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The Norwegian high speed rail study

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This paper presents the main issues in the noise calculations and considerations as well as some main results from the study. The emission noise source values are set equal to the European limits for high speed trains. The propagation model is based on the software Nord2000 in which 4 different source heights are implemented. On the basis of the calculated noise levels and noise requirements in Norwegian legislation a rough method for cost estimation for noise reduction treatments have been made.

1 Introduction

The Norwegian Rail Administration has been given a mandate from the Ministry of Transport and Communication to assess the issue of a high speed rail study in southern Norway. 3 corridors from Oslo; north, west and south in Norway, plus 2 corridors to Sweden, south and east have been planned by 4 Norwegian consulting companies, Norconsult , Multiconsult, Sweco and Rambøll. Cost has also been estimated for the corridors in question. Brekke & Strand akustikk have in collobaration with Asplan Viak established the calculation basis which the consulting companies have used in their work regarding noise assessment and cost estimation. [1], [2]

In figure 1, the corridors which have been assessed are shown.

Figure 1. Corridors which have been assessed. [1]

2 Speed and journey times

The High Speed Rail Study has analysed lines for both 250 km/h operation and 330 km/h operation, and in the results of the studies a combination of these maximum speed operations have been used.

Journey time calculations estimate the following journey times to/from Oslo to major destinations:

- Less the 3 hours between Oslo and Trondheim, Bergen, Stavanger and Stockholm respectively
- Less than 2 hours between Oslo and Gothenburg

With a journey time of around 3 hours between the main cities, there will be a huge market. A great potential exists for high-speed railway lines between the major cities of Southern Norway relative to the population. The study has indicated that 30-40% of traffic on the lines would be enroute traffic, i.e. passengers travelling at intermediate stations between the respective termini.

3 Costs

The development costs for each alternative are substantial and vary considerably depending on the proportion of tunnels on the respective lines. The costs pr km is around 350 – 400 million Norwegian kroner. In figure 2 is shown the costs for the different alternatives and comparisons with European high speed railway projects.

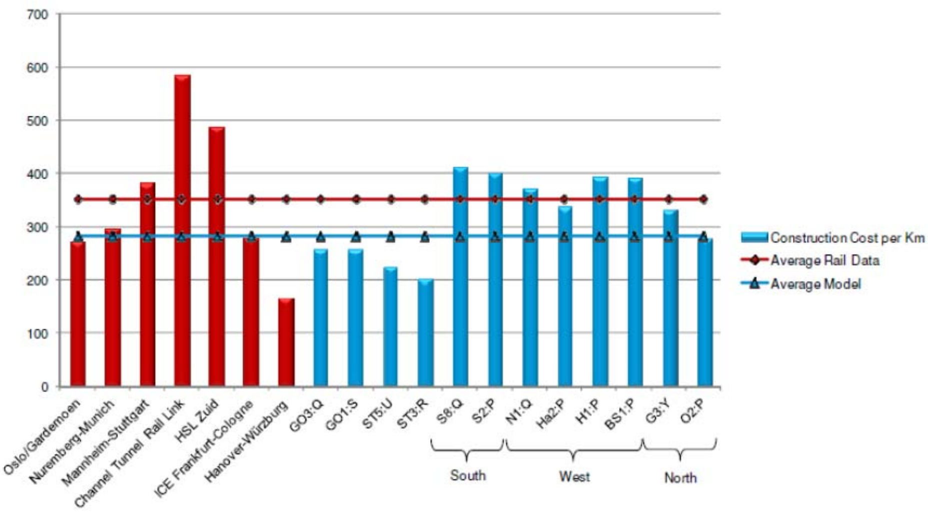

Figure 2. Cost in million NOK pr km: South, east and north is from Oslo to Stavanger, Bergen and Trondheim respectively. GO and ST is Gothenburg and Stockholm. These prices are lower because some of the routes already are established. [3]

The distances for the lines to Stavanger, Bergen and Trondheim is around 500 km each. The costs for each corridor then are calculated to the order of 150 – 200 billion NOK or 20 – 30 billion Euro.

4 Track systems

The track system in the Norwegian lines is ballasted track having UIC60 rails and monoblock sleepers. There are some advantages concerning noise by using biblock sleepers, but in high speed lines the advantage is smaller. And since monoblock sleepers are used in the ordinary railway lines we foresee that this solution will be chosen in the high speed lines as well. The relatively soft rail pad which is used in Norway will give considerable higher noise level than a stiffer pad in high speed lines. During the detail design phase of the track for the new high speed lines the rail pad stiffness must be studied and optimised.

In slab track there is no ballast, and the track is fastened to a concrete slab. The fastening system must give the elasticity in the track which is lost when there is no ballast. In HSR slab track are used in some countries. In drilled tunnels this is the most cost-effective solution because of smaller radius. In Norway there are no slab track lines. The initial costs are reckoned to be higher for slab track than for ballasted track, however the maintenance costs are lower._Noise from a slab track generally is higher than from a ballasted track, typically a 2 – 4 dB increase is found. One reason is that the sound absorption in the ballast is lost, but the main reason is that in a slab track the rail fastening system is usually softer in order to obtain the elasticity that is lost from the ballast. Therefore the rail vibrates more, and the noise radiation from the rail is higher. The noise radiation from the massive slab can usually be neglected.

For slab track the requirements for long time settlements are very strict because the possibility for rail height adjustment is limited. This may require considerable stiffening of the ground in clay areas. In addition slab track gives more noise. Based on these two reasons we expect that it is most probable that ballasted track will be chosen in Norway except for in the drilled tunnels. In the calculation method for noise ballasted track is foreseen.

5 Noise sources from high speed railway

The noise radiated from a railway line is very complex and the noise contribution from the dominant noise sources will depend on the train speed. At very low speeds the traction noise dominates, at higher speeds the rolling noise dominates, and at speeds higher than 200 km/h the aerodynamic noise contributes and increases strongly with the train speed.

The train speed v_e for which the aerodynamic noise equals the rolling noise depend on the track. In the Harmonoise reports from 2001-2003 this speed was assumed to be around v_e = 250 km/h. However in later references this speed is higher, more around v_e = 300 km/h. In figure 3 is shown the noise level as a function of speed that is used in the calculations of the noise level from a future high speed line between England and Scotland. This is based on the measured noise level of currently operated high speed trains (Gauitier et al) [7], and the current noise level requirements for new trains from the European Community (Directive 96/48/EC).

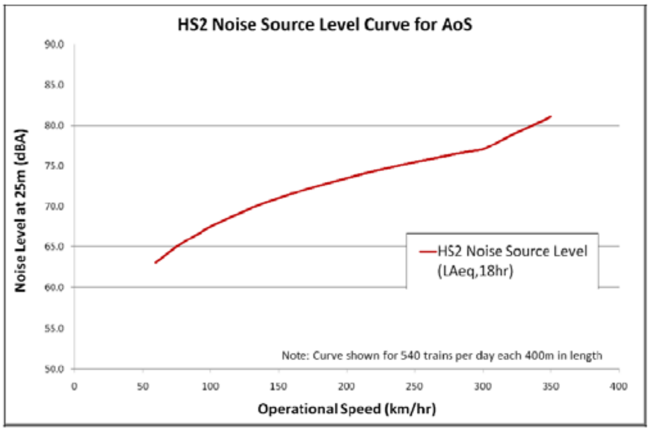

Figure 3. From British studies of high speed lines. Day time average noise level ($L_{eq,06\text{-}18}$) at 25 meters. [4]

6 Noise emission data for future Norwegian high speed lines

It is likely that DIRECTIVE 96/48/EC: "Interoperability of the trans-european high speed rail system", will be a guideline for Norwegian HSR as well. Table 1 shows the limits for pass-by noise levels for different speeds. Our experience from existing high speed trains in Scandinavia is that the extrapolated limit for 200 km/h is rather low. However, as newer, less noisy high speed railway is developed, there are reasons to believe that the TSI limits as well as this extrapolated limit will be fulfilled for future high speed lines.

Table 1 Limiting Values in the HS TSI, measured 25 meters from the track.

Speed (km/h)	200	250	300	320
HS TSI Limits, $L_{pAeq,Tp}$ Class 1 railway	84 [1] db(A)	87 db(A)	91 db(A)	92 db(A)

1) There is no limit for 200 km/h, since class 1 railway is defined for speeds above 250 km/h. This value is extrapolated using the 30 x log relation between the noise emission and the velocity.

7 Noise calculation method

For speeds up to around 200 km/h the noise sources are the rolling wheel and the track. These are implemented in the current calculation methods. For high speed trains, a new description of the noise source is necessary, having in mind the contribution from aerodynamic noise at higher speeds. The distribution of the sound power to four different heights above the rail is shown in figure 4.

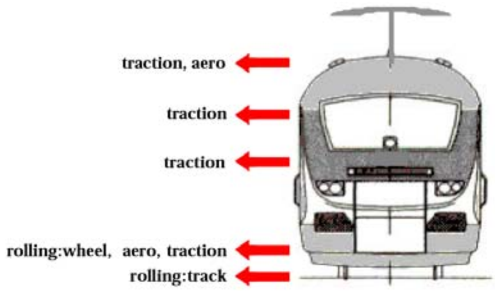

Figure 4. Vertical distribution of railway noise sources [6].

The calculation method for railway noise in Norway is the common Nordic method from 1996. This method is implemented in three soft ware programs that are widely used in Norway: Cadna, Soundplan and NoMeS.

In the methods there are input data for trains up to 260 km/h (Swedish train type X2000). The two first programs have facilities for using digital 3D terrain. The Nordic method for railway traffic noise has been revised under the name Nord 2000 [6]. In this method the possibilities for different sources heights as shown in figure 4 are implemented. This work has been strongly connected to the development of the European methods Harmonoise and Imagine. There have been several other improvements. It takes account for the influence from metrology and has new algorithms for sound diffraction and ground absorption. It also has better provisions for calculating the effect of low barriers close to the track.

Nord2000 was found to be the best method in our calculation work because it allowed for the varying noise source heights of the train. However, when studying this in more detail, it is recognised that the rail source part of Nord2000 has an important disadvantage in that it does not allow one to define different source heights and distribute the sound power spectra. The model prevents the definition of both the low-situated aerodynamic noise source from the bogie part and the high-situated aerodynamic noise source from the pantograph as low frequency sources. All efforts to correct for this have shown unsatisfactory results. Therefore, the decision was made to perform the calculations using line sources for the noise source modelling and the Nord2000 method for the propagation.

The maximum noise from railways is commonly known to attenuate 6 dB per distance-doubling, although on small distances the attenuation can be smaller. As the attenuation from an infinitely long and an infinitely short (=point) line source is 3 dB and 6 dB per distance-doubling respectively, the described method had to include corrections. For the used line source length, these correction terms are less than 2 dB for all distances in the range 12.5-500 meters.

For the wheel noise and rail/track noise parts, there are both semi-empirical and theoretical models describing and calculating the generated sound power. Unfortunately, for aerodynamic noise, which is an important contribution to the total noise impact from high speed trains, there is no such model. However, there are a rather large number of reported measurements on high speed trains, including train types such as ICE, TGV and Shinkansen. Yet, there are just a few reported investigations on the source distribution. Surely this is partly due to the high demands on measurements that could enable such investigations, including large microphone arrays, acoustic cameras or similar instruments. Relevant work on this subject is reported by Mellet et al [8] and Martens et al [9].

In connection with a Swedish investigation on high speed rail, a particularly interesting work is reported by Statens Provningsanstalt, SP [10], dealing with the same kind of issues as this present project. The approach of the SP work has been to calculate theoretically the wheel and rail/track noise, using TWINS source modelling and the Nord2000 propagation method, and compare the results with measurements on X2000 trains. The “empirical” difference, visible especially at high speeds, is stated to represent the aerodynamic noise contributions and used to correct the source model. In a final step, the aerodynamic noise contribution is divided into a bogey part and a pantograph part, referring to measurements on the Shinkansen train.

We have also chosen to use the source data reported in the SP report for the Norwegian High Speed Rail Noise Calculations, modified slightly with respect to the height of the highest situated source. In the SP report, the height of this source is suggested to be 5 meters. In other investigations, however, it is shown that the “pantograph” noise actually can originate from all kinds of obstacles on the train roof, for instance low antennas. Therefore, the height in our source model for the pantograph noise is set to 4 meters.

The SP source data, expressed as sound power per meter train, in our calculations are normalized to connect to the TSI limits defined at a height of 3.5 meters on a distance of 25 meters from the track centre line. The heights of the four different sources are shown in table 2.

Table 2. Noise source heights used in the project.

Source	Source height, meters
Rail/track noise	0
Wheel noise	0,5
Aerodynamic noise, bogey	0,5
Aerodynamic noise, pantograph	4

It has to be noted that in the used source data, the contribution from the aerodynamic noise is still smaller than the wheel noise at a speed of 320 km/h, in contradiction to what is indicated in the works of Mellet [8] or HS2 [4]. Along with the fact that there are different possible heights of this source, an uncertainty is brought into the calculations and results have to be treated with care.

The method and source data, as described above, are used to calculate the noise emission from a high speed railway for a number of typical cases, including the case without barrier and with barriers of 1, 2, 3, 4, 5 and 6 meters heights over the rail head. The ground absorption is defined by a flow resistivity $\sigma = 300$ kNsm^{-4} and roughness $\sigma_r = 0$ m, referring to a ground similar to a grass lawn. The calculations height is set to 3.5 meters at all distances. A section of the rail embankment, including the positions of the barriers, is shown in figure 5.

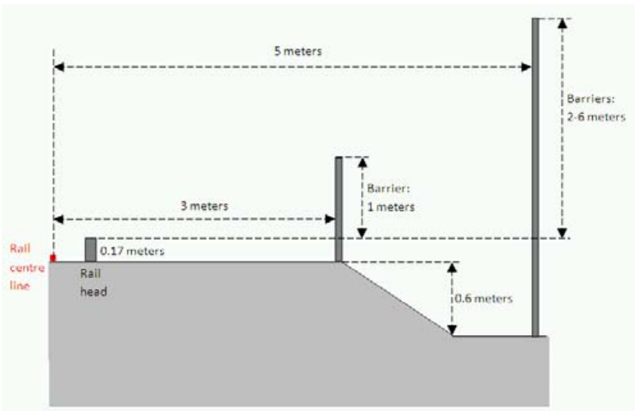

Figure 5. Embankment and position of barriers

Noise calculation is made for ballasted track and slab track. The difference in noise emission is typically 2 – 4 dB. In the German calculation method for railway noise, Schall 03 2006 [11], the difference is 3 dB. In the calculation in this report 3 dB is added to the noise contribution from the wheel / rail contact. The contribution from aerodynamic noise is assumed to be identical for ballasted track and slab track. For the pantograph noise this seems obvious. However for the noise from the front boogie the slab track may give higher noise generation because the sound absorption in the ballast is lost. On the other hand, the slab is smoother than the ballast which may influence on the noise generation. The noise from the pantograph is the most important aerodynamic source, the assumption of equal contribution in slab track and ballasted track therefore probably gives only minor errors.

8 Calculated noise levels

In figure 6, the calculated maximum noise levels for the typical cases with the different screening configuration are presented for ballasted track.

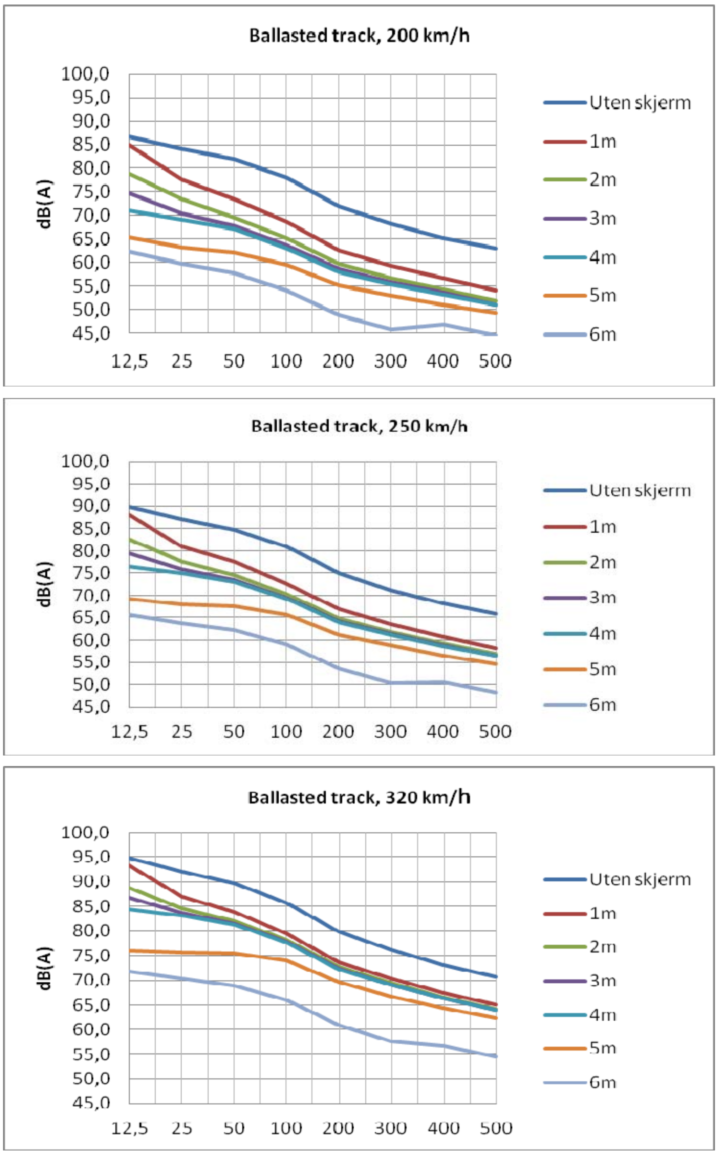

Figure 6. Calculated maximum free field noise levels for different speed, distances and screening

The noise spectrum for the noise from the rail / wheel contact does not differ very much with increasing speed. However around 300 km/h the aerodynamic noise starts to contribute significantly and the noise spectre is altered. Figure 7 shows the noise spectrum with different train speeds in 25 meter distance.

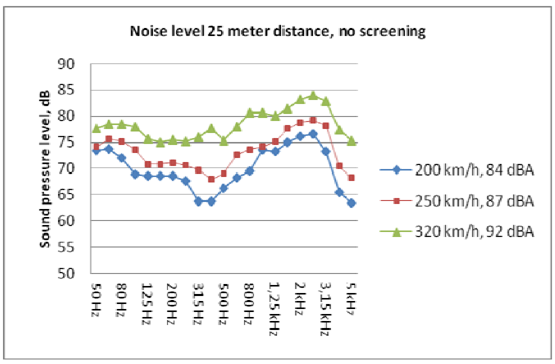

Figure 7. Noise from high speed train with different speed at 25 meter distance.

It is seen that the aerodynamic noise increases the noise level in the low and medium frequency region.

The contribution from the pantograph is increasingly important in cases when noise screens are established. This is because of the source height which is set to 4 meter in the calculations. In figure 8, calculated noise level in 25 meter distance including the noise reduction from a 4 meter high noise screen is shown.

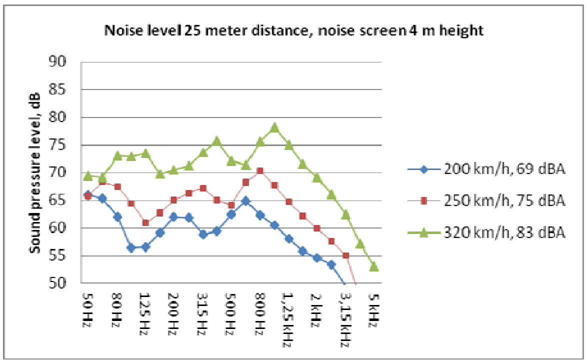

Figure 8. Noise from high speed train with different speed at 25 meter distance, 4 m noise screen.

The dBA noise reduction from the screen is 15 dB for the 200 km/h case, 12 dB for the 250 km/h case and only 9 dB in the 320 km/h case. The contribution from the pantograph is apparent in the 320 km/h case, and it can be seen that it also contributes in the high frequency region in the screening case.

In chapter 7 it is explained that the contribution from the aerodynamic noise is less in the calculations in this report than is reported in other references. This is a very important topic which needs to be studied further.

9 Indoor noise level

The noise insulation of the houses defined as the reduction in the noise dBA value difference depends on the noise frequency spectrum. Figure 9 shows the arithmetic mean value for sound insulation for 83 different wooden houses having double glazing and ventilation openings in the walls from our database.

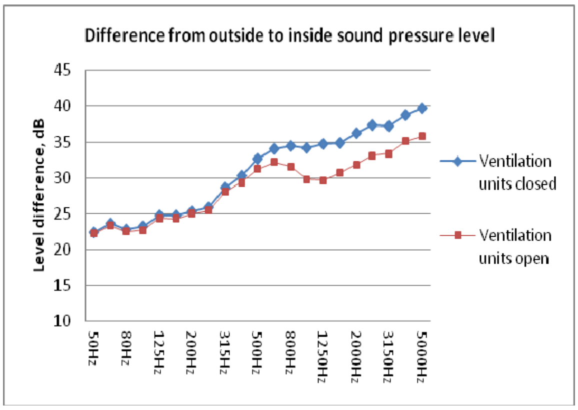

Figure 9. Noise reduction in wooden houses: arithmetic mean value from 83 measurements.

The level difference is the measured noise level in front of the house including reflection minus the indoor noise level. In figure 9, data with open ventilation units and closed is given. In the calculations open ventilation units are assumed. The difference between the open and closed case is around 2 dB in dBA-reduction.

We have calculated the dBA noise reduction for 42 spectra in each train speed. Screen heights are 0, 1, 2, 3, 4, 5 and 6 meter and distances are 12.5, 25, 50, 100, 200 and 400 meters. The noise reduction in dBA varies from 31.6 to 29.9 dB. Typical values are given in table 3.

Table 3. Calculated noise reduction in dB for different noise spectra in different distances with and without screening.

	200 km/h	250 km/h	320 km/h
25 meter, no screening	31,4	31,6	31,6
25 meter, 4 m noise screen	30,4	30,4	30,1
100 meter, 4 m noise screen	30,5	30,2	29,9

It is seen that there are only minor differences between the noise reductions for different train speeds.

10 Costs for noise reduction treatments

In this early HSR study the main issue of the noise calculations is for the calculations of costs. The maximum indoor noise levels are the decisive value concerning noise reduction treatments. The noise regulation for indoor noise level in Norway is $L_{p,AF,max}$ = 45 dB. From table 3 it is seen that the noise reduction is 30 dB for the screened cases. Based on input from free field values the difference is 27 dB. The contour line for the $L_{p,AF,max}$ = 45 + 27 = 72 dB therefore is found for the corridors. This is the distance to which the façade insulation in the houses may need to be improved.

In the cost calculations a mean speed of 250 km/h is assumed and in densely populated areas a 4 m high noise screen is used. This gives the basis for the cost calculations which are:

- Noise screened sections: Houses nearer than 75 meters: 20.000 NOK pr house
- No noise screen: 20 – 100 meters: 200.000 NOK pr house. 100 – 300 meters: 20.000 NOK pr house

References

[1] Asplan Viak AS, MiSA,, Verkehrswissenschaftliches Institut Stuttgart GmbH (VWI Stuttgart) and Brekke & Strand Akustikk AS: A Method for Environmental Analysis for High Speed Railway Assessment Project-Phase 2. Client : Jernbaneverket. 7/1- 2011.

[2] Brekke & Strand Akustikk AS, Asplan Viak AS: Norwegian high speed railway project. Noise calculation method in phase 3: Study of corridors. Client: Jernbaneverket. 7/6-2011.

[3] Norway high speed assessment study. Summary report part I. 25/1-2012.

[4] HS2 project. Explenatory note. Noise. May 2010.

[5] 2008/232/CE, “COMMISSION DECISION concerning a technical specification for interoperability relating to the ‘rolling stock’ sub-system of the trans-European high-speed rail system”.

[6] Hans G. Jonasson & Svein Å. Storeheier: ”Nord 2000. New Nordic Prediction method for rail traffic noise.” SP Rapport 2001:11, Acoustics, Borås.

[7] P. Fodiman and P. Gautier (SNCF): “Noise emission for railway Interoperability in Europe: application to High-speed and Conventional rail”. Forum acusticum 2005.

[8] Mellet et al (SNCF): “High speed train noise emission: Latest investigation of the aerodynamic/rolling noise contribution”, Journal of Sound and Vibration vol. 293, 2006.

[9] Martens A., Wedemann J., Meunier N., and Leclere A.: “High speed train noise – sound source localization at fast passing trains”, Deutsche Bahn AG, SOCIEDAD ESPAN˜OLA DE ACU´ STICA, S.E.A., 2009.

[10] Zhang Xuetao: “Prediction of high-speed train noise on Swedish tracks”, SP Report 2010:75, SP Sveriges Tekniska Forksningsinstitut, 2010.

[11] SCHALL 03 2006.”Richtlinie zur Berechnung der Schallimmissionen von Eisenbahnen und Strassenbahnen”.