agustenborgsgården 2	71	-	50	19
Bicycle path	6	92	-	-
Augustenborgs park	68	78	-	-

most important ones for this case. The remaining hours does not affect the learning of the children since they are not present in this area around that time. The screen was placed 1.9 m from the centre of the nearest lane, which resulted in that it was placed 0.5 m from the lane edge. Since Ystadvägen had a traffic island between the two directions, a low-height noise screen was also implemented and placed on the traffic island. For the single point sound calculations the equivalent and maximum levels were determined.

The new version of SoundPLAN has a new function called Wall design which can calculate a desired noise barrier height which depends on a selected target value. In this case the target value was set to 55 dBA based on Table 2.1. The calculations performed in Wall design was produced from two screen positions, one close to the road and the other by the site boundary of the school. The reason for these calculations was to compare the heights of the screen depending on its position.

Once all the calculations were finished the results were analysed and plotted.

6.3.2 Settings and calculations for Magistratsparken

In the second case, Magistratsparken, five receiver positions were implemented on a ground with a ground factor of 1. Receiver positions for this case are shown in Figure 6.4 and their distances are found in Table 6.4.

Figure 6.4: Receiver positions for Magistratsparken.

Table 6.4: Receiver point distances measured from the surrounding roads.

Receiver points	Distance [m]		
	P.v.	Ö R.v.	B.g.
Bicycle path	11	50	-
Flower bed	36	24	-
Park	85	35	48
Benches	57	84	42
Playground	52	-	29

The same calculations as mentioned in Section 6.3.1 were also performed for this area. However, the maximum levels and the Wall design calculations were not performed in this case. The results from the calculations can be found in Chapter 7.

6.3.3 Settings and calculations for the theoretical case

For the theoretical case the entire model was made from scratch. The ground factor was set to 0 as the material was Concrete,asphalt (ASJ). No buildings or topography were added. The driving lanes had the same settings as the previous cases. Four receiver positions, based on the distances from the receiver points affected by Ystadvägen, found in the case Augustenborgsskolan, were implemented and can be found in Table 6.5 and seen in Figure 6.5.

Table 6.5: Receiver point distances from nearby road

Receiver points	**Distance [meter]**
Position 1	6
Position 2	15
Position 3	27
Position 4	40

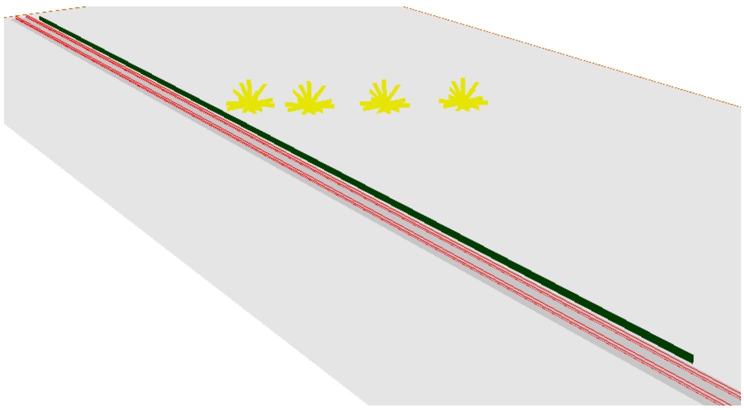


Figure 6.5: Receiver positions for the theoretical case.

Only single point sound calculations were performed for this case where equivalent levels were achieved for a screen with a height of 1.2 m and 1.4 m. Results for these calculations are presented in the next chapter.

6.4 Calculations with BEM and the analytical solution by Pierce

For the different calculations of a sound barrier, a given MATLAB code was used. In this code it was possible to achieve IL, L_{Aeq} and L_{AFmax} using both BEM and the analytical solution by Pierce mentioned in Chapter 3. Within both methods the sound source strength was provided by using the Nord2000 sound source model.

Many screens were calculated on as the height of the screen could be varied using the analytical solution by Pierce. Also, with BEM the width of the screen could be changed and an acoustically soft screen top could be added. Calculations made by using the analytical solution by Pierce had two different barrier heights, 1.2 m and

1.4 m. With BEM the calculations were made using different barrier thicknesses, 10, 20, 40 and 80 cm which had a fixed height of 1.2 m.

The receiver points used in the calculations were the same as the ones mentioned in Section 6.3, except for the ones with a distance larger than 50 m. This was due to a limitation set within the MATLAB code. All the receiver points were set to a height of 1.5 m and due to that some receiver positions were affected by several roads, the levels were added together to reach the real sound pressure level at those receiver positions. All the screens were also positioned 0.5 m away from the road edge.

The input data for the traffic flow was the same as the values used in the calculations made with SoundPLAN, namely the values found in Table 6.1. The vehicle speed used in all the calculations was 40 km/h.

For all calculations, the topography and reflections from buildings were not taken into account. Instead the ground was considered as hard and non absorbing. Only the reflections from the ground and from the barrier were included in the calculations. Also, all the barriers were considered to be infinitely hard except from the soft top surface implemented in selected calculations.

Once all the calculations were made the equivalent levels, maximum levels and the screens ILs were plotted, they can be found in Chapter 7

6.5 Meeting and discussion in Borlänge

A meeting was held in Borlänge where many people from STA attended. A long discussion was held about how a combined product should be constructed, has to act and reach regulations so that it is possible to place it inside a road environment. The highlights from the meeting are found in the list below [39].

- The Swedish Transport Administration puts out CE-marked products on their roads.
- There are no regulations or support for combined systems.
- It is better with a low-height noise barrier from a aesthetic point of view and for the road users view. A 70-80 cm high barrier allows the driver to detect pedestrians behind it, for example small children on bikes.
- A screen with a height of 1.2 m might decrease the noise, but may endanger the pedestrians.
- The sound barrier has to be lower around crossings as these areas have to be open and visible. However, the sound reduction around these areas becomes negatively affected as it will deteriorate.
- The maintenance department would like to avoid putting up barriers since the maintenance is quite expensive.
- The working width is of big importance, it is crucial to understand how much space that is needed behind the barrier for the protection of pedestrians.
- Right material on the barrier is essential for the long term usage.
- Screen maintenance should be as low as possible. Workers present on the road should preferably be completely avoided. It is of interest to keep the working

environment safe. The best way to avoid accidents is to avoid having people on the road.
- Barriers made out of concrete makes the colliding vehicle go along the road, while a railing made out of wire pulls the vehicle in.
- Traffic disruption has to be avoided, there cannot be any disturbances in the traffic flow.
- Snow banks have to be removed systematically using for example snow throwers to avoid the prevention of drainage. Different municipalities can solve these problems in different ways.
- Snow that is removed from the road is not allowed to be placed wherever behind the barrier as permission is required, this is due to chemicals that gets stuck in the snow from the exhaust gases.
- The barrier needs to have regular openings so that there is chance of evacuating a person in case of an accident.
- The most important aspects that should be pointed out are traffic safety, maintenance, work environment, life cycle analysis and barrier material.
- Everything is about cost, cost-effectiveness is seen from a social perspective.
- There are no tests, such as an impact test, for two combined CE marked products.
- There may be a shortcut to the CE-marking. The so-called Harmonised standard related to the product itself does not take sub-products into consideration, instead the functionality of the product according to the standard requirements is focused on more.
- It may be smart to do simulations on the barrier before running an impact test at The Swedish National Road and Transport Research Institute (VTI) since this sort of test is very expensive.
- In the end, urban planning should be considered instead of barriers. Also, the sound source could be overseen where for example the road and the tires could be investigated to make the sound source more quiet. It would be better from both the maintenance and the environment perspective.

6.5.1 Recommendations

Except from the meeting a conversation with Patrik Ekberg was started (personal communication through Email, June 14, 2017) [40]. He explained in short the process a product has to go through to get the CE-marking. Firstly the product has to be impact tested to see which performance class it qualifies in. The report produced by VTI is then given back to the client and a third party for example Research Institutes of Sweden (RISE). There the product is evaluated for CE-marking and a Statistical Process Control (SPC), which looks at the product process, is made. Once the product has passed all the steps and is approved it can be mounted in a road environment. Ekberg also emphasised that it is important to do an impact test on the barrier according to SS-EN 1317. The reason being that the product will be fully accepted on the market as it will be able to get the CE-marking if it passes the tests. In addition, by following SS-EN 1317 it is possible to avoid the discussion concerning if the product has undergone a full-scale testing on Notified Body or not. The last mentioned is an entity in the European Union that oversees if a product meets the requirement that are set for it in different standards. The producer also avoids applying for approvals each time a new object is installed on the barrier and the product would most likely be able to be used on high speed roads. Lastly, Ekberg suggested that when the product is impact tested the producer should apply for a higher containment level, such as H2, as it would cover heavier vehicles as busses.

7
Results

The results from the different types of calculations described in Chapter 6 will be presented in this chapter by noise maps, bar charts, plots and tables. The results for the three cases Augustenborgsskolan, Magistratsparken and the theoretical case will be presented in the sections that appertains to each case.

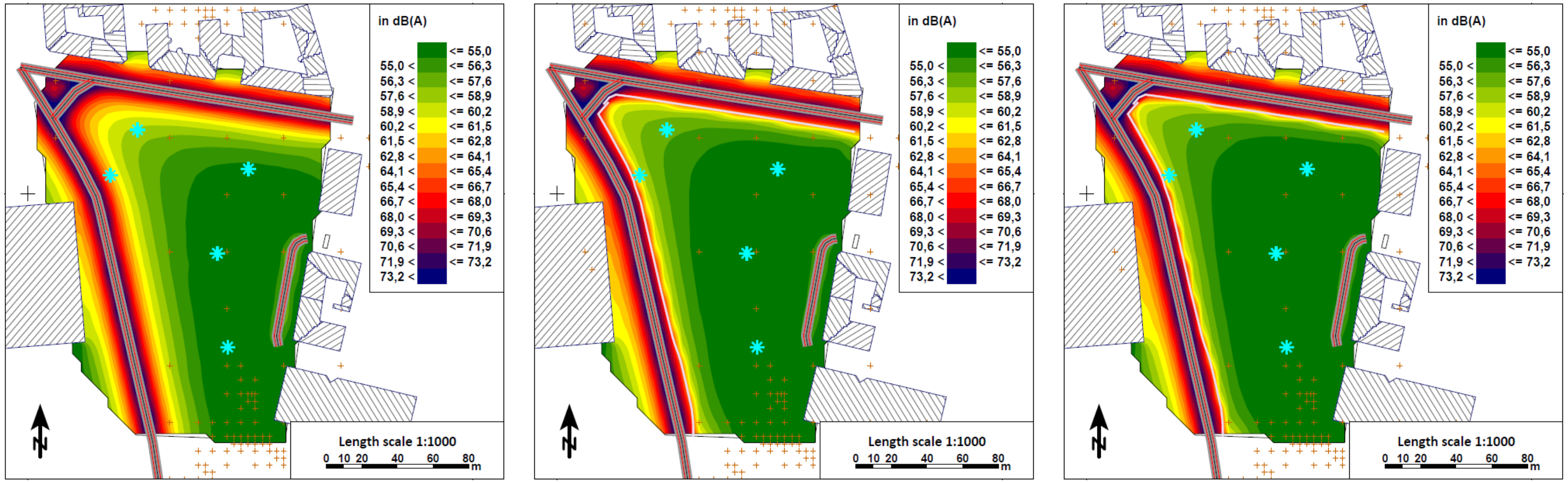
7.1 Results achieved with SoundPLAN

The following section will present the results achieved with SoundPLAN for both cases Magsitratsparken and Augustenborgsskolan where the method presented in Section 6.3 is used.

7.1.1 Magistratsparken

The noise reference SPL together with the reduction caused by a low-height noise barrier is shown in Figure 7.1. It is possible to see that the receiver positions closer to the road are exposed to high levels of community noise while the receiver positions inside the park meet the requirements presented in Table 2.1. The 1.4 m high noise barrier gives a higher reduction compared to the barrier of height 1.2 m.

The IL for both barrier cases are visible in Figure 7.2 where the range is 0.5 - 3 dB(A) for the lower barrier. For the 1.4 m high noise barrier the IL is increased and lies in the range of 0.6 - 3.9 dB(A). For each receiver point the reduction can be found in Table 7.1 and Table 7.2.

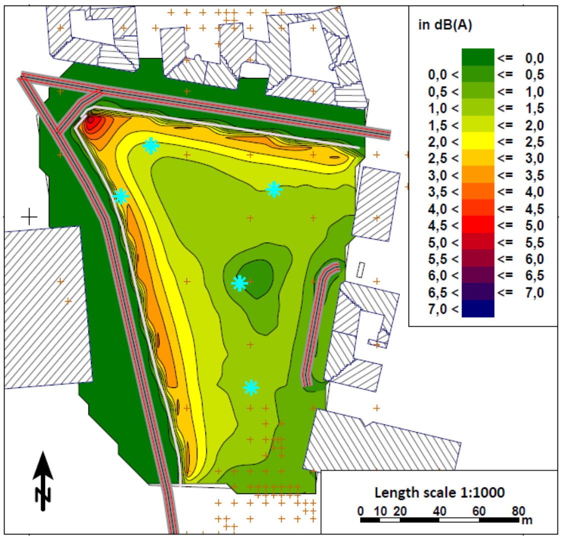


(a) Without Noise reduction device

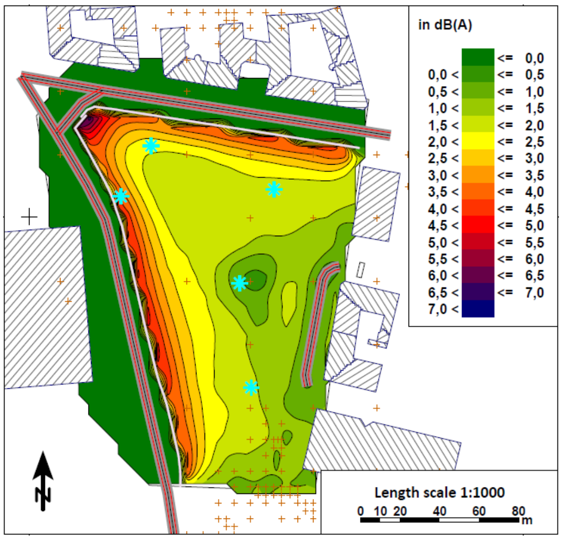
(b) With a low-height noise barrier of 1.2 m

(c) With a low-height noise barrier of 1.4 m

Figure 7.1: Comparison between noise maps without noise reduction devises and with low-height noise barriers.



(a) Noise map for the IL using a 1.2 m high noise protection barrier at Magistratsparken.



(b) Noise map for the IL using a 1.4 m high noise protection barrier at Magistratsparken.

Figure 7.2: IL for both low-height noise barriers.

Table 7.1: L_{DEN} for each receiver position calculated in dB(A) with a 1.2 m low-height noise barrier.

Receiver points	L_{DEN} Reference	L_{DEN} with barrier	IL
Bicycle path	62.5	59.5	3
Flower bed	58.5	56.7	1.8
Park	54.6	53.1	1.5
Benches	53.7	53.2	0.5
Playground	53.1	51.9	1.2

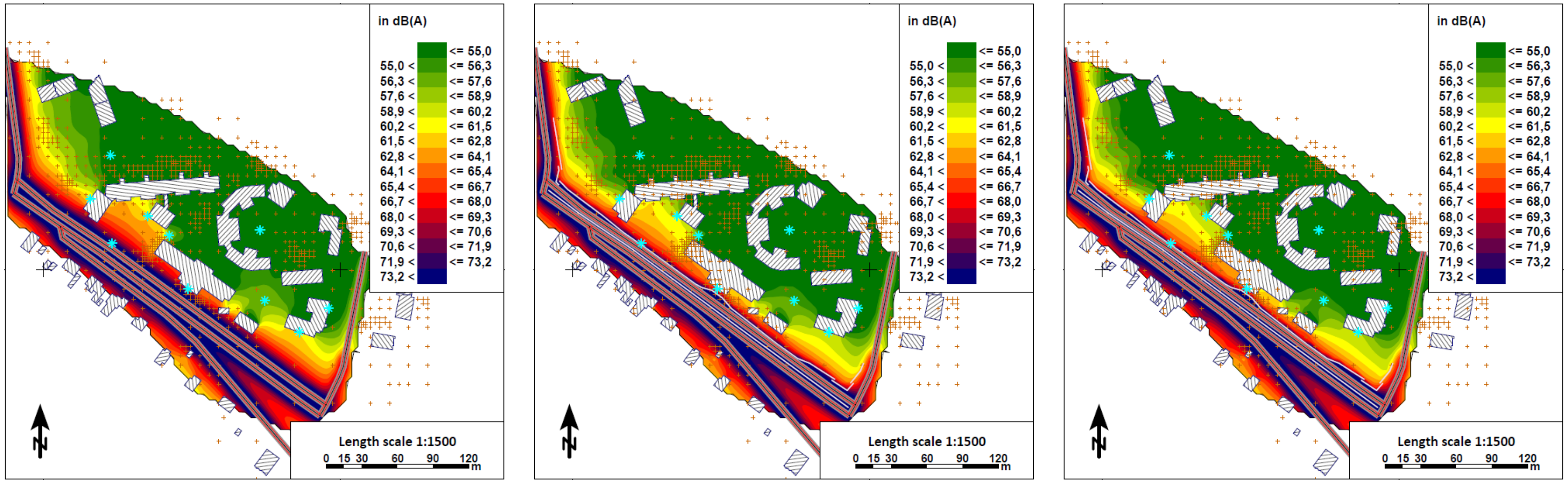
Table 7.2: L_{DEN} for each receiver position calculated in dB(A) with a 1.4 m low-height noise barrier.

Receiver points	L_{DEN} Reference	L_{DEN} with barrier	IL
Bicycle path	62.5	58.6	3.9
Flower bed	58.5	56.4	2.1
Park	54.6	52.7	1.9
Benches	53.7	53.1	0.6
Playground	53.1	51.5	1.6

7.1.2 Augustenborgsskolan

How loud the traffic noise is and how it spreads is noticeable in Figure 7.3a. As it can be seen in the noise map the sound pressure levels within and around the schoolyard varies. The receivers close to the road are exposed to higher community noise than the receivers that are more distant. The receivers with the highest levels are exposed to between 60 and 75 dB(A). For the receivers positioned within the schoolyard, the sound pressure levels are lower. Three of the receivers meet the requirement of 55 dB(A).

The reduction of the community noise that the 1.2 m and the 1.4 m low-height barriers achieve once they are implemented can be observed in Figure 7.3b and Figure 7.3c respectively.



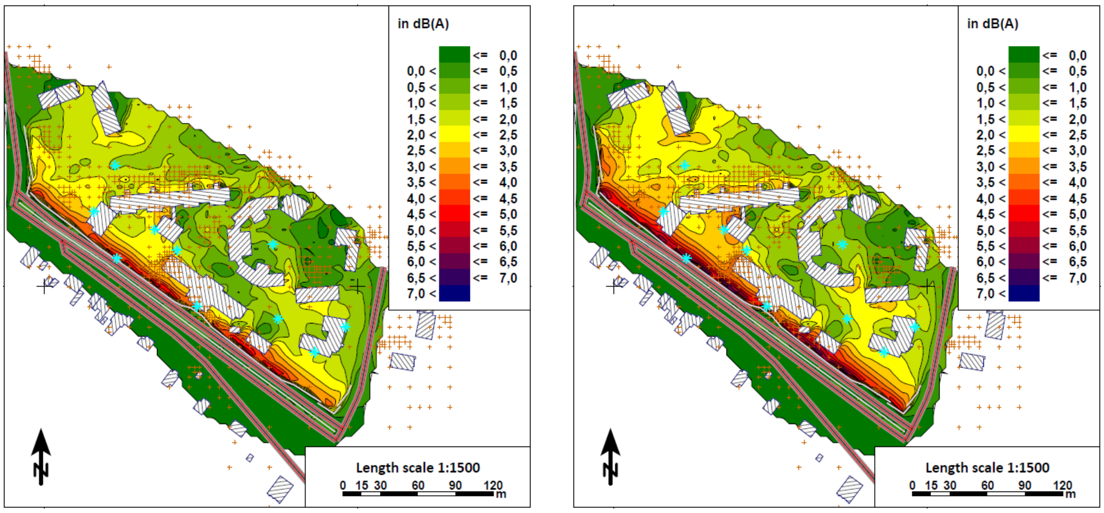
(a) Without Noise reducing device

(b) With a low-height noise barrier of 1.2 m

(c) With a low-height noise barrier of 1.4 m

Figure 7.3: Comparison between noise maps without noise reducing devises and with low-height noise barriers.

In Figure 7.4 it is possible to see the 1.2 m and the 1.4 m barriers' ILs. The reduction that is achieved lies between 1.1 and 4.7 dB(A) for the barriers with height of 1.2 m while the reduction is between 1.3 and 6.7 dB(A) for the barrier with height 1.4 m.



(a) Noise map for the IL using a 1.2 m high noise protection barrier at Augustenborgsskolan.

(b) Noise map for the IL using a 1.4 m high noise protection barrier at Augustenborgsskolan.

Figure 7.4: IL for the two low-height noise barriers of different height.

The reduction for each receiver point in the case Augustenborgsskolan can be seen in Table 7.3 and Table 7.4 for the two used low-height barrier.

Table 7.3: L_D for each receiver position calculated in dB(A) with a 1.2 m low-height noise barrier.

Receiver points	L_D Reference	L_D with barrier	IL
School facade 1	61	58.2	2.8
School facade 2	61.8	59.7	2.1
School facade 3	69.6	68	1.6
Schoolyard 1	58.3	56.6	1.7
Schoolyard 2	48.1	47	1.1
Schoolyard 3	57.4	56.1	1.3
Agustenborgsgården 1	60.4	58	2.4
Agustenborgsgården 2	49.2	48	1.2
Bicycle path	75	70.3	4.7
Augustenborgs park	54	52.7	1.3

For four of the receiver points the maximum levels L_{AFmax} were calculated with and without the presence of a barrier. The values achieved for these calculation are shown in Table 7.5 and Table 7.6. The range for the IL is 2.6 - 7.6 dB(A) for the lower noise barrier and 4.4 - 9 dB(A) for the higher noise barrier.

Table 7.4: L_D for each receiver position calculated in dB(A) with a 1.4 m low-height noise barrier.

Receiver points	L_D Reference	L_D with barrier	IL
School facade 1	61	57.6	3.4
School facade 2	61.8	59.2	2.6
School facade 3	69.6	67	2.6
Schoolyard 1	58.3	56.1	2.2
Schoolyard 2	48.1	46.8	1.3
Schoolyard 3	57.4	55.7	1.7
Agustenborgsgården 1	60.4	57.6	2.8
Agustenborgsgården 2	49.2	47.8	1.4
Bicycle path	75	68.3	6.7
Augustenborgs park	54	52.4	1.6

Table 7.5: L_{AFmax} for each receiver position calculated in dB(A) with a 1.2 m low-height noise barrier.

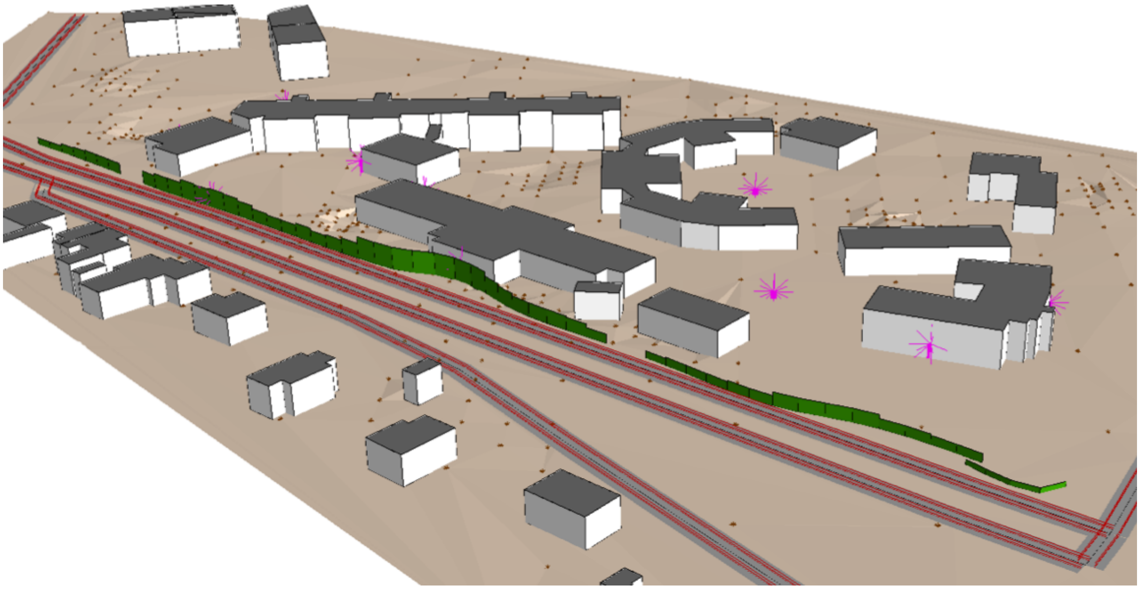
Receiver points	L_{AFmax} Reference	L_{AFmax} with barrier	IL
School facade 1	74.2	68	6.2
School facade 3	81.9	79.3	2.6
Schoolyard 1	67.8	60.2	7.6
Bicycle path	91.8	86.1	5.7

Table 7.6: L_{AFmax} for each receiver position calculated in dB(A) with a 1.4 m low-height noise barrier.

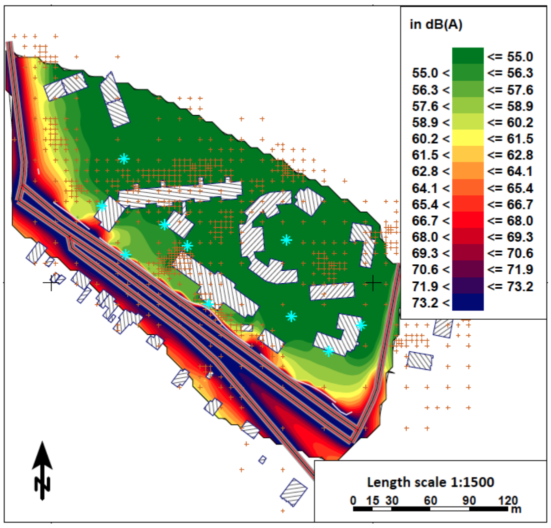
Receiver points	L_{AFmax} Reference	L_{AFmax} with barrier	IL
School facade 1	74.2	66.9	7.3
School facade 3	81.9	77.5	4.4
Schoolyard 1	67.8	59	8.8
Bicycle path	91.8	82.8	9

7.1.3 Augustenborgsskolan with Wall Design

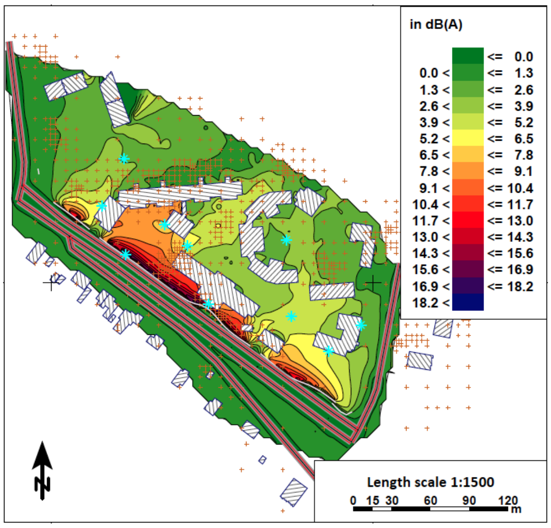
The barrier mentioned in Section 6.3.1 can be seen in Figure 7.5 where its height varies between 1 m up to 5 m. The IL for this wall is presented in Figure 7.5c and the reduced community noise is seen in Figure 7.5b.



(a) 3D picture of the optimised noise barrier placed close to the road lane.



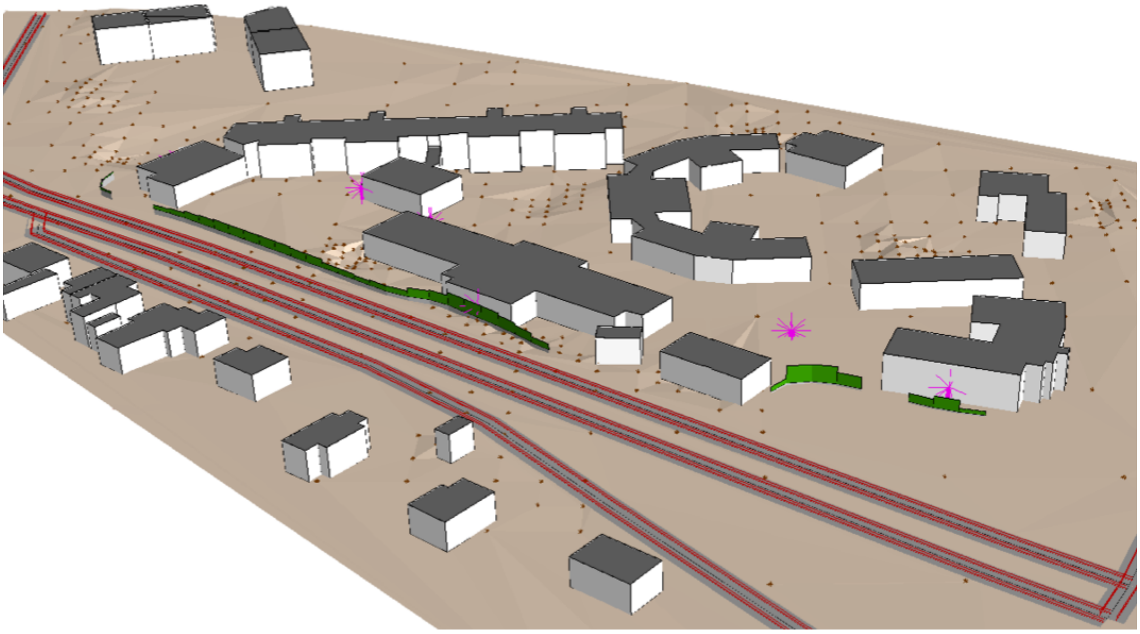
(b) Noise map for the SPL.



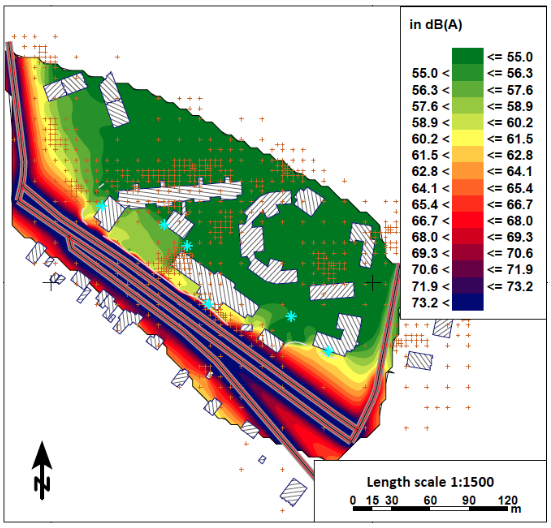
(c) Noise map for the IL.

Figure 7.5: 3D picture and noise maps for a noise barrier placed 0.5 m from the road lane.

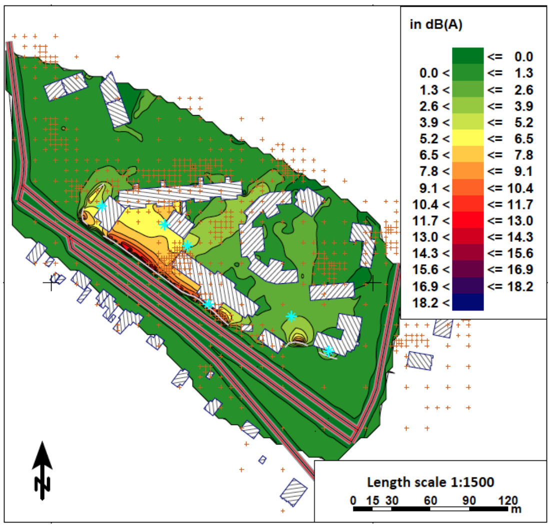
The same results as mentioned earlier are visible in Figure 7.6 but for a barrier placed at the boundary of the school. The wall differs in height from 1.5 m up to 4.5 m.



(a) 3D picture of the optimised noise barrier placed at the boundary of the school's lot.



(b) Noise map for the SPL.

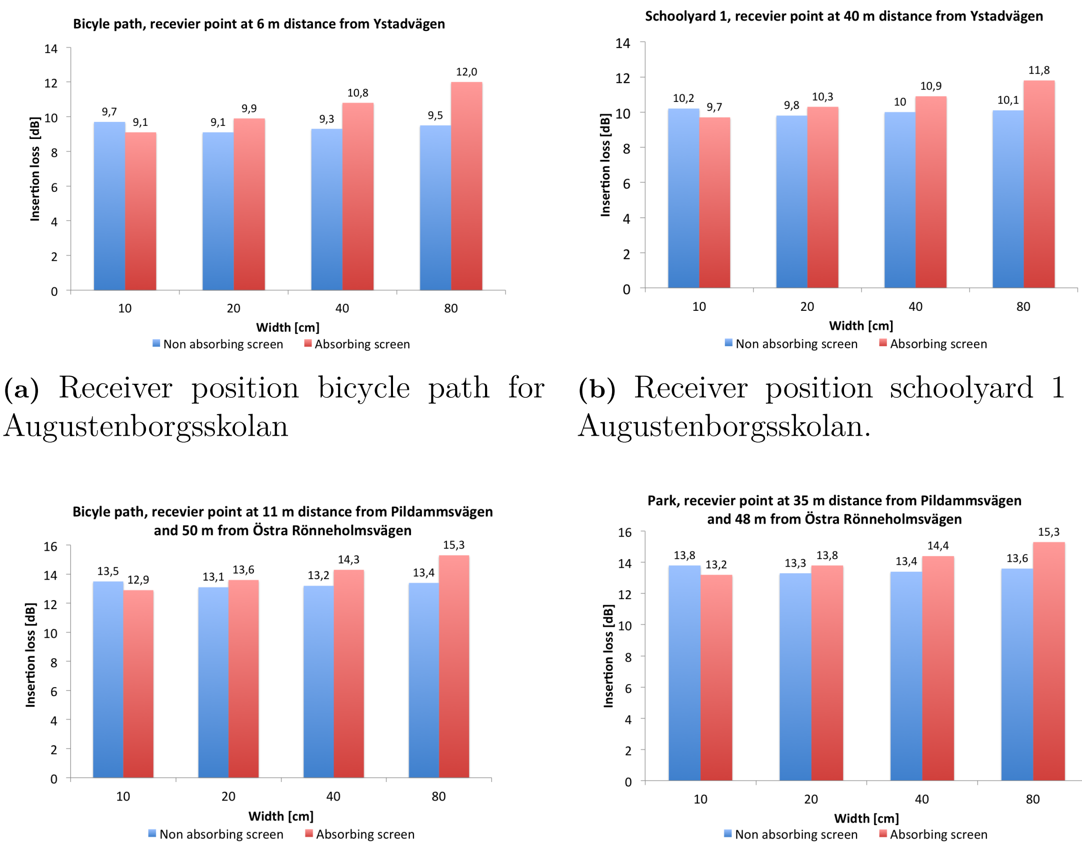


(c) Noise map for the IL.

Figure 7.6: 3D picture and noise maps for a noise barrier placed at the boundary of the school's lot

7.2 Barrier width and an added absorbing surface

In Figure 7.7 it is possible to see that the IL of a low-height noise barrier is slightly increased when in it is made wider, except from the first width. By adding an absorbing element to the barriers top, whose area increases when the barrier becomes thicker, it becomes more effective as the IL is enhanced. This trend is relatively apparent in the figure which shows the calculated equivalent values for both Magistratsparken and Augusteborgsskolan, and does not change even though the distances of the receiver position are varied. The thinnest barrier, of 10 cm width, differs as it has a higher IL and therefore does not follow the pattern that the other widths give.



(a) Receiver position bicycle path for Augustenborgsskolan

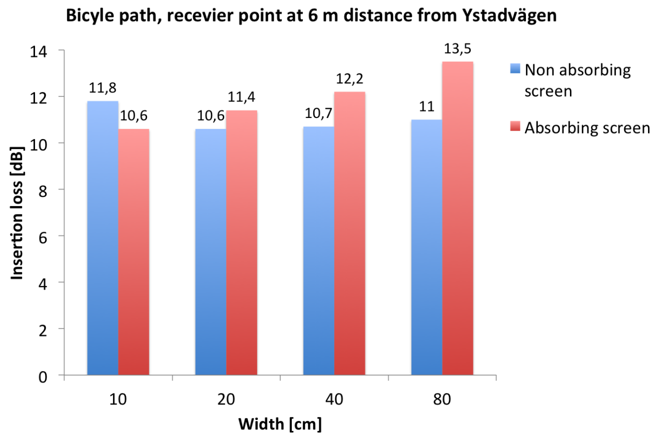
(b) Receiver position schoolyard 1 for Augustenborgsskolan.

(c) Receiver position bicycle path for Magistratsparken

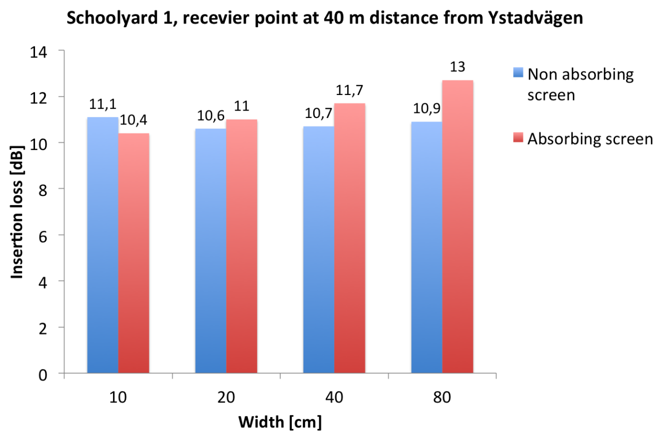
(d) Receiver position park for Magistratsparken

Figure 7.7: Comparison of the IL between a barrier with and without an absorbing top surface for receiver positions based on equivalent levels L_{Aeq}. Barrier height is 1.2 m.

The IL based on equivalent sound pressure levels varies less between each other in the receiver points than the IL based on maximum levels, Figure 7.8. The same trend where the IL increases when the barrier is made wider and an absorbing element is added on the top surface can be seen for Augusteborgsskolan in the following Figure 7.8.



(a) Receiver position bicycle path.



(b) Receiver position schoolyard 1.

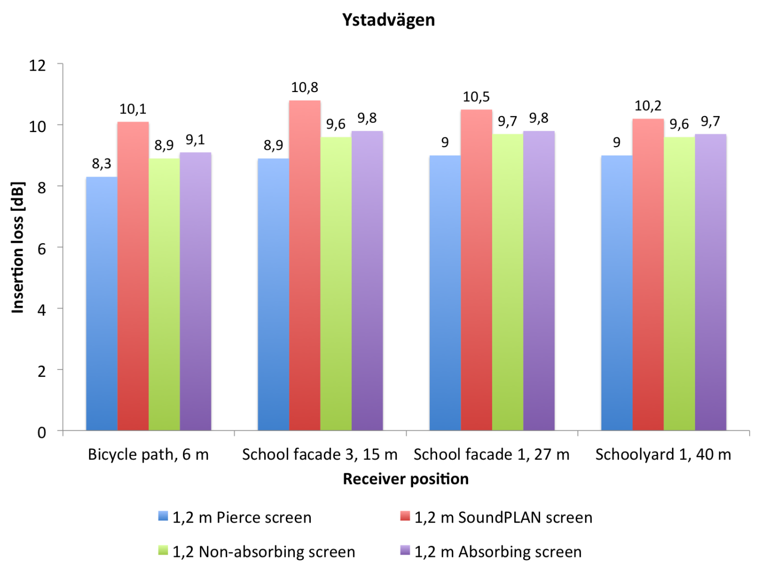
Figure 7.8: Comparison in IL between a barrier with and without an absorbing top surface for receiver positions based on maximum levels L_{AFmax}. Barrier height is 1.2 m.

7.3 Comparison of noise predicting methods

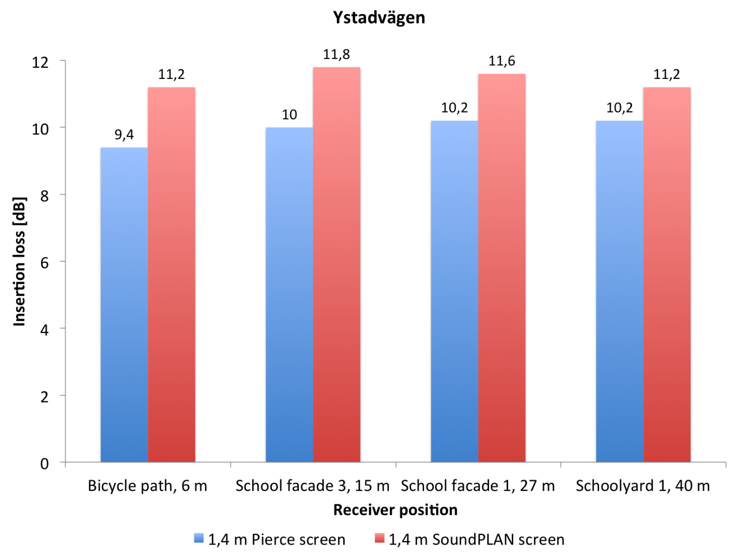
The compared results presented in Figure 7.9a were achieved by using three methods to calculate the influence that a low-height noise barrier has on community noise, in other words the barriers' IL. The methods used were SoundPLAN, the analytical solution by Pierce and BEM mentioned in Chapter 6 and Chapter 3. For the barrier calculated with BEM a width of 5 cm was implemented for enabling comparison with the other two barriers. The reason being that the other barriers are seen as very thin and infinite small due to the change of impedance.

In general the IL results calculated in SoundPLAN are a bit higher than the others. Also, it is possible to see that this result varies with distance. For the results achieved with the analytical solution by Pierce the lowest IL is found, while the BEM results lie in between the other results.

In Figure 7.9b, results are not compared to results achieved with BEM as in Figure 7.9a due to that the barrier height was fixed to 1.2 m and could not be changed. The same pattern as mentioned earlier is visible where the results achieved with SoundPLAN giver higher levels of the IL.



(a) Comparison in IL for a barrier with height 1.2 m.



(b) Comparison in IL for a barrier with height 1.4 m.

Figure 7.9: Comparison of the IL for two barrier cases based on equivalent levels.

8
Discussion

This chapter will bring up different ways a low-height noise barrier can be used. The first section discusses the acoustical characteristics of the barrier. The results obtained will be compared to the requirements. The second section consists the non-acoustical aspects such as safety and maintenance requirements as well as requirements regrading how this sort of product must be tested to be approved by the road authorities. The third part is a comparison between the different predicting method used in this thesis. The last section brings up some suggestions on further work.

8.1 Barriers from an acoustical point of view

A noise barrier has to reduce community noise so that the requirement of the equivalent sound pressure level, L_{Aeq}, 55 dB(A) is met according to *Vägar och gators utformning kapitel 7* [7], as mentioned in Section 2.2. For the two cases mentioned in Chapter 6, namely Magistratsparken and Augustenborgskolan, it is possible to see that without any noise reducing devise (NRD) the sound pressure level (SPL) caused by the community noise is too high. This is visible in Figure 7.1a and Figure 7.3a. By implementing a low-height noise barrier, reduction can be achieved by approximately 1.5 - 7 dB(A) for receiver positions which do not meet the requirements mentioned earlier. This can be seen in Figure 7.2 and Figure 7.4 the the insertion loss (IL) is presented for the two cases. The reduction in at the receiver positions depends on the distance between the source and the receiver. However, the requirements in certain receiver positions do not live up to the requirements after the implementation of a low-height noise barrier. To reach the desired SPL the barrier must increase in height which is shown in Figure 7.5 and Figure 7.6. Since the NRD calculated in SoundPLAN only considers a reflective surface, a higher reduction for the low-height noise barrier cannot be achieved in this calculations. If an absorbing element would be implemented, a higher reduction may be reached. The results for this sort of barrier, achieved by the BEM calculations is shown in Figure 7.7 and indicates an improvement of about 0.5 to 2.5 dB(A). This is depending on the dimensions of the absorbing area and the receiver position.

The calculations were based on two barrier heights, 1.2 m and 1.4 m where the latter gives the higher noise reduction. The difference in IL was around 0.5 to 2 dB(A) which indicates that the higher noise barrier should be considered instead of the lower one.

In the calculations for Augustenborgsskolan made with SoundPLAN a barrier placed on a traffic island was implemented together with the barrier placed on the road edge to investigate if it would generate more reduction, mentioned in Section 6.3.1. However, the calculations showed that the barrier gave an enhancement of less than 0.5 dB(A).

Except from the 55 dB(A) requirement the low-height noise barrier has to live up to the requirements that are set for a NRD, mentioned in Section 5.1.1. In all calculations the barrier is considered to be a continuous construction where no gaps are present. In practice, one of the most important aspects is to make the barrier completely sealed. No gaps within the barrier or in the connection to the ground should be present to be able to get as closely as possible to the reduction achieved from calculations. In addition, for the barrier to be used, it has to be tested according to SS-EN 1793 so that the acoustical properties are determined.

8.2 Barriers from a non-acoustical point of view

For an object to be implemented in a road environment it has to live up to the regulations set for this sort of situation as well as the regulations for maintenance. Looking at a combination of a low-height noise barrier and a road restraint system there are no specific regulations regarding this sort of combined product. Therefore both products have been investigated where the noise barrier is the same as mentioned in the section above.

In a road environment the safety is the most important aspect to consider when developing a new product. This is due to that it should be an instrument to increase the traffic safety instead of putting road-users in dangerous situations. All objects that are included in a road environment have accomplished tests and got a CE-marking which allows them to be used. This is reached once all the tests have been completed and when the objects have got an approval for their purpose. The procedure to fulfil the CE-marking is mentioned in Section 6.5.1.

The low-height noise barrier should help the road-users if an impact occurs by both reducing the damage and secondary accidents. In addition, the barrier should prevent accidents between different road-users as it directs them to safer crossings. However, these areas are the most critical when it comes to reducing noise since it both creates gaps in the noise barrier and must decrease in height due to the sight triangle explained in Section 5.2.1. A barrier along the road have to contain gaps for emergency use which may also affect the acoustical properties of the barrier. This requirement is mentioned in SS-EN 1794 where also suggestions have been given to preserve the noise reduction quality of the barrier.

At the meeting in Borlänge other important aspects were brought up such as maintenance, durability, security, work environment and barrier materials. Many of these aspects can be connected to requirements that are in accordance to SS-EN 1317, VGU and Vitt på svart, mentioned in Section 5.2 and Section 5.3. To be able to maintain the road during its life cycle, certain dimensions between the road edge and an object have to be fulfilled. The maintenance that is the most crucial since it intrudes the most on the dimensions of the road environment is winter road maintenance, further explained in Section 5.3. This aspect will set the guidelines for how close an object can be placed next to a road together with the requirements for the working width, to mention the most central ones. Further aspects that affect this dimension can be found in Section 5.2.1, Section 5.1.4 and Section 5.3. The dimensions for the safety zone used in the calculations are based on the regulations mentioned in Section 5.1.4.

The material of the product should be seen as a crucial aspect since many of the regulations and recommendations mentioned above will be affected. If the barrier is made out of a material that is in need of a lot of maintenance it will most likely not be approved due to that the traffic safety might be endangered. The maintenance department at the Swedish Transport Administration (STA) highlighted during the meeting in Borlänge the importance of keeping people outside the road environment. By considering the material of the barrier in an early stage of the development, complications can be avoided. Choosing the right material that needs little or no maintenance can result in a safer road environment which can ease the product to become manufactured and put into use. In the end it is important to have in mind that a new product has to be profitable for it to be used. Otherwise it will only cost the road authorities a lot of money instead of being an useful investment.

8.3 Comparison between methods

As mentioned in Chapter 7 the sound pressure levels (SPL) are higher for the calculations made with SoundPLAN. This is believed to be due to that more environmental properties are included such as weather, topography, reflections and buildings, mentioned in Section 6.3. This predicting method might be the most realistic way to calculate noise prediction for a real case since the two other methods only considering hard ground and reflections on the barrier together with air attenuation, mentioned in Section 2.2.1. Due to these simplifications in the predicting methods, not all the results will be compared to each other. For the real case in SoundPLAN, the results for the 1.4 m barrier will be compared to the measurement mentioned in Section 6.2. The results done in MATLAB will be compared to the theoretical case calculations made in SoundPLAN. Since the BEM calculation is the only method that is considering different barrier thicknesses and absorbing surfaces these properties are impossible to compare with the other predicting methods. On the other hand, this property can be discussed together with the other methods by observing the emerging trend.

When comparing the equivalent SPL results for the noise barrier of 1.4 m calculated in SoundPLAN with the previous made measurements in Holmiaparken (not measured within this thesis) it is possible to see that the equivalent level IL is very alike. For the receiver point at 20 m in the real measurements the IL was measured to be 3.4 dB(A). No receiver point at the same distance was calculated in SoundPLAN. Receiver points at 15 m and 27 m was therefore selected in the case of Augustenborgsskolan which were the closest ones to 20 m. In the receiver position first mentioned the IL was calculated to 2.6 dB(A) while the second position was calculated to 3.4 dB(A).

The resulting maximum values for both the measurements and the caluclations of Augstenborgsskolan in SoundPLAN can also be compared. As mentioned earlier the old prediction method was implemented in SoundPLAN to achieve the maximum levels. The IL for the two receiver distances, 5 m and 20 m, in the measurements (not measured within this thesis) was 10.9 dB(A) and 5.7 dB(A). These values are the average levels for receiver heights of 1.2 m and 1.5 m. The calculated IL for receiver distances of 6 m, 15 m and 27 m are considered which have the values of 9 dB(A), 4.4 dB(A) and 7.3 dB(A) respectively. This indicates that the calculated values are relatively reliable.

A comparison between the theoretical case results calcualted in SounsPLAN, the results accomplished with BEM and the results achieved by using the analysed solution by Pierce are presented in Figure 7.9a. This figure shows that even in a case where no topography or buildings are implemented in SoundPLAN the result achieved using this method ends up higher in SPL. This is believed to be due to that the Fresnel zone correction mentioned in Section 3.2 is implemented in SoundPLAN. The insertion losses achieved by the different methods do not deviate remarkably. The analysed solution by Pierce is the method that has the shortest computation time but is the method where the least modulation is possible. In the other two methods the modulations are easier to vary, but consists of a longer computation time. For the results achieved for a 1.4 m barrier seen in Figure 7.9b the same conclusions can be drawn as in Figure 7.9a. In this figure the results from the BEM calculations are not included since the barrier height was fixed to 1.2 m.

For the results achieved with BEM it is possible to see that the insertion loss is increased when an absorbing element is included on the top. This trend is possible to observe in Figure 7.7 and Figure 7.8. In these figures the IL is increased as the width of the barrier is enlarged. This is due to that the area of the absorbing element is increasing and influences the propagated sound more. When the barrier width is increased without including an absorbing element, the IL achieved will not change remarkably. For the barrier with the width of 10 cm the IL for the non-absorbing barrier does not follow the pattern. This is believed to be due fluctuations in the results that are caused by for example ground reflections. However, it is of minor concern since it lies within the error margin.

8.4 Further work

An aspect that are not discussed in this thesis but still is of great importance is how the absorbing elements should be constructed and maintained. This construction should not only consider dirt but also air particles.

The sustainability and the mechanical aspects, when it comes to the construction of the barrier, still need to be simulated, tested and overall investigated. For example, before testing a barrier for impacts the same test could be simulated to understand approximately how well the barrier is fitting to its purpose.

The economical part to see how profitable the barrier can be is another aspect that should be further investigated. This is according to building and maintenance costs as well as the amount of people affected by a low-height noise barrier.

In addition, the material and design is two very important aspects that are in need of more investigation.

9
Conclusion

A low-height noise barrier is of advantage when investigating the acoustical properties of a barrier. It is possible to achieve a reduction of the noise, L_{Aeq}, with about 3 dB(A). This sort of noise reducing device, NRD, is preferable in urban environments as it does not affect the aesthetic of the city as a higher noise barrier would have done. If a tall barrier is implemented in such an area it would be hard to follow all the regulations set for the security aspects. With a low-height noise barrier, the sight of the road-users will not be endangered while its acoustical purpose is reached. Worth mentioning is also that around crossings the barrier height will not be reduced as much as a higher barrier would have been. The reduced length would neither have to be as long as for the taller barrier.

When a barrier with a working width which fits inside an urban environment is found, the low-height noise barrier will not only protect pedestrians from community noise but also from collisions. Furthermore, once the right material and design which requires minimum maintenance has been determined, the security around the road areas will be increased since the presence of people on the road will be avoided. This will in addition lead to less accidents.

Low-height noise barriers are most suitable within urban areas due to that lower velocities are found here compared to the velocities found at the highways, which enables that the low height noise barriers can be placed closer to the sound source as the safety zone decreases. Also, usually there are greater distances between the source and the receiver which will result in the need of a taller barrier. In addition, the loudness of the source, which is higher on roads at the country side, will also affect the height of the barrier.

It has been mentioned before that a low-height noise barrier must be placed close to the source to be of use. At high speed roads, the safety zone is increased which means that the barrier must be placed further away from the road. This indicates that the low-height noise barrier is most useful in urban environments where the space between the roads and the pavements are relatively small and restricted.

When constructing this new sort of product it is of great importance to include requirements for both a road restraint system and a noise reduction device. It must pass all the tests that allows it in a road environment. All product implemented in the road environment has to be CE-marked. All the requirements mentioned in this thesis are important and should be implemented, even though the requirements found in SS-EN 1317 have been most discussed. To avoid the barrier from being rejected, the producer should consider to test the barrier according to SS-EN 1317, since by passing the tests mentioned in this standard will give the product its CE-marking.

In the end, urban planning should mainly be considered and invested to reduce the community noise. Also, the sound source could be overseen to make the sound source more quiet. This would be better from both the maintenance perspective as well as the environment perspective. However, noise barriers are very useful and should be implemented when an action is planned to be taken to reduce the community noise in an existing urban environment.

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