May 2010
Reprint Report: UCPRC-RP-2010-04

Noise Barrier Design: Danish and Some European Examples

Author:
Hans Bendtsen, Danish Road Institute—Road Directorate

This report is based on research performed by the Danish Road Institute-Road Directorate on behalf of the University of California Pavement Research Center for the California Department of Transportation, and is reprinted here in its original form.

Work Conducted as Part of the "Supplementary Studies for Caltrans QPR Program" Contract

PREPARED FOR:

California Department of Transportation
(Caltrans)

Division of Research and Innovation

PREPARED BY:

The Danish Road Institute—
Road Directorate and
University of California
Pavement Research Center

Caltrans

Road Directorate
Danish Road Institute

UCPRC
UNIVERSITY of CALIFORNIA | PAVEMENT RESEARCH CENTER
Davis • Berkeley

DOCUMENT RETRIEVAL PAGE			**Reprint Report** UCPRC-RP-2010-04
Title: Noise Barrier Design: Danish and Some European Examples			
Author: Hans Bendtsen			
Prepared for: Caltrans	**FHWA No.:** CA101735D	**Date Work Submitted:** July 2009	**Date:** May 2010
Contract/Subcontract Nos.: Caltrans Contract: 65A0293 UC DRI-DK: Subcontract 08-001779-01	**Status:** Final		**Version No:** 1

Abstract: Noise barriers are widely used as an effective means to abate highway traffic noise. With public interest in eco-friendly and aesthetic designs for noise barriers growing, highway agencies are exerting greater efforts to provide the public with "green" noise barriers that are functionally sound as well as adaptive to the surrounding environment.

This report presents a summary of green noise barrier design practices experienced by the Danish Road Institute (DRI-DK) and other European countries for the last two decades. Some example noise barrier designs are described with recommendations for more effective and innovative ones. The report contains a recommendation to use varied approaches in green noise barrier designs that are adapted to urban and rural settings.

Keywords: Noise barrier, green noise barrier, aesthetic design, adaptive design

Proposals for implementation: It is recommended that Caltrans begin to consider aesthetic and other innovative features in the design of noise barriers to build the ones that are better both adapted to the surrounding environment as well as functionally effective.

Related documents:

- H. Bendtsen, H., Q. Lu, and E. Kohler. 2009. *Temperature Influence on Road Traffic Noise: Californian OBSI Measurement Study.* Reprint report: UCPRC-RP-2009-02
- Bendtsen, H. 2009. *Highway Noise Abatement: Planning Tools and Danish Examples.* Reprint report: UCPRC-RP-2010-03
- H. Bendtsen, H., Q. Lu, and E. Kohler. 2009. *Acoustic Aging of Asphalt Pavements: A Californian/Danish Comparison.* Reprint report: UCPRC-RP-2010-01

Signatures:

Hans Bendtsen **1st Author** **DRI-DK**	John T. Harvey **Technical Review** **UCPRC**	John T. Harvey **Principal Investigator** **UCPRC**	S. David Lim **Contract Manager** **Caltrans**

DISCLAIMER

This report is based on a subcontract research study performed by the Danish Road Institute-Road Directorate (DRI-DK) on behalf of the University of California Pavement Research Center (UCPRC) for the California Department of Transportation (Caltrans). The contents of this report reflect the views of the authors and DRI-DK who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the UCPRC, the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. The content of the original is unchanged in this version and has been reprinted with the consent of DRI-DK.

For more information:

University of California Pavement Research Center, Davis
One Shields Avenue, Davis, CA 95616

University of California Pavement Research Center, Berkeley
1353 S. 46th St., Bldg. 452, Richmond, CA 94804

www.ucprc.ucdavis.edu

Noise Barrier Design

Danish and some European Examples

Hans Bendtsen

Danish Road Institute
Report 174
2009

UCPRC UNIVERSITY of CALIFORNIA PAVEMENT RESEARCH CENTER Davis • Berkeley

Caltrans

Road Directorate

Contents

Executive summary

Noise barriers are used as an effective measure of noise abatement in Europe as well as in California. Different types of “green” noise barriers adapted to the surrounding environment are used. Because of their size and conspicuousness, noise barriers and noise embankments often set their mark on the environment in which they are placed. Therefore it is important to focus on aesthetically and visually satisfactory solutions both with regard to the urban environment “behind” the barrier and as seen from the road “in front” of it. This report presents a series of examples of noise barrier design used in Denmark and other European countries. The report is primarily based on the work carried out by the Danish Road Directorate in the last fifteen to twenty years.

This report is produced by the Danish Road Directorate/Danish Road Institute for the California Department of Transportation. For comprehensive guidance on sound wall issues in California, please reference Caltrans’ *Technical Noise Supplement* and *Traffic Noise Analysis Protocol* manuals.

Noise barriers and noise embankments are often relatively large and conspicuous structures which may not fit in with the surrounding environment. When a noise barrier has been erected, it represents a considerable economic investment and can be expected to remain standing for several decades. The people who live in the neighborhood of a noise barrier will have to look at the structure every day. This is also true for the pedestrians, cyclists or motorists who daily pass a noise barrier. A noise barrier or noise embankment could therefore be regarded as a structure that has two facades, one facing the road one the nearby town or landscape.

In connection with the planning and the design of noise screening structures it is important that it should be adapted to the road and its surroundings. An increasing proportion of people’s time is spent commuting on highways, and it is therefore an important task to make this time a positive experience, among other things, by seeking to ensure that roads pass through attractive surroundings.

Noise screening can constitute an actual physical barrier in a town or housing area. Both visually and physically it can divide the town and prevent communication between the various districts. If thoughtfully planned, noise barriers and embankments can create visually attractive and functional urban spaces.

Various strategies for the adaptation of noise barriers and embankments to urban and rural surroundings can be used. One strategy is the planting of trees and other vegetation so that the noise barrier fits in with its surroundings.

Another strategy is to allow the noise barrier to bring out the lines and forms of the landscape or town to the roadside, while a third strategy is to make the noise barrier stand out as a striking and visible addition to its surroundings through a conscious selection of colors and forms. This report gives examples of noise barriers designed on the background of these different design strategies. The report includes noise barriers constructed of many different materials, such as steel, brick, concrete, wood and transparent materials. Earth embankments and various kinds of supported earth embankments are also presented.

Sammenfatning

Støjskærme anvendes som virkningsfuld støjbekæmpelse i Europa og Californien. Forskellige typer "grønne" støjskærme tilpasset de omkringliggende omgivelser anvendes. På grund af størrelsen og synligheden af støjskærmene og støjvoldene, sætter de ofte deres præg på omgivelserne. Det er derfor afgørende at finde æstetiske og tilfredsstillende løsninger i bymiljøet både "bag" skærmen og set fra vejen "foran" skærmen. Denne rapport præsenterer en række eksempler på støjskærme anvendt i Danmark og andre europæiske lande. Rapporten er hovedsageligt baseret på arbejde udført af Vejdirektoratet i de seneste 15 til 20 år.

Denne rapport er skrevet af Vejdirektoratet/Vejteknisk Institut for California Department of Transportation i USA.

Støjskærme og støjvolde er ofte store og synlige strukturer, som ikke altid passer ind i de omkringliggende omgivelser. Når en støjskærm er blevet bygget, repræsenterer den en stor økonomisk investering, skærmen kan forventes at blive stående i mange år. De mennesker som bor i nærheden af en støjskærm skal se på dette bygværk hver dag. Dette gælder også fodgængere, cyklister og bilister, som dagligt kommer forbi støjskærmen. En støjskærm kan derfor anses som et bygværk med to facader, en som peger mod vejen og den anden som peger mod byen eller landskabet.

I forbindelse med planlægningen og udformningen af støjskærme er det vigtigt at de tilpasses vejen og omgivelserne. En større del af menneskers tid tilbringes på vejene og det er derfor en vigtig opgave at gøre dette til en positiv oplevelse, blandt andet ved at sikre at veje fører igennem flotte omgivelser.

Støjskærme kan blive en fysisk barriere i en by eller boligområde. Såvel synsmæssig som fysisk kan de opdele en by eller boligområde. Forskellige strategier for anvendelsen af støjskærme og støjvolde i by og land kan anvendes. En strategi er anvendelse af træer og andre planter, således at støjskærmen passer ind i området. En anden strategi er at give støjskærmen mulighed for at fremhæve landskabets former og en tredje mulighed er at støjskærmen fremstår som en bemærkelsesværdig og synlig tilføjelse til området ved at bruge et gennemtænkt udvalg af farver og former.

Denne rapport giver eksempler på støjskærme som er opført på baggrund af disse forskellige designstrategier. Rapporten inkluderer støjskærme bygget af forskellige materialer, som stål, mursten, beton, træ og gennemsigtige materialer. Jordvolde og andre former for støttede jordvolde præsenteres ligeledes.

Preface

Noise barriers are used as an effective measure of noise abatement in Europe as well as in California. Different types of “green” noise barriers adapted to the surrounding environment are used. Because of their size and conspicuousness noise barriers and noise embankments often set their mark on the environment in which they are placed. Therefore it is important to focus on aesthetically and visually satisfactory solutions both with regard to the urban environment “behind” the barrier and as seen from the road “in front” of it. This report presents a series of examples of noise barrier design used in Denmark and other European countries.

The project is carried out under the framework of the research technical agreement titled “Supplementary Studies for the Caltrans Quieter Pavement Research Program” between California Department of Transportation (Caltrans) and University of California Pavement Research Centre (UCPRC) as a part of the task: “Policy documents: guidelines for Caltrans policy”. The Danish Road Directorate/Danish Road Institute (DRI-DK) is subcontracted by UCPRC to work on the project. Caltrans has asked DRI-DK to produce a brief catalogue of innovative barriers used in Denmark as well as in other European countries which might have application in a California setting, to be used by Caltrans Head Quarters to facilitate innovation and address context sensitive design challenges. For comprehensive guidance on sound wall issues in California please reference Caltrans’ *Technical Noise Supplement* [10] and *Traffic Noise Analysis Protocol* [9] manuals.

The report is primarily based on the work carried out by the Danish Road Directorate in the last fifteen to twenty years. The main sources for information are the following four reports from the Danish Road Directorate:

- Noise Barriers – Examples and Experiences [1].
- Noise Barriers – Examples and Experiences II [2].
- Noise Barriers – A Catalogue of Ideas [3].
- Noise Barriers Project Design [4].

Except for the catalogue of ideas these reports have not been published in English. A main objective of this project is to present some of these Danish and European experiences in a brief and short, illustrated English report.

The report is compiled and written by Hans Bendtsen DRI-DK. Jakob Fryd from the Planning Division of the Danish Road Directorate and Bruce Rymer from Caltrans has given comments and advice. The report is partly based on work carried out by Christian Sauer and his colleagues from the Planning Division of the Danish Road Directorate as well as staff at Møller & Grønborg, Architects and Planners and other consultants. Most of the photos are taken by Martin Larsen Nielsen, Karen Skou and Hans Bendtsen. The author would like to thank everybody for their efforts and qualified work that has made it possibly to compile this report. This report is written from the Danish perspective and does not represent official Caltrans policy.

Forord

Støjskærme anvendes som virkningsfuld støjbekæmpelse i Europa og Californien. Forskellige typer "grønne" støjskærme tilpasset de omkringliggende omgivelser anvendes. På grund af deres størrelse og synlighed sætter støjskærme og støjvolde tit deres præg på omgivelserne. Det er derfor afgørende at finde æstetiske og tilfredsstillende løsninger i bymiljøet både "bag" skærmen og set fra vejen "foran" skærmen. Denne rapport præsenterer en række eksempler på støjskærme anvendt i Danmark og andre europæiske lande.

Projektet er gennemført som en del af den tekniske forskningsaftale "Supplementary Studies for the Caltrans Quieter Pavement Research Program" mellem California Department of Transportation (Caltrans) og University of California Pavement Research Centre (UCPRC), som en del af opgaven: "Policy documents: guidelines for Caltrans policy". Det danske Vejteknisk Institut/Vejdirektorat (DRI-DK) er underleverandør til UCPRC for at arbejde på projektet.

Caltrans har bedt DRI-DK at producere dette katalog om støjskærme anvendt i Danmark og andre europæiske lande.

Rapporten er fortrinsvis baseret på arbejde udført af Vejdirektoatet i løbet af de sidste 15 -20 år. Hovedoplysninger er hentet fra de følgende 4 rapporter fra Vejdirektoratet.

- Støjskærme – Eksempler og erfaringer [1].
- Støjskærme – Eksempler og erfaringer II [2].
- Støjskærme – Et idekatalog [3].
- Støjskærme Projektering [4].

Bortset fra idékataloget, er disse rapporter ikke udgivet på engelsk. Et hovedformål er at præsentere nogle danske og europæiske erfaringer i en kort, illustreret engelsk rapport.

Rapporten er sammensat og skrevet af Hans Bendtsen DRI-DK. Jakob Fryd fra Planlægningsafdelingen i Vejdirektoratet og Bruce Rymer fra Caltrans har bidraget med værdifulde kommentarer. Rapporten er delvis baseret på arbejde udført af Christian Sauer og hans kolleger fra Planlægningsafdelingen i Vejdirektoratet og medarbejderne hos Møller & Grønborg, Arkitekter og planlæggere og andre konsulenter. De fleste billeder er taget af Martin Larsen Nielsen, Karen Skou og Hans Bendtsen. Forfatteren vil gerne takke alle som har bidraget for deres værdifulde indsats i fremstillingen af rapporten. Rapporten er skrevet fra et dansk synspunkt og repræsenterer derfor ikke official Caltrans politik.

1. Introduction

The best solution to road traffic noise problems is normally to reduce the noise at source. For road traffic, this will mean doing something about the noise emission from vehicle tires and road pavements. Traffic and town planning can make effective contributions to the reduction of nuisance from noise. This can be achieved by ensuring that there is a considerable distance between noise sensitive housing areas and roads with heavy traffic and by moving traffic away from roads passing close by noise-sensitive areas.

Along existing roads and highways as well as in places where it will not be possible to reduce nuisance from noise through planning measures within the foreseeable future, it may be necessary instead to establish noise screening in the form of noise barriers or embankments. Where homes affected by noise in urban areas are situated close to the road from which the nuisance derives, it will not always be possible to find space for noise screening. In this case, the noise can be reduced through the insulation of the façades of the buildings, for example, by providing special noise reducing windows etc. An additional advantage of noise screening compared to the insulation of façades is that the former also provides a reduction of noise at the outside areas adjacent to the road.

Figure 1.1. Noise barriers have a "front" side facing the highway. Transparent 5 m high noise barrier at a 1½ m high embankment at Highway M14 north of Copenhagen, Denmark.

Figure 1.2. Noise barriers have a "back" side facing the nearby town or landscape. Transparent 5 m high noise barrier at Highway M14 north of Copenhagen, Denmark.

Figure 1.3. Noise barriers can be large structures which have an impact on the local physical environment. Shaped gray and white concrete barrier at a highway in the Netherlands.

Noise barriers and noise embankments are often relatively large and conspicuous structures which may not fit in with the surrounding environment. When a noise barrier has been erected, it represents a considerable economic investment and can be expected to remain standing for several decades. The people who live in the neighborhood of a noise barrier will have to look at the structure every day. This is also true for pedestrians, cyclists or motorists who daily pass a noise barrier. A noise barrier or noise embankment could therefore be regarded as a structure that has two facades, one facing the road and one the nearby town or landscape.

In connection with the planning and the design of noise screening structures, it is important that it should be adapted to the road and its surroundings. An increasing proportion of people's time is spent commuting on highways, and it is therefore an important task to make this time a positive experience, among other things, by seeking to ensure that roads pass through attractive surroundings.

Figure 1.4. Brown wooden noise barrier adapted to the green surroundings on Highway M11 west of Roskilde, Denmark.

Noise screening can constitute an actual, physical barrier in a town or housing area. Both visually and physically it can divide the town and prevent communication between the various districts. If thoughtfully planned, noise barriers and embankments can create visually attractive and functional urban spaces.

Various strategies for the adaptation of noise barriers and embankments to urban and rural surroundings can be used. One strategy is the planting of trees and other vegetation so that the noise barrier fits in with the surrounding environment. Another strategy is to allow the noise barrier to bring out the lines and forms of the landscape or town to the roadside, while a third strategy is to make the noise barrier stand out as a striking and visible addition to its surroundings through a conscious selection of colors and forms [3]. This report gives examples of noise barriers designed on the background of these different design strategies. The report includes noise barriers constructed of many different materials, such as steel, brick, concrete, wood and transparent materials. Earth embankments and various kinds of supported earth embankments are also presented.

Figure 1.5. 4 m high profile brown concrete noise barriers with 1 m high plant box for vegetation along Highway A4 southeast of Cologne, Germany [3].

Figure 1.6. 3½ m high dark green steel noise barrier with red steel posts designed using typical building shapes of the surrounding urban environment along a highway south of Hanover, Germany [3].

Figure 1.7. 5 m high steel and Plexiglas noise barrier from the Netherlands on a bridge at Highway A9 functioning as a visible addition to its surroundings through a conscious selection of materials, colors and forms [3].

In Chapter 2 some acoustic basics regarding noise barriers are presented. This is followed by Chapter 3 presenting some design guidelines supplemented with many noise barrier examples. The noise levels presented in this report are A-weighted. The unit "dB" is used and it is equal to what is often denoted "dB(A)" and "dBA".

2. Basic noise barrier acoustics

This chapter introduces the most important basic acoustic factors relating to the placing, shape and design of noise barriers and noise embankments. In connection with the aesthetics and planning of specific noise barriers, noise prediction methods and modeling software, like the Federal Highway Administration's Traffic Noise Model (TNM) [6] or the Nordic NORD2000 method [7] or similar can be used to predict the actual noise reducing performance of the noise barrier. The noise reducing effect of a noise barrier derives from the formation of an acoustic "shadow". If a noise barrier is placed between a noise source and an observer (or receiver), an acoustic shadow is produced behind the barrier and the receiver perceives a reduction in noise levels. The noise reduction depends on many different factors such as the height of the barrier and its placement in relation to the road and the area or the buildings to be protected from noise. The normal possibilities of achieving various levels of noise reduction in the areas close to the barrier can be outlined as:

- 5 dB is relatively easy to obtain
- 10 dB is obtainable using barriers of considerable size
- 15 dB is difficult to obtain
- 20 dB is practically normally impossible to obtain

Figure 2.1. 700m long concrete cover over a new highway alignment to Copenhagen Airport through a preexisting residential area with apartments. The cut-and-cover strategy used here solved two problems; reducing traffic noise levels and keeping the new roadway from dividing the community. The covering has been planted and established as a green recreational area.

With screening in realistic dimensions it is thus normally possible to achieve a noise reduction of up to approximately 5 to 10 dB. If a larger effect is desired, it will be necessary to use very high barriers or to undertake a total or partial covering of the road in question (see Figure 2.2, 2.3 and 2.4).

Acoustically, a tunnel is the most effective way of lowering traffic noise (see Figure 2.1). The covered area can be used as a sports ground or a park. As a noise-reducing installation, a tunnel has many advantages with regard to design, but construction costs are high.

Figure 2.2. 20 m high transparent and colored noise barrier in Paris, France between two 5 story apartment blocks [3].

2.1 Construction materials and barrier placing

The noise-reducing effect of a barrier depends on the following factors:

- The effective height of the barrier.
- The distance between noise source and barrier.
- The distance between barrier and receiver.
- The length of the barrier.
- The thickness of the barrier.
- The materials used for the barrier.

The traffic noise heard on the side of the barrier facing away from the road consists partly of noise passing over the barrier and partly of noise that has passed directly through it.

As a rule, screening is carried out in such a way that the noise transmitting through the barrier is minimal in relation to the noise that passes over it. This means that the barrier's noise transmission capacity (or transmission loss) should be 10 dB greater than the desired noise reduction.

As the normal highest feasible upper limit for noise reduction is normally 8-12 dB, it will be possible to use any barrier wall with a transmission loss of 20-25 dB or more. A single wall with a weight of approx. 20 kg/m^2 (4 lbs/sq ft) will normally have sufficient transmission loss capacity. A noise barrier, constructed of 2.5 cm (1 inch) thick boards placed one over two, normally weighs more than 20 kg/m^2, and is thus in most cases a acoustically satisfactory noise barrier, provided it is solid. Noise barriers can be made of many different materials, as will be presented in this report.

If a given noise barrier has a noise insulating capacity (for noise passing through the barrier) that is 10 dB greater than the desired effect, it is therefore not possible to obtain correspondingly greater noise reduction by choosing a construction with a noise-insulating capacity that is, for example, 20 dB greater.

On the other hand, it is important that the barrier should be completely solid, and that materials are chosen that will not form cracks or other leaks as a result of wear or weathering. Even small gaps in a noise barrier lead to a considerable reduction of the noise-reducing effect. It is therefore also important that noise barriers are constructed in such a way that they are completely flush with the surface of the ground or with the base on which they stand.

If a noise barrier is thicker than 1-2 m (3 to 6.5 ft), its noise reducing effect will be increased in relation to a thin barrier with a thickness of between 5 and 50 cm (2 to 20 inches) [7]. This means that in some cases increased noise reduction can be obtained through the use of thick earth embankments or by using buildings, for example, garages or outhouses as noise barriers.

The effective barrier height marks the distance between the top of the barrier and a straight line drawn between the receiver and the source of noise. The larger the effective barrier height, the greater the noise-reducing effect.

Figure 2.3. Steel noise barrier in Vienna, Austria bending over the highway in order to increase the noise reduction.

Noise screening normally has a noise reducing effect up to the second or maybe the third level of a building depending on the barrier height and how close to the road it is placed. The effect diminishes if the buildings are higher than that. For buildings of more than two stories, it may thus be necessary to install special noise-insulating windows in order to obtain reasonable noise levels indoors, unless, of course, very high noise barriers have been used. Even in the case of a multi-floored building, noise barriers can be used to reduce noise at outdoor areas (gardens, balconies at ground level etc) and for the lowest floors of the building.

Figure 2.4. Depressed highway partly covered at the road sides and with white concrete noise barriers bending over the highway with colored transparent elements in Barcelona, Spain.

Geometry between the noise source, the noise pathway, and the position of the receiver is critical. Optimal noise-reducing effect is obtained if the screening is placed either as close to the road as possible or as close as possible to the housing or outdoor areas that are to be protected. If a noise barrier is placed midway between the road and the noise-sensitive areas, the noise reducing effect will, in most cases, be considerably less than with the above mentioned optimal placing. The effect of a noise barrier with a given height (placed close to the road) diminishes the further away the road one moves. As another option to further increase noise reduction, a noise barrier can also be placed along the middle centerline of a highway in addition to the barriers on just the outside of the roadway (see Figure 2.5).

Figure 2.5. High noise barriers placed both at the side of a highway and at the center of the highway in order to increase the noise reducing effect at a highway in Italy.

In areas close to the end of the noise barrier its effect diminishes because the sound propagates around the end of the barrier. Therefore, the barrier should be continued some way past the noise-sensitive area or be concluded by a curve along the border or the area, away from the road.

Figure 2.6. Noise barrier with reduced height at the end in Hanover, Germany [3].

If the noise screening is interrupted by a sidewalk, driveway, or intersection, its effect is considerably diminished. It is, therefore, extremely important that necessary interruptions are carried out correctly. In a “thin” noise barrier, a path can be led through as a sluice running parallel to the road. The sides of the noise sluice could be made of noise-absorbent material to prevent the noise being reflected between its sides (see Figure 2.7).

Figure 2.7. 2.5 m high wooden noise barrier in Denmark with passage for pedestrians and bikes at National Road 411 in Skive. A transparent barrier is used behind the wooden barrier to create a noise sluice [1].

The further the receiver is from a noise source, the greater the reduction. This reduction is also dependent on the character of the terrain lying between the source (the road) and the receiver. This form of noise reduction is called terrain reduction, and is an independent factor that is not immediately related to noise screening [6, 7].

In connection with large noise screening structures, plans will often be drawn up for landscaping and consolidating the areas around the screening. If soft surfaces in front of a barrier such as grass, bushes, and other kinds of vegetation which absorb noise are used, the surface of the terrain will have a certain noise reducing effect. If, on the other hand, hard noise reflecting surfaces like asphalt or concrete are used, the noise reduction due to distance will be less than across soft terrain surfaces.

2.2 Reflections and absorbing barriers

As already mentioned, noise screening achieves its effect by interrupting or blocking the direct path between the sound source and the receiver. The barrier may also reflect the noise. This may have the unfortunate consequence of increasing the noise for the people living on the opposite side of a road.

How much the noise level on the other side of the road will be increased depends on site conditions, the height of the barrier, and the nature of the building opposite it. If these consist of an unbroken line of multi-storied buildings, the erection of the barrier will form a “closed” canyon, in which the sound is repeatedly thrown back and forth. Sound reflection can theoretically increase the noise level by up to 6 dB when there are reflecting surfaces on both sides of a road [5, 6].

Figure 2.8. 2½ m high transparent noise barrier reflecting noise to the other side of the road along Highway M14 north in Gentofte of Copenhagen, Denmark [1].

Figure 2.9. 2 m high Transparent noise barrier tilted away from the road in order to reflect the noise upwards to reduce the disturbance of residents on the other side of the road, at National Road 152 in Næstved, Denmark [1].

For low, open housing areas the noise level on the opposite side can theoretically be increased by up to 3 dB due to reflections form a barrier [5, 6]. This is a significant increase as it corresponds to the increased noise level resulting from a doubling of traffic.

If noise screening is established on both sides of the road, the noise can be reflected back and forth between the barriers. The screened effect for the reflected noise is not effective as for the direct noise. The total noise-reducing effect will be considerably diminished. The further the reflecting surface is from the road, the slighter the contribution from reflection will be, in as much as noise reduction occurs as a result of the long distance that the sound has to travel.

When a road is depressed and the side retaining walls are composed of hard surfaces of steel or concrete, the sides will reflect the noise. This can mean an increased noise load for the surroundings. The reflection problem can be mitigated by covering the sides with sound absorbent materials.

There are different solutions to reflection problems deriving from noise screening installations. These solutions involve different visual impacts, which can make their mark on the surroundings of the road. The barrier can be erected at a slant so that the noise is reflected up into the air, where it will not disturb anyone (see Figure 2.9 and 2.10). For an earth embankment with sloping sides this will always be the case.

Figure 2.10. Dutch concrete noise barrier bent at a small angle from the road in order to reflect the noise upwards to reduce the disturbance of residents on the other side of the highway.

Vegetation can disperse noise before and after reflection. Vegetation can be planted between the road and the barrier (see Figure 2.11). Vegetation will disperse the noise both before and after reflection from the noise barrier. Vegetation should be as dense (all year), broad and high as possible.

Figure 2.11. Danish transparent noise barrier with vegetation that can reduce the noise reflection.

Figure 2.12. Danish absorbing noise barrier made as a steel frame with absorbing mineral wool and a steel grid in front (close op in left corner).

Figure 2.13. Absorbing noise barrier with vegetation at Highway M14 north of Copenhagen, Denmark.

Finally, there is a third solution, in which a noise barrier is provided with sound absorbent material on the side facing the road, so that reflection is reduced or entirely eliminated (see Figure 2.12 to 2.15).

Figure 2.14. Noise absorbing steel barrier with perforated surface and absorbing material at a highway in Denmark (close up to the right) [2].

Figure 2.15. 3 to 3½ m high steel noise barrier with absorption elements (see close up to the left) and support for vegetation on Highway M14 north of Copenhagen, Denmark [1].

Figure 2.16. 3 to 4 m high transparent steel and glass barrier along Highway M11 near Fløng west of Copenhagen, Denmark [1]. The glass is placed at an angel of 45 ° to reflect the noise up in the air. The bottom sides of the steel elements are noise absorbing, see inserted photo to the right.

Figure 2.17. 4½ m high colored noise absorbing steel barrier with perforated surface and absorbing material at Highway A9 in the Netherlands [3].

Figure 2.18. 4 m high noise absorbing steel barrier with perforated surface and absorbing material at Highway A6B in Paris, France [3].

3. Design guidelines and examples

This chapter introduces some general guidelines for the forming and design of noise screening that were presented in the report “Noise Barriers – A Catalogue of Ideas” [3] published by the Danish Road Directorate. These guidelines should not be regarded as absolute rules that must always be followed. Rather, they should be seen as some strategies and recommendations, which, if adapted to local conditions, can be used in connection with specific planning tasks. In connection with the design of a specific noise screening structure, there may be a number opposing considerations to be taken into account. Thus, there might be a wish for a considerable degree of noise reduction, which would require a high structure and therefore conflict with the wish for the barrier to fit in with an existing 1.8 m hedge or fence at the place in question.

3.1 The planning process

In connection with the process in which a noise screening structure is planned and designed, it is important to take into account the wishes and views of the people who live in the area. For the resident will have to live with and near the screening installation every day for many years, and this may mean a perceptible change in their living conditions. It is important to ensure that one does not just solve a noise problem and replace it with a visual problem or an impediment to movement through the town. This can be avoided by involving the residents in the planning process.

The participation of local inhabitants can be achieved in a variety of ways, for example, by arranging information meetings, organizing working groups and/or by carrying out interview surveys, etc [8]. In connection with this work it may be appropriate to make models, drawings or photographs showing visual simulations of various alternative solutions and their effects on the surroundings. It is important to give the inhabitants realistic expectations of the noise reductions that can be obtained by a noise barrier. This might be done by audio noise simulations etc.

It can also be relevant to involve official bodies and organizations that will be interested in the project, for example, road authorities, traffic safety organizations, architects, landscape architects and road planners. These groups may have different demands and interests with respect to the design of the noise screening installation. In making the final choice of a solution, careful account must be taken of such conflicting considerations.

In connection with the planning of large noise screening installations architectural competitions might be organized to produce a number of alternative solutions, on which the choice of the final solution could be based.

Figure 3.1. Transparent noise barrier designed for use on a highway bridge in an urban environment in Nørrebro, Copenhagen, Denmark.

3.2 Design guidelines

The principles for the design of noise barriers can vary considerably. Some basic strategies for the design of noise screening installations are listed below:

- The installation can be designed to merge with the natural surroundings.
- The installation can be designed to fit in with the urban environment and nearby buildings.
- The installation can be designed as a landmark, as a conspicuous addition to the landscape.
- The installation can be designed as an independent piece of architecture/work of art and thereby become a striking new element in the landscape or urban environment.

This report presents examples that illustrate very different points of departure and principles for the choice of noise screening installations.

From an immediate aesthetic viewpoint, noise screening will, as a rule, seem undesirable. The views on both sides of the noise barrier may be impacted. It is therefore important not only to reduce the environmental disturbance in the form of noise, but also to take into consideration the appearance and character of the road and its surroundings. The design of noise screening must therefore take its starting point in the functions and form of the road and its surrounding and in the volume and speed of the traffic.

The design should also be influenced by whether the noise screening will have to fit in with urban buildings or with large landscape forms in the open country. In the former case, it is necessary to give much thought to the adaption of the noise barrier to the surrounding buildings, both because it is here that the residents will have to live with the screening and also because it is in an urban environment that details in the design will be clearly perceptible for light road users passing by at walking or cycling speed.

In both cases, the barrier will have two façades, one towards the road, the other towards neighboring buildings or the adjacent landscape. In an urban environment, the acoustic demands for noise reduction might not be the sole criteria for the height and form of the barrier, as visual criteria may also be of decisive importance for the final decision regarding its height.

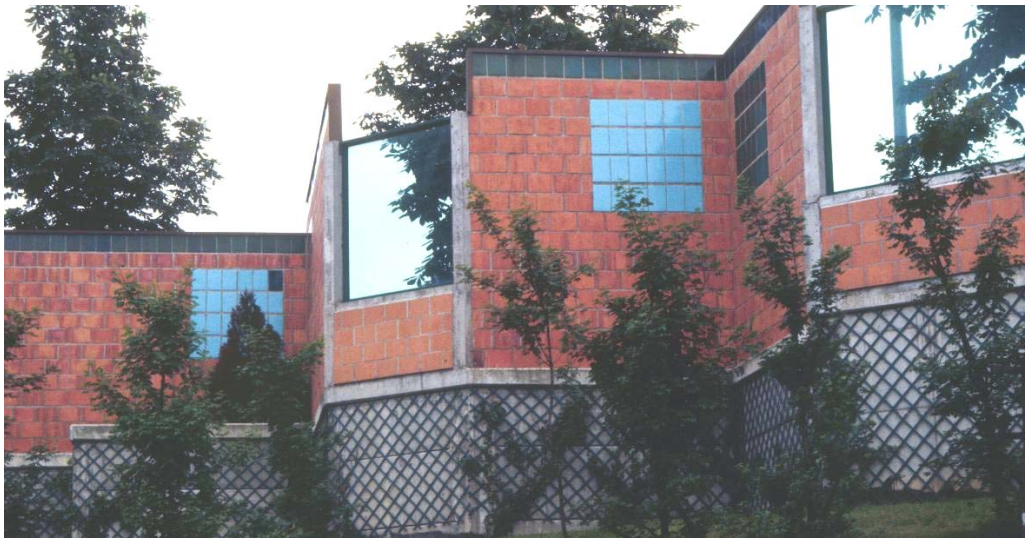

Figure 3.2. Noise barrier constructed of bricks with a lot of details along a highway at an urban residential location in Paris [3].

Noise screening constructions are seen by different groups of road users and residents who pass the installation at very different speeds. Residents living near a noise screening installation have a direct and constant view of it from their windows, from outdoor activity areas and approach roads. Pedestrians and cyclists pass the installation at low speeds and therefore have times to perceive details of form and colors.

Figure 3.3. 2 to 3 m (6 to 10 ft) high wooden noise barrier at Highway M30 in Sakskøbing in Denmark [1].

Figure 3.4. Brown concrete noise barrier with details and vegetation adapted to low a speed road in an urban environment in Århus along National Road 405 [1].

Noise screening installations should be constructed so that they make a good visual impression on the different groups of road users who pass by at different speeds. It may be desirable that the side facing a motorway, where road users drive at a speed of 100 km/h (60 mph), should be formed differently from the side facing some building and recreational areas.

Figure 3.5. Highway side of 3½ m (12 ft) concrete noise barrier in Rødovre along the M3 ring road around Copenhagen, Denmark [1].

Figure 3.6. The residential side of a concrete noise barrier with vegetation along a high speed highway in Copenhagen, Denmark [2].

In cases where a noise barrier is to be placed at the countryside, where the buildings are not situated close to the road, the barrier could be adapted to the road, the landscape and to the existing vegetation.

Figure 3.7. 3 m (10 ft) high wood noise barrier along a highway at the countryside adapted to the existing old vegetation at Highway M40 near Nyborg, Denmark [1].

Figure 3.8. Transparent noise barrier used where Highway M70 crosses a local road in Ålborg, Denmark [1]. This allows the drivers on the highway to get a sight of the surrounding landscape.

The height of a noise screening installation is also important for road users and their possibilities of orientation in the urban area or landscape through which they are passing. Even the erection of a 1.5 m (5 ft) high barrier affects visibility conditions for motorists. They will, however, still have a certain overview of the town or landscape. With a barrier that is 3 m (10 ft) high, it is only possible to see the highest elements in the surroundings, such as multi-storey buildings, water towers, church towers or hilltops, which typically function as landmarks. A barrier of 5 m (16 ft) will, however, cut off practically all view of the surroundings. In such cases, high consideration must be taken of the form, colors and materials of the noise screening in order to ensure that motorists have an acceptable road space to look at.

The following measures can be used in order to “tone down” the visual effect of a high noise barrier:

- The use of colors: for example, painting the barrier with vertical color strips with light colors at the top and dark colors below.
- The use of transparent materials.
- Slanting the barrier slightly away from the road.
- Planting low vegetation in front of the barrier and tall vegetation behind it.

Figure 3.9. Transparent noise barrier along Danish highway in an urban area [2].

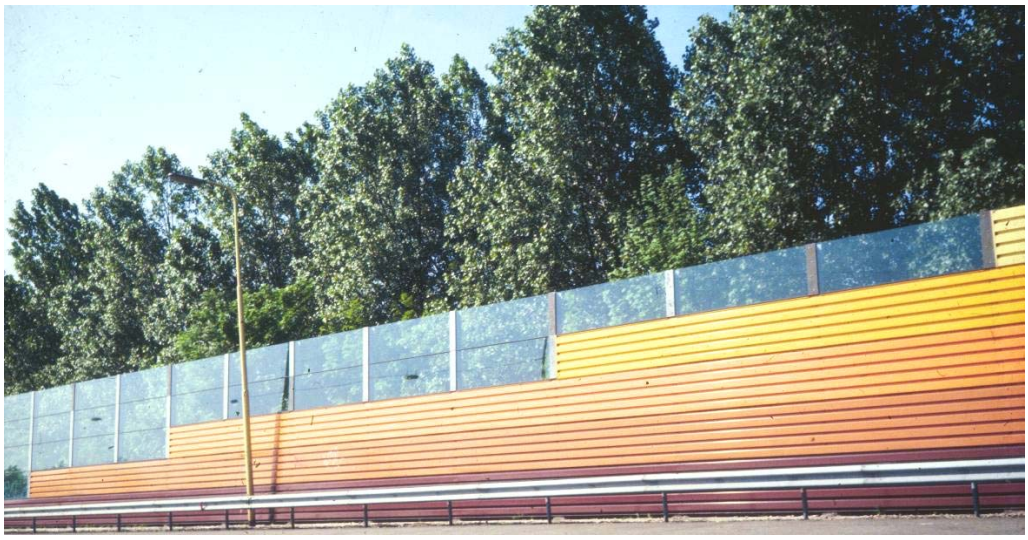

Figure 3.10. 4.5 m (15 ft) high noise barrier with light yellow color at the top and dark read colors below. There is a transparent part and high vegetation behind this barrier at Highway A9 in the Netherlands [3].

The higher a noise screening installation is, and the closer it is situated either to the road or to buildings, the more effective the noise protection will be, but, on the other hand, the more it will dominate the road and its surroundings. A noise screening installation should harmonize with the lines of the road network or with the urban environment in which it is placed. The installation itself should have harmonious lines. Over long distances, however, variation may be important in order to avoid monotony and, thereby, inattentive drivers. The endings of noise screening installations could be marked by special architectural features.

Figure 3.11. Transparent section as part of long wooden noise barrier where Highway M30 passes over a local road in Sakskøbing in Denmark [1].

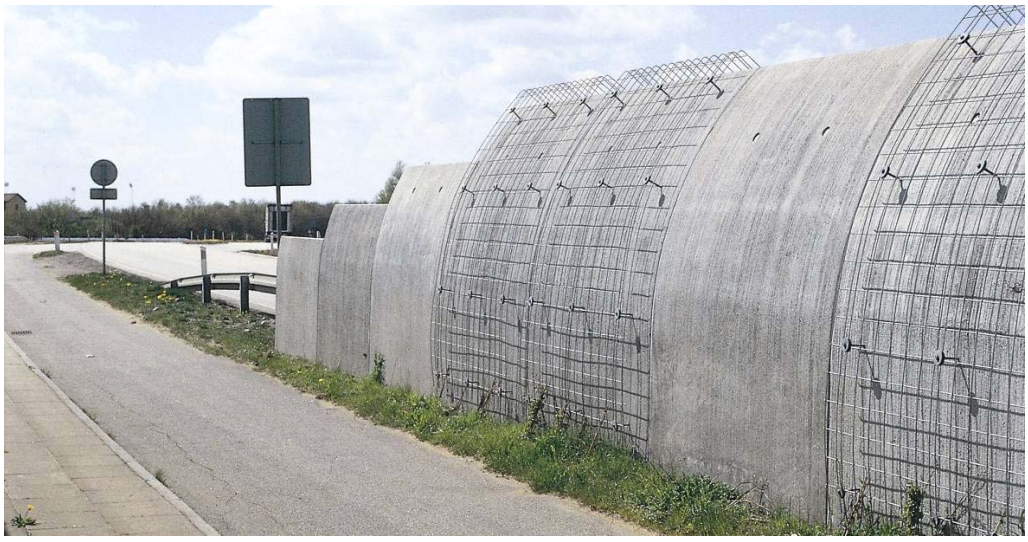

Figure 3.12. Reduced height at the end of a concrete barrier on National Road 411 in Viborg, Denmark [1].

Noise screening installations can be combined with other functions than noise protection, such as solar heating or electricity installations, garages, playgrounds, works of art or sculpture. Similarly, a noise barrier can function as fencing or boundary for a residential area.

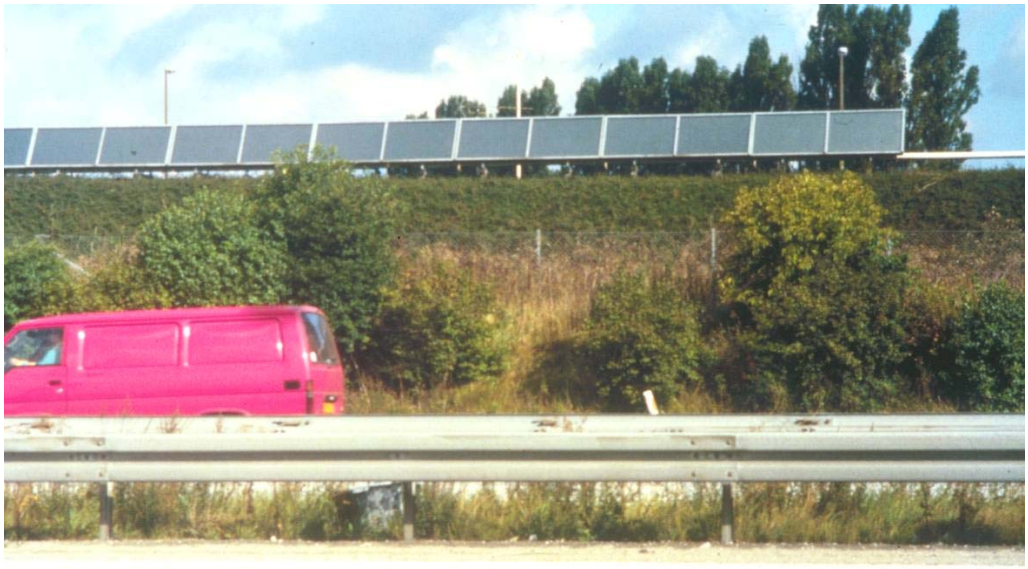

Figure 3.13. Earth embankment with solar panels on the top in Copenhagen, Denmark [3].

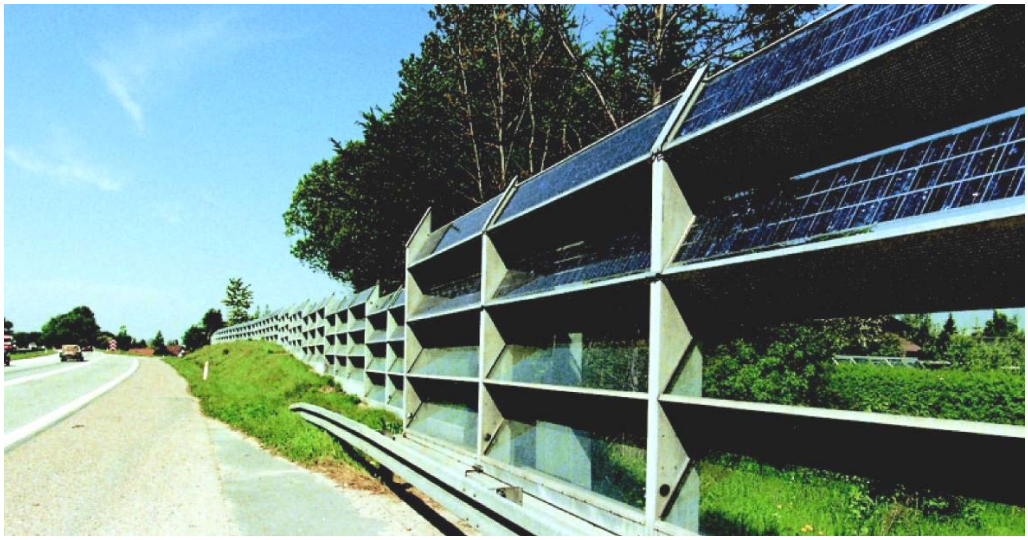

Figure 3.14. Transparent steel noise barrier with electric solar panels at the top. At Highway M11 at Fløng, West of Copenhagen, Denmark [1].

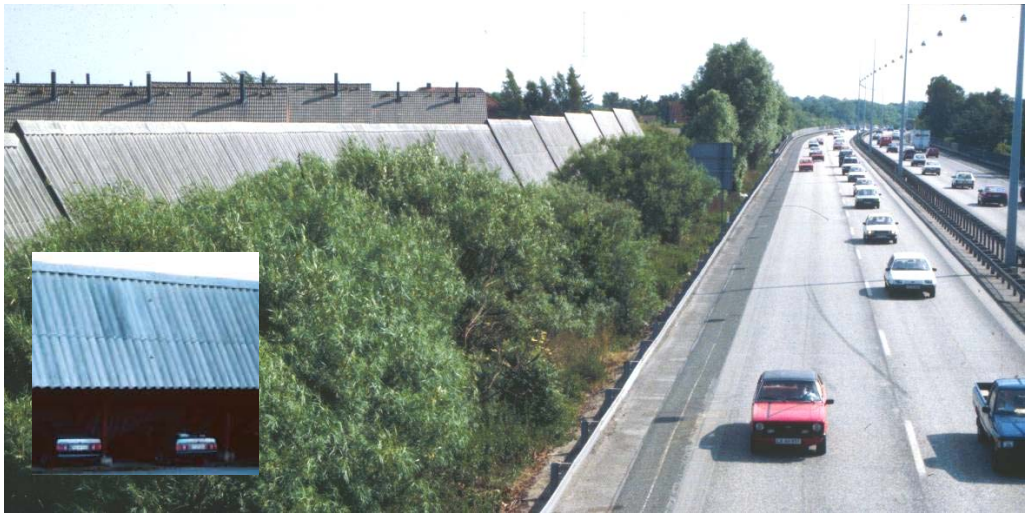

Figure 3.15. The roof of the carport construction for a residential row house area used as a high noise barrier along the M3 ring road around Copenhagen, Denmark [3].

Figure 3.16. Two stories building with laundry and meeting room constructed between two apartment blocks also to function as a noise barrier for the road noise in the hole between the apartment blocks reducing the noise at the outdoor areas in Århus, Denmark.

Figure 3.17. Noise barrier as a colorful urban element where Highway 555 in Germany passes on a bridge over a local road [3].

3.3 Choice of colors and materials

Noise barriers and embankments should have a robust appearance and harmonize with the character of the road and its surroundings. However, they may also appear as deliberate contrasts to the surrounding in order to enhance weak but characteristic landscape elements. Finally, the barrier can stand out as a unique landmark. Furthermore, it is important to use materials that wear well, so that the appearance of the barrier does not become more and more shabby. A smooth surface will be perceived as being larger than a broken surface. The use of different materials, colors and of vegetation can contribute significantly to breaking the monotony of long and high noise barriers.

Figure 3.18. 4 m (13 ft) high aluminum absorbing noise barriers bent 10° towards the road along both sides of the M3 ring road around Copenhagen, Denmark (photo Jens V. Nielsen).

Vegetation can also be used to break the monotony of long straight surfaces. If part of the barrier is formed as a plant box, this may make the barrier seem lower than it really is.

Figure 3.19. 4 m (13 ft) high brown profiled concrete noise barrier with 1 m high plant box with new vegetation in the front at Highway A4 in Germany [3].

A noise screening installation can be constructed according to different principles as, for example:

- An earth embankment.
- A supported earth embankment.
- An earth embankment surmounted by a barrier.
- A barrier with vegetation.
- A barrier.
- A road in a cutting.
- A covered road.

Figure 3.20. Earth embankment as a noise barrier in Germany.

If the desired barrier height is more than 4 to 5m (13-16 ft), it will often be easier to harmonize an earth embankment with the surrounding landscape than a noise barrier. As they require a relatively large amount of space, earth embankments will primarily be used in the countryside and in connection with areas where housing is less dense or scattered. In the course of a few years, a manmade earth embankment with vegetation will appear to blend in with nature. Earth embankments can have the effect of additions to the road environment and can enhance the natural character of the landscape.

The sloping form of the earth embankment and the variations of structure that are possible through the shaping of earth mass and through planting can reduce the observer's impression of its height. As a result earth embankment can be experienced as exciting new elements in the landscape. Paths can be constructed on top of the earth embankment, which give a good overview of the surrounding landscape. The side of the earth embankment that faces the nearby housing can be formed and planted so that it becomes part of the recreational area through the construction of a play area, tobogganing slopes, etc.

Earth embankments might be constructed with surplus earth from the road construction or excavations from new building construction. Waste material from demolitions, etc., might be used for the core of an earth embankment, if properly encapsulated. Hazardous materials should not be used.

In the course of time, a planted earth embankment will become a small ecological system, in which various animal species and plants flourish.

A supported earth embankment can be constructed in a number of fundamentally different ways. One type is the so-called growth barrier in Aarhus, Denmark (see Figure 3.21), where the earth is supported by a slanting steel frame of 12 mm (1/2 in.) round steel with 10 cm (4 in.) openings and plastic netting with 6-7 mm (1/4 in.) meshes [3]. The barrier has an irrigation system in the top. This kind of noise barrier can be used where there is not enough room for an earth embankment, but where a green barrier with a natural appearance is desired. In the course of a few years and with good growth conditions, a supported earth embankment will appear as a green hedge in the summer period and will as such merge well with a suburban environment, where green hedges are common.

Figure 3.21. A supported 3 m (10 ft) high earth embankment with a slanting steel net to the left (details to the right) at National Road 405 in Århus, Denmark [3].

Another type of green barrier is a supported earth wall where concrete elements are used to create plant boxes (see Figure 3.22). To achieve a satisfactory result using concrete plant boxes it is, however, important that the soil should have a certain horizontal surface so that rainwater can be retained. Growth conditions will also be improved if the plants are able to send their roots into the underlying terrain. It is also important that the plant box is formed in such a way that the soil is neither blown nor washed away and so that it can retain moisture. Growth conditions can be improved by artificial watering as in the case in Aarhus.

Figure 3.22. Supported earth embankment made of concrete pipes piled on top of each other in triangles and filled with earth along Highway A3 near Cologne in Germany [3].

Figure 3.23. 7 m (23 ft.) high supported earth embankment with vegetation along Highway A3 near Cologne, Germany [3].

Figure 3.24. Noise barrier with vegetation on top of earth embankment in Denmark [2].

Figure 3.25. Colored concrete noise barrier made of 8 cm (3 in.) thick corrugated element with green vegetation at National Road 405 in Århus, Denmark [1, 3].

If vegetation is planted along a wooden barrier, this can, however cause maintenance problems, as the plants will have to be removed when the barrier is to be painted.

If a noise barrier is constructed of concrete, the following factors regarding durability and aesthetics could be taken into consideration:

- The concrete surfaces can be attacked and eroded by salt water.
- Unless particular attention is paid to its design, concrete often has a heavy, hard and massive appearance, which can be emphasized by dirt and graffiti, etc.
- Prefabricated grey concrete constructions with supporting pillars and vertical panels do not always create a positive visual impression.

Concrete can be used to give noise barriers many different shapes. Concrete barriers can be given many different surface structures and they can be constructed with plant boxes, so that they can be combined with vegetation. Concrete can also be colored and thus adapted to the surroundings; for example, a barrier can be colored dark brown, which forms a good background for vegetation. If concrete is treated properly, good results can be achieved, and with its thickness and structure, concrete has qualities that can fit in a well with the road environment.

Figure 3.26. 3 m (10 ft) concrete noise barrier constructed in a curved shape and painted along Highway M13 in Gladsaxe north of Copenhagen, Denmark [1].

Transparent material can be used where a transparent barrier is called for, for example, when a barrier is situated close to a building, thus significantly blocking the residents' view. These materials are best suited to urban surroundings and will often mean that the noise barrier is relatively anonymous in appearance. But they can also be used in the countryside to allow road users to be able to see a view or a landmark. Glass can also be used to reduce the visual effect of a noise barrier in an open landscape. Transparent noise barriers need cleaning to prevent them from appearing soiled and dull.

Figure 3.27. Transparent noise barrier with a "bike print" along a highway in am urban district in Denmark [2].

Figure 3.28. Transparent noise barrier in Nærum at bus stop along Highway M14 north of Copenhagen, Denmark.

Acoustically, a tunnel is the most effective way of lowering traffic noise. The covered area can be used as a sports ground or a park. As a noise-reducing installation, a tunnel has many advantages with regard to design, but construction costs are high.

Noise-reducing installations can be implemented as a combination of a number of different materials.

Figure 3.29. Dutch curved steel noise barrier with long transparent section.

Figure 3.30. PVC barrier with vertical transparent elements along Highway M40 at Nyborg, Denmark.

Figure 3.31. Steel and transparent noise barrier along highway in Vienna, Austria.

It is important that noise barriers are kept clean and in a good state of repair, as neglected or soiled barriers are very liable to give the road and its surroundings a shabby and decaying appearance. Graffiti can be a problem in relation to noise barriers. Effective methods for removal are available. Vegetation and difficult access to barriers reduces the risk for graffiti. Transparent barriers can at some locations increase the risk of vandalism. Artificial transparent materials (eg. acrylic or polycarbonate) are normally more resistant to vandalism than glass barriers. In planning a new noise screening installation, ongoing maintenance and cleaning of the structure should be considered.

3.4 Planting

Figure 3.32. Steel noise barrier with steel grid to support vegetation on the barrier at Highway M14 north of Copenhagen, Denmark.

The use of vegetation together with noise barriers has already been highlighted in several of the previous examples. The road can be given a new visual quality through planting. Planting can, among other things, soften the hard effect of new road construction. Planting is often a good measure for obtaining a favorable impression. Planting along roads can underscore the line of the road and can also mark side-roads, exit ramps and crossroads. Planting can also give protection against side winds and stabilize earth slopes along the road. The monotony that can arise along long straight roads can be reduced by the use of planting. Especially along noise barriers and earth embankments planting can diminish the impression of the road as a closed space.

Climbing plants or bushes growing up against a barrier will make the barrier less conspicuous. Planting along the base of a barrier in plant boxes can break the monotony of the barrier and make a high barrier seem lower. It is, however, important to evaluate planting in relation to the totality of the landscape or town of which it is to be part, so that this measure is not uncritically adopted when other materials would have been more appropriate.

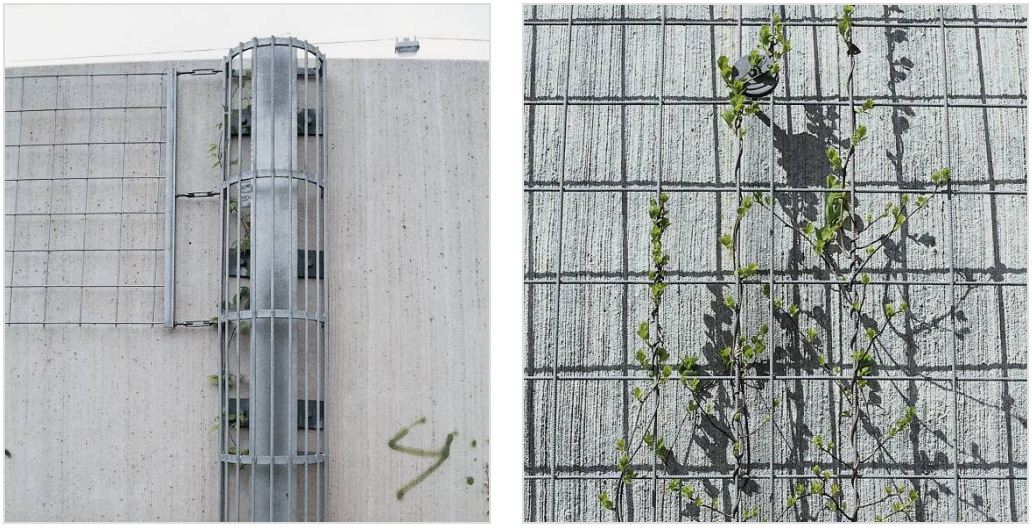

Figure 3.33. Steel nets to support green vegetation on the residential side of concrete noise barriers [1].

Roadside trees give the scenery of the road living variety, both through seasonal variations and through variations among individual trees. Provided that they are high enough, roadside trees planted in connection with noise screening can reduce the dominance of the barrier and give variation and an important aesthetic quality to the road and its surroundings. Planting of the median will divide up the road and contribute to drivers not being blinded by the headlights of oncoming traffic.

It is necessary to give vegetation good growth conditions including access to sufficient water. At dry locations irrigating systems might be needed. Vegetation must have plenty of soil to grow in and while being protected from salt water from the winter maintenance of the road.

Figure 3.34. 1½ m high eternite (fiber cement) noise barrier with wooden frames on top of an earth embankment at Highway M10 in Greve vest of Copenhagen, Denmark. The barrier has steel net where plants can grow as times goes by [1].

New plants normally need maintenance, especially in the first years. There are two different possibilities when plants are to be chosen in connection with a noise screening installation: cultivated plants can be used or it can be chosen to let nature itself show what plants can grow there.

A combination of evergreens and deciduous plants will give an impression of greenness all year round. The exclusive use of deciduous plants will, however, mean that the changing seasons can be followed from the road. Evergreens do not do well with road dust, as in time the dust will settle on the plants and prevent them from breathing. Deciduous plants change their leaves and therefore have a greater tolerance of road dust.

Figure 3.35. Wooden noise barrier with steel net to support vegetation at National Road 310 in Horsens, Denmark (detail to the left).

Figure 3.36. Green noise barrier made of panels with willow branches at both sides. When newly constructed to the right and after getting green to the left [2].

3.5 Traffic Safety Considerations, etc.

In connection with the planning and design of noise screening installations there are some aspects of traffic safety that must also be considered [3]:

- Noise barriers and earth embankments must not restrict the field of vision for road users at crossroads, bus stops, pedestrian crossings, path intersections, etc.
- A high noise barrier may cause a shadow effect and lead to icing and slipper conditions.

- It is necessary to consider the consequences of a collision with the noise barrier, and whether it is necessary to erect a crash barrier.
- It can be useful to divide a noise barrier into modular sections so that in case of collision or vandalism it is necessary only to replace the damaged elements.
- The placing of signposting and lighting should be carefully considered.
- On long stretches of road, noise barriers and earth embankments should not create a monotonous visual setting. This can be avoided by, for example, varying the colors, materials and height of the installation, and also by introducing elements which are in strong contrast to the whole.
- A noise barrier on earth embankment should clearly underscore the direction of the road in order to prevent motorists from being visually led away. An installation that is parallel to the direction of the road will normally have a good guiding effect.
- Long and high noise screening installations can completely eliminate the road user's view of landmarks and other local orientation points. This can be avoided by reducing the height of the installation or by using transparent materials. Another strategy is to make the noise screening installation, or parts of it, into a landmark which will help road users to orientate themselves.
- The surfaces of noise screening installations should not reflect light which might become a distraction. In choosing materials, colors, and surface structures, it is important to consider reflected light.
- If noise barriers are erected on both sides of a road over a considerable distance, it will be necessary to establish emergency access doors at suitable intervals to enable road users to leave the road rapidly in case of an accident. Emergency doors can also be used to give both maintenance personnel and emergency crews access to the road.
- In the case of long, planted earth embankments it may also be necessary to establish cleared paths across the embankment at regular intervals for use in emergencies. These paths should also be marked with signs and lighting. Emergency doors and paths can be established at the sites of already existing emergency telephones.

4. References

[1] Noise Barriers – Examples and Experiences ("Støjskærme - Eksempler og Erfaringer" in Danish language). Road Directorate. Report 183, 1999. www.vd.dk.

[2] Noise Barriers – Examples and Experiences II ("Støjskærme - Eksempler og Erfaringer II" in Danish language). Road Directorate. Report 282, 2004. www.vd.dk.

[3] Noise Barriers – A Catalogue of Ideas. Road Directorate, Road Data Laboratory. Report 81, 1991.

[4] Noise Barriers Project Design ("Støjskærme Projektering" in Danish language). Road Directorate. Report 184, 1999. www.vd.dk.

[5] Noise abatement along the state highways: Goal and strategy ("Støjbekæmpelse langs statsvejene : Mål og strategi" in Danish language). Road Directorate. Report 79, 1999. www.vd.dk.

[6] TNM reference. Grant S. Anderson, Cynthia S.Y. Lee, Gregg G. Fleming, and Christopher W. Menge, FHWA Traffic Noise Model, Version 1.0: User's Guide, Report No.s FHWA-PD-96-009 and DOT-VNTSC-FHWA-98-1 (U.S. Department of Transportation, John A. Volpe National Transportation Systems Center, Massachusetts 1998, TNM v2.5 Addendum2004).

[7] User's Guide Nord2000 Road. Jørgen Kragh et. al. Delta, SINTEF, SP and VTT.

[8] Knowledge Sharing on Noise Management and Abatement. CEDR report 2009. Can be downloaded from the CEDR homepage in late 2009 at: http://www.cedr.fr/.

[9] Traffic Noise Analysis Protocol. California Department of Transportation. Division of Environmental Analysis. August 2006.

[10] Technical Noise Supplement (TeNS). A Technical Supplement To The Traffic Noise Analysis Protocol. California Department of Transportation. Environmental Program. Environmental Engineering – Noise, Air Quality, and Hazardous Waste Management Office. October 1998.