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	Prototype of cylindrical sound absorbing screen top element	
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APPENDIX 1 Logged sound levels without screen top
APPENDIX 2 Logged sound levels with screen top

EXECUTIVE SUMMARY

The test site for a new type of screen top element

Sound measurements have been performed with the aim to determine the insertion loss for a new type of sound absorbing screen top element, aimed for increasing the screen insertion loss by absorption and reduced diffraction. The picture below shows the test section at Lahäll north of Stockholm.

Noise reducing cylindrical screen top elements with absorption has been studied by e.g. Fujiwara & Okubo and others. In previous investigations the screen top element has been either supplied with a single layer absorbing material or quarter-wave resonators without sound absorbing material.

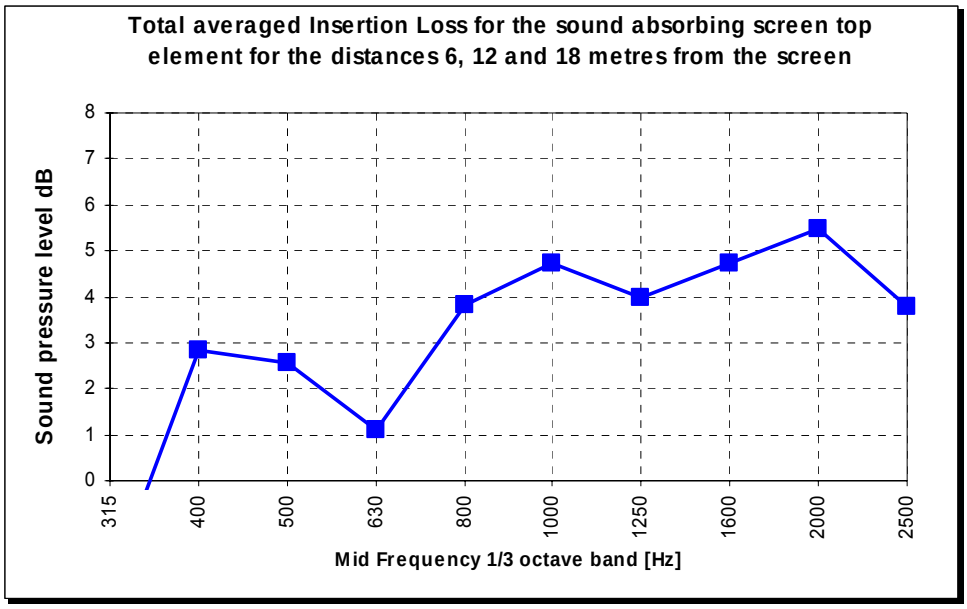
Twin-layer technique

The prototype to a screen top element presented in this delivery has been supplied with porous sound absorbing material of *twin layer type (see picture above)*. This means that the sound absorbing material consists of two layers where the outer porous layer has very low flow resistance while the inner layer has a flow resistance that is 2-4 times higher compared to the outer layer. By the twin layer technique we ensure that we create an increased refractive characteristic (decreased speed of sound along the depth of the absorbing layer) so that the sound entering the sound absorbing material will be efficiently absorbed. This is desirable since sound transmission along the surface of the absorber should be avoided.

Measurement results

Measurements of the insertion loss with aid of a loudspeaker sound source providing 1/3 octave band filtered noise, was performed *before* and *after* mounting the screen top element. The insertion loss for the screen top element in each 1/3-octave band is shown below. The insertion loss in dB(A) when using a typical traffic noise spectrum was found to be about **four (3.5-4.5) dB(A).**

One year after the screen top was mounted, the measurements were repeated. It was found that about the same results (4.0-5.0 dB(A) reduction) was obtained. This means that there are no negative environmental (rain, snow, dust etc.) long-term effects on the sound absorbing material or construction details.



The insertion loss has also been determined for existing traffic noise measured by sound level meters (also including measurements in 1/3-octave bands) during several days. The measured mean value of the insertion loss was about **2 (1.9) dB(A)** or about half of the insertion loss measured with loudspeaker as sound source. This lower insertion loss is due to the fact that the test section with screen top elements (60 m long) has been too short. The leakage effects due to sound transmitted over the untreated screen outside the test section have been simulated. The software CadnaA® has been used for this simulation. The calculation results reveal that if a longer section had been equipped with the sound reducing screen top, then the insertion loss would have been the same (about 4-5 dB(A)) as was measured with the loudspeaker as sound source.

Angle dependence of the insertion loss.

We believed that the insertion loss for a point source with small angel of incidence (almost parallel to the screen) relative to perpendicular incidence could give increased insertion loss primarily due to the longer propagation path over the sound absorbing material and an experienced larger radius of the cylinder. To the best of our knowledge no studies of the angle dependence has been performed in previous studies.

The results of this study (see chapter 5 in this delivery) was that a constant absolute value of the insertion loss for the screen top element was achieve independently of the angle of incidence.

However, the relation (*insertion loss for the screen top element)/(total screen attenuation*) may be higher for small angels (almost parallel to the screen) compared to the perpendicular incidence. This is due to the fact that the screen attenuation will decrease because the small angels also give a smaller path difference and thereby a smaller Fresnel number.

1. INTRODUCTION

Swedish Road Administration, Stockholm has installed a traffic noise protection screen along a 2600 metres long section of the motorway E18, Täby/Lahäll. The originally performed calculations for the design of these noise screens revealed that a mean height of approx. four (4) metres, with maximum heights of about 5.5 meters, was necessary to decrease the equivalent sound levels to below 60 dB(A) for the majority of nearby residents.

Acoustic Control has conducted a study on improvement of the insertion loss of the screens with the goal to reduce the equivalent sound levels further down below 60 dB(A).

The study resulted in that that a cylindrical sound absorbing screen top with diffraction reducing capabilities was selected as a method to increase the Insertion Loss of the screen[1]. Such improved insertion loss could apart from reducing the sound levels for already existing screen installations also be used for reducing the screen height at maintaining the originally selected noise level target for projects in the design phase.

1.1. PREVIOUS STUDIES OF SOUND REDUCING SCREEN TOPS

1.1.1 The full scale examination by Fujiwara

The excess noise reduction achieved by an absorbing cylindrical screen top element has previously been studied[2] by K Fujiwara at Kyosho Inst. of Design, Japan. Fujiwara reports that, by theoretical calculations, as much as **7-8 dB(A)** reduction could be achieved. However, at full scale measurements performed in Japan, by installing sound absorbing cylindrical elements on the screen top element (of existing traffic noise screens) an insertion loss for the top element of **2-3 dB(A)** has been achieved compared to the original sharp-edged screen top shape. Typical spectral shapes and source positions relevant for road traffic noise was assumed.

---

[1] Another proposal to give increased Insertion Loss which was studied, was to mount sound absorbing material on the inside of the screens. Proposals from this study are now performed for stage 1 as well as stage 2.

[2] Fujiwara K: Sound shielding efficiency of a barrier with a cylinder at the edge , *Noise Control Engineering Journal v 37 Jul-Aug 1991 p 5-11*

1.1.2 The scale model attempts by Arenas/Monsalves

J P Arenas at Auburn University AL, USA, has studied[3] various types of screen top elements in model scale together with A M Monsalve at SESA, Germany. One of the alternatives studied in the laboratory has been a screen of height 2.5 m and equipped with an absorbing cylindrical screen top element of a diameter of 320 mm. A sound source with a frequency spectrum corresponding to typical road traffic noise for velocities exceeding 50 km/h (i.e. road/traffic noise) was used. The results show that the noise reduction increases by 2,5 dB(A) or more compared to a sharp-edged ordinary screen top geometry. What is interesting is that these 2.5 dB(A) is achieved independent of the distance to the screen at least up to 25 metres from the screen. Other investigations based on field measurements as well as BEM (Boundary Element Method) calculations have revealed an insertion loss of this size order magnitude up to 50 meters from the screen. There is nothing in the presented theory which indicates that the effect would decrease rapidly with increased distance.

[3] J P Arenas and AN M Monsalve: Modification of the Diffracted Sound Field by Some Noise Barrier Edge Designs.
Int Journ of Acoustics and Vibration Vol 6 No 2 2001.

2. SOUND ABSORBING SCREEN TOP ELEMENT TEST SECTION AT LAHÄLL/TÄBY – DESIGN PROCEDURE AND TECHNICAL DESCRIPTION

In this chapter the cylindrical sound absorbing screen top element is described in detail.

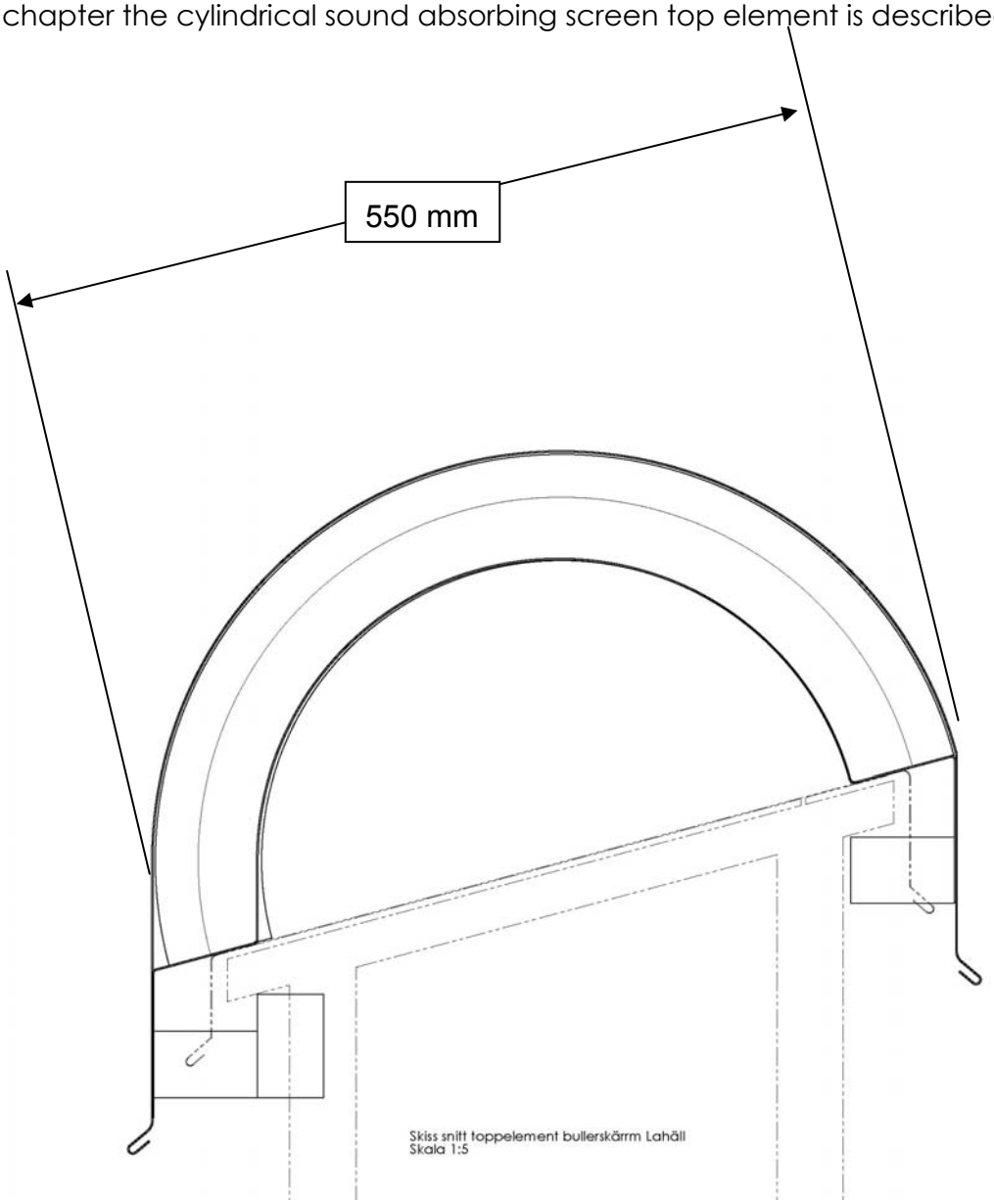


Fig. 1. Conceptual sketch showing the tested, low diffracting, cylindrical sound absorbing screen top element.

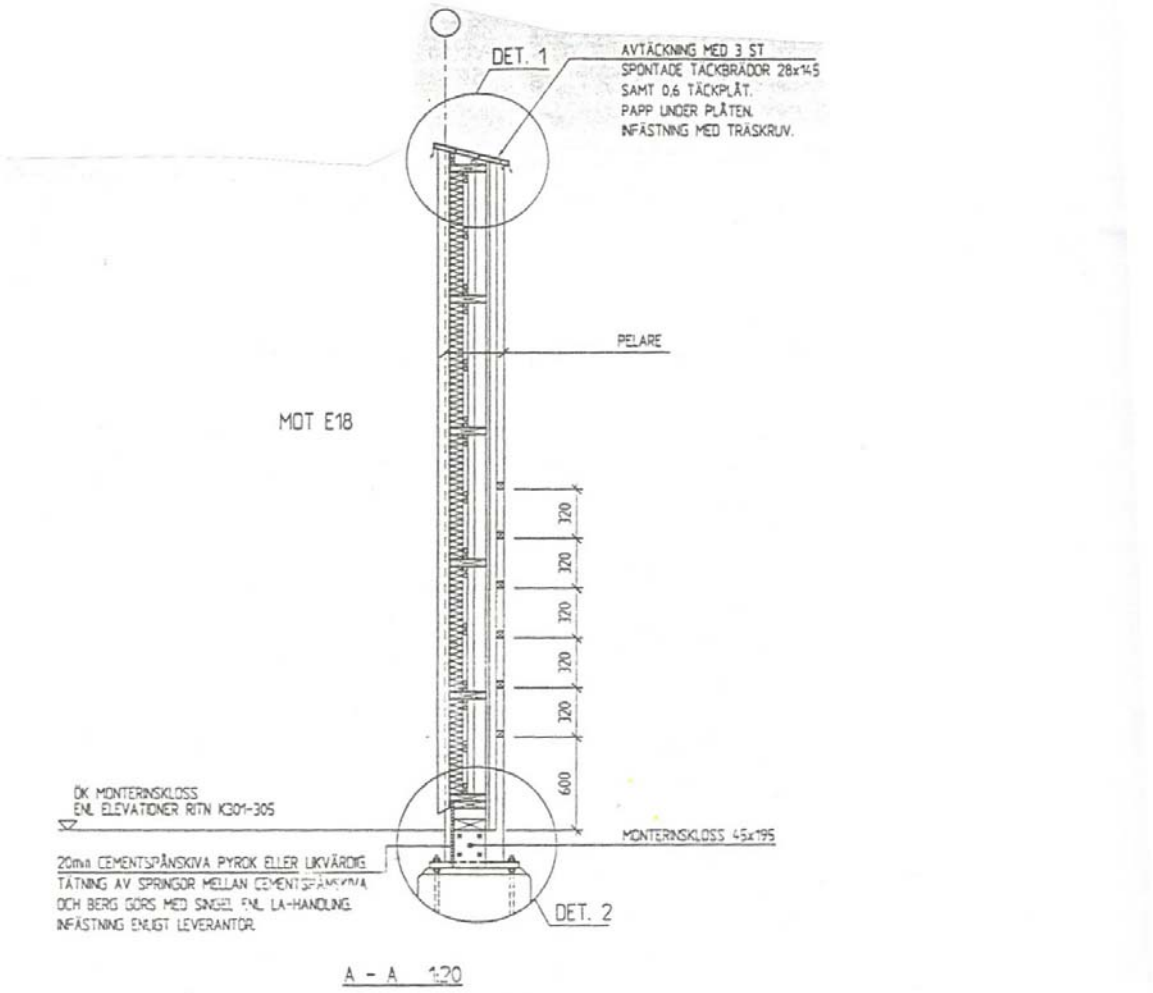


Fig. 2. Cross section of screen design at E18 in Lahäll Stockholm Sweden. The screen top element has not been mounted.

Fig. 3 Diffraction-reducing cylindrical sound absorbing screen top element.
Test prototype at the manufacturing plant GSE in Arboga.

Fig. 4. Photo of the mounting of the cylindrical sound absorbing screen top element (manufactured by Ground Support Equipment in Arboga). Note the surface protection of perforated sheet metal and the sound absorbing material below. First glass wool is mounted and there under a cylindrically shaped mineral wool of density 140 kg/m^3. Below a cylindrically shaped steel sheet can be seen. This will prevent direct sound transmission through the screen top element.

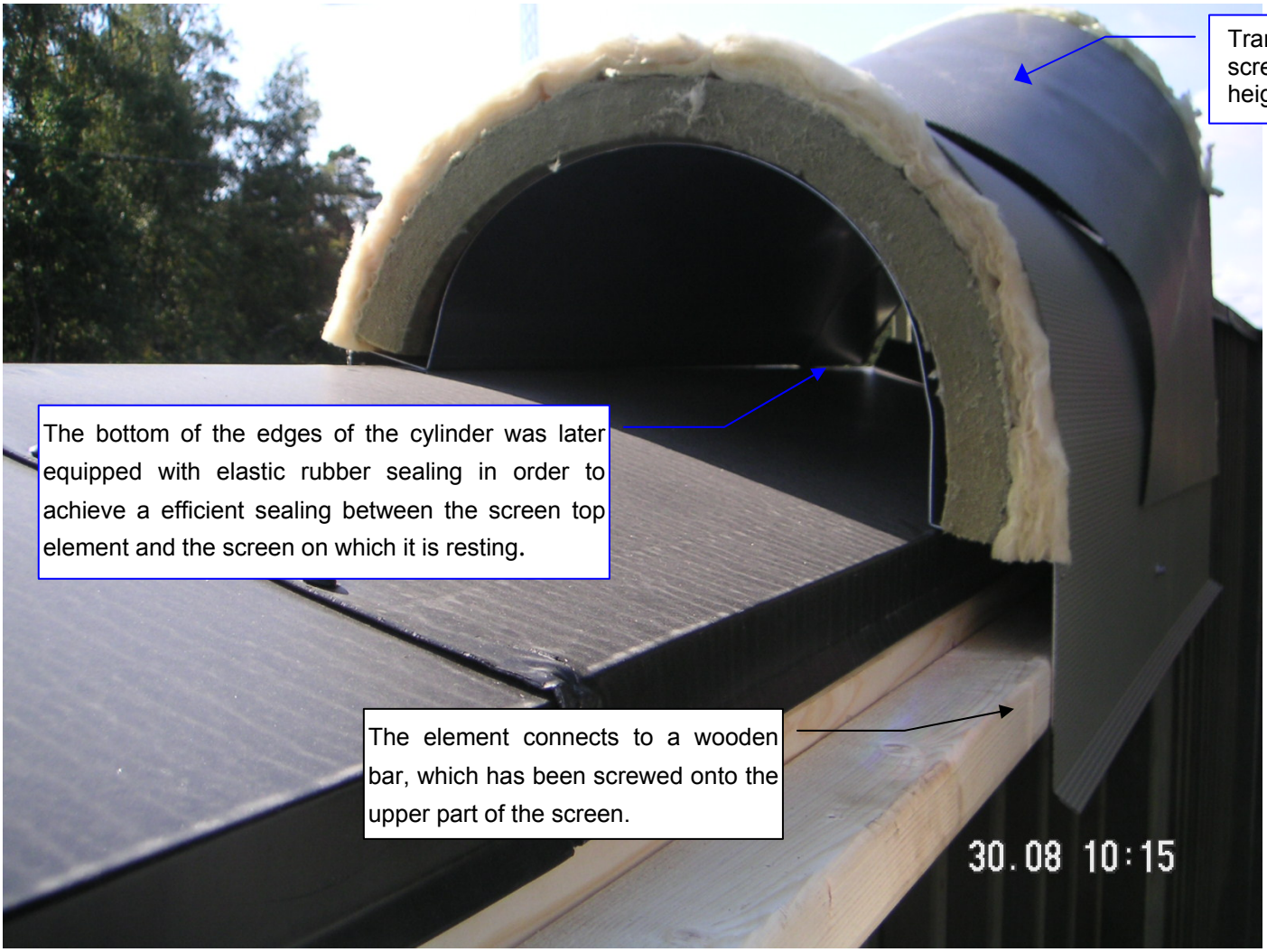


Fig. 5. Photo showing the mounted screen top element. Note also the transition unit to get low diffraction also between screen sections of different height.

2.1. ABSORPTION FACTOR OF SCREEN TOP ELEMENT

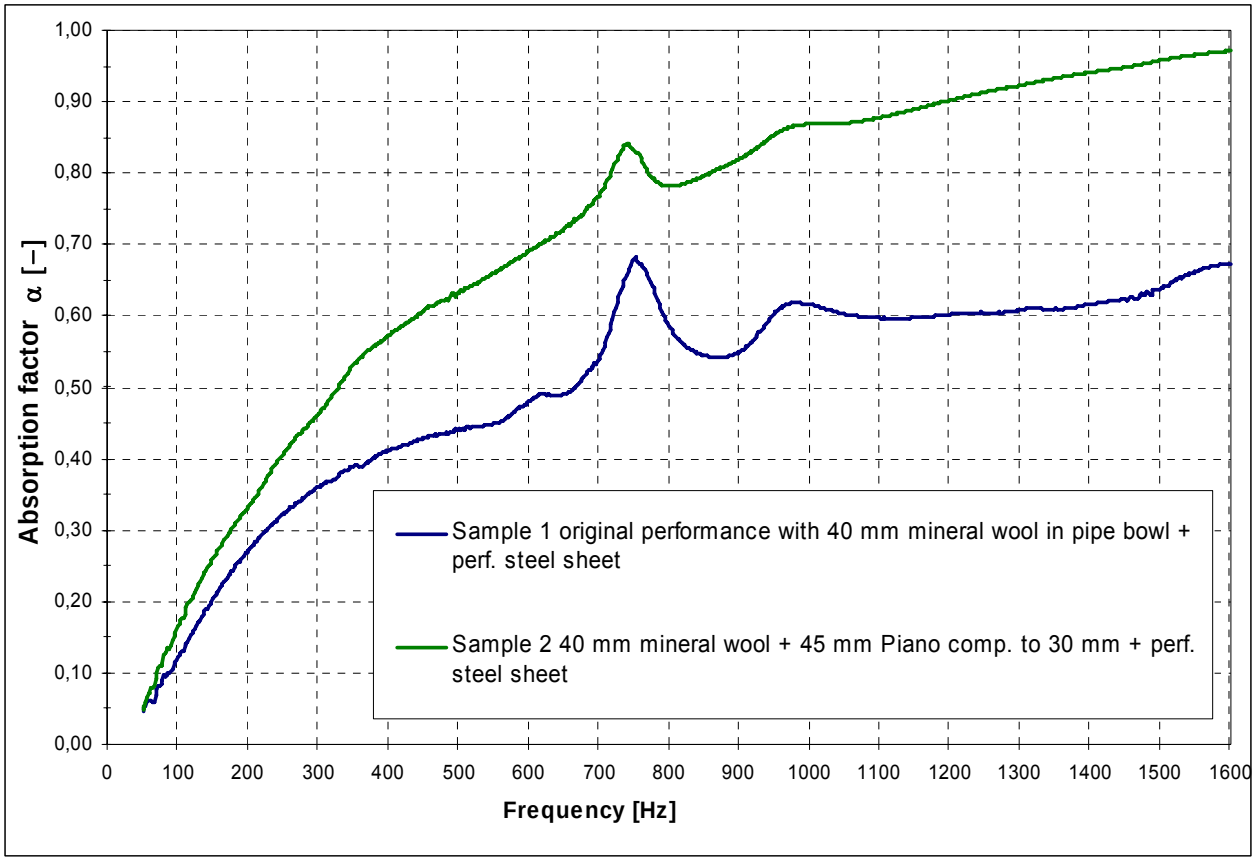


Fig. 6. Absorption factor of original and improved screen top element in narrow band, frequency resolution Δf = 2 Hz.

Absorption measurements in an impedance tube revealed that 40 mm mineral wool (140 kg/m^3) combined with 45 mm (compressed to 30 mm) glass wool of type ISOVER "Piano" gave the optimal sound absorption coefficient for the .

2.2. POROUS ABSORBING MATERIAL OF TWIN LAYER TYPE.

As mentioned before noise reducing cylindrical screen top elements with absorption has been studied by e.g. Fujiwara & Okubo and others. In previous investigations the screen top element has been either supplied with a single layer absorbing material or quarter-wave resonators without sound absorbing material.

The prototype to a screen top element presented in this delivery has been supplied with porous sound absorbing material of ***twin layer type***. This means that the sound absorbing material consists of two layers where the outer porous layer has very low flow resistance while the inner layer has a flow resistance that is 2-4 times higher compared to the outer layer. By the twin layer technique we ensure that we create an increased refractive characteristic so that the sound entering the sound absorbing material will be efficiently absorbed also for lower frequencies. We also believe that the increased refractive index for the twin layer absorbing material will make it more locally reacting. This is desirable since sound transmission along the surface of the absorber should be avoided.

3. FIELD MEASUREMENTS 2004 AND 2005

3.1. OVERVIEW OF TEST SECTION

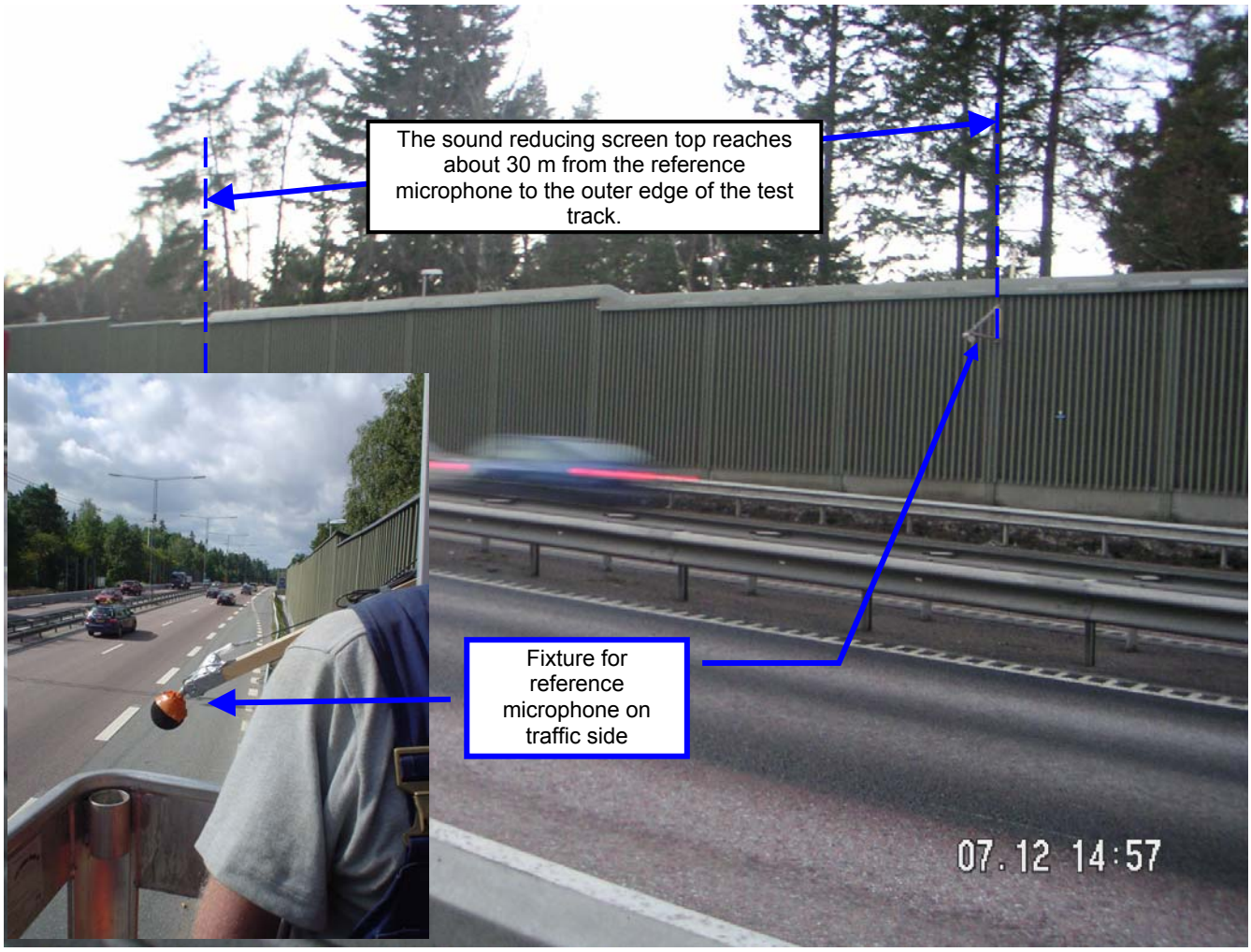


Fig. 7. Detail of test section for sound reducing screen top element. The picture shows the length from the reference microphone to the edge of the test section.

3.2. MICROPHONE POSITIONS AT THE INSTALLED TEST SECTION

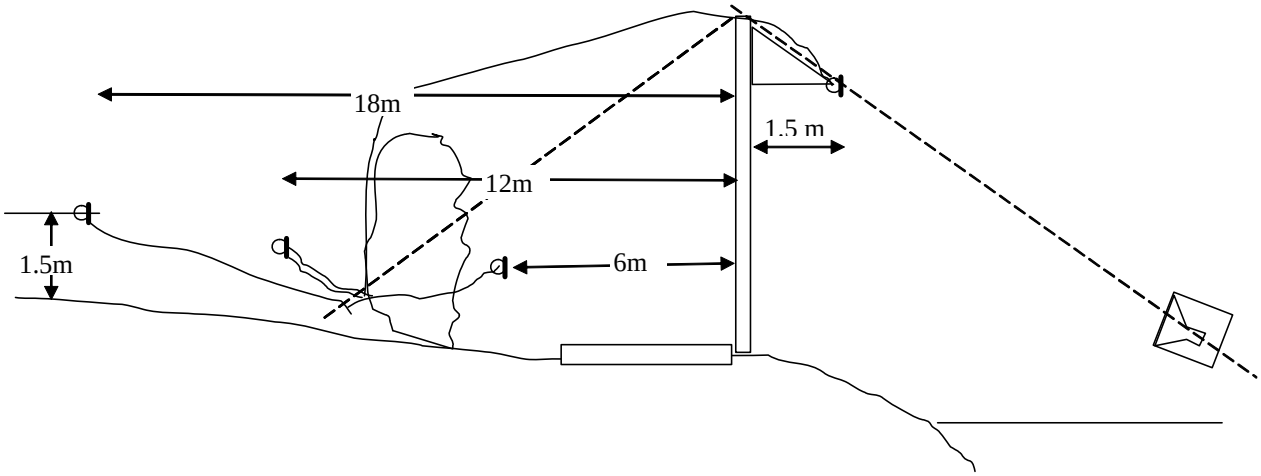


Fig. 8. Cross section through the screen at the measurement site for testing the sound reducing screen top element. Note also the distances from the screen to the various microphone positions at the receiver side as well as the reference microphone at the traffic side.

On the traffic side of the screen, a reference microphone was mounted on a fixture as shown in the Figures 8 and 10. This microphone served as reference microphone to give information on the source traffic noise level for the determination of the Insertion Loss. The three microphones on the receiver side are shown at a cross section sketch in Figure 8. All microphones on the receiver side were mounted 1.5 m above ground. The microphone on the screen was mounted on a wooden cantilever 1.2 m below the upper edge of the screen (as measured before mounting the sound reducing screen top element) and at a horizontal distance of 1.5 m from the screen surface (see also Figure 8).

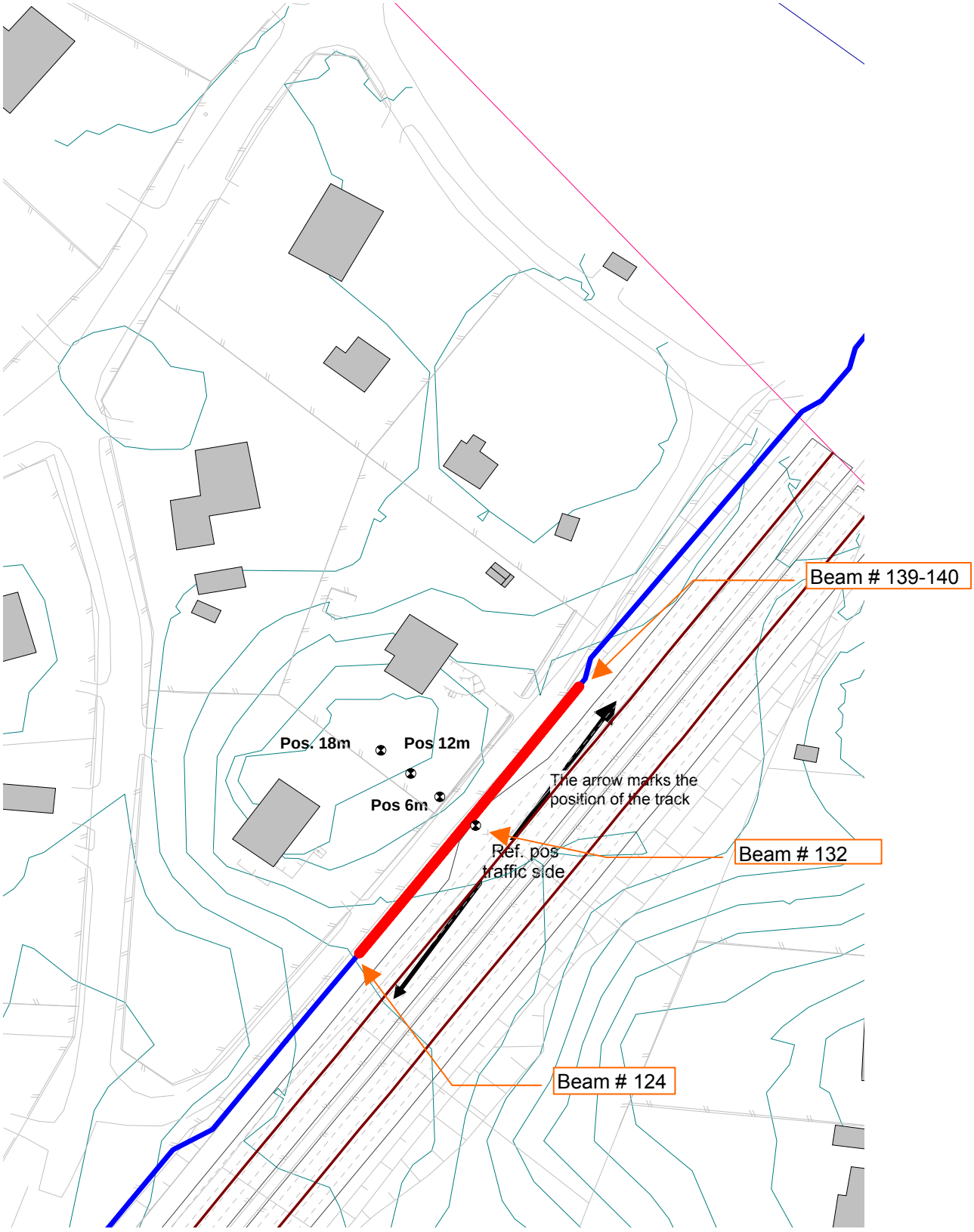


Fig. 9. View of test section with sound reducing screen top element.

3.3. PERPENDICULAR LOUDSPEAKER MEASUREMENTS 2004

3.3.1 Measurement using a loudspeaker noise source BEFORE mounting the sound absorbing screen top element

On the night of 28th of August, the screen reduction *without* screen top element was measured using loudspeaker noise. The loudspeaker position is shown in Figure 10 below. The microphone which was mounted on the traffic side of the screen was used to calibrate (normalise) the level on the 'sending side' to be able to compare sound level differences for the screen measured before and after the cylindrical non-diffracting sound absorbing screen top element. To get sufficient signal-to-noise ratio in order for the loudspeaker noise to exceed the background noise, band-limited noise was used. This leads to an improved signal-to-noise ratio of approximately 13 dB units. The measurements were performed for the 1/3 octave bands 315 Hz to 2.5 kHz. The same microphone positions were used as for the traffic measurements, see Figure 8.

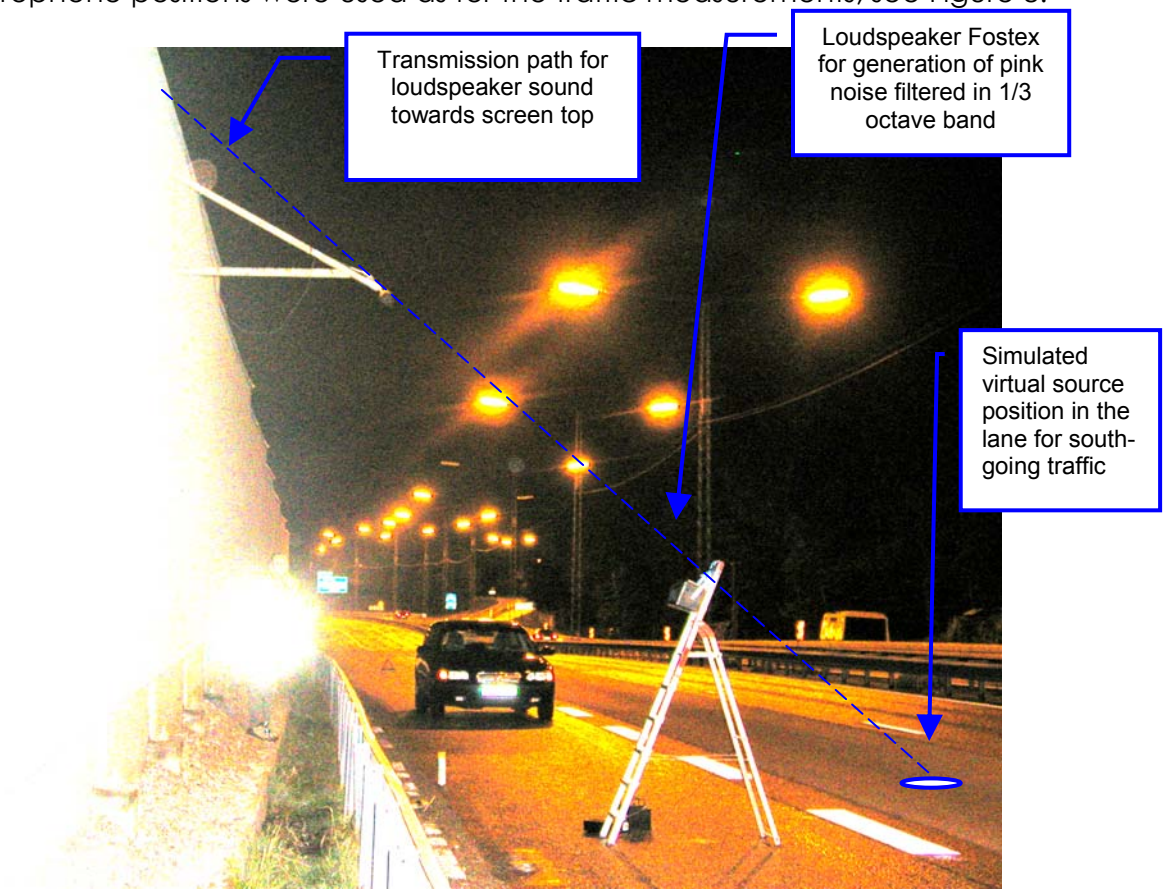


Fig. 10. Night-time measurement of sound pressure level difference for the screen (with and without the screen top element). The sound source was 1/3-octave band limited pink noise from a loudspeaker.

3.3.2 Measurement using a loudspeaker noise source AFTER mounting the sound absorbing screen top element

The night of September 2nd, sound measurements were performed using loudspeaker noise. The screen top element was **mounted**. The measurement, (microphone positions and the loudspeaker position) was the same compared to the measurements **without** the screen top mounted.

3.4. TRAFFIC NOISE MEASUREMENTS

3.4.1 Logging of traffic noise BEFORE mounting the sound absorbing screen top element

Before mounting the screen top element, sound levels from the traffic was also logged from Thursday the 19th of August to Tuesday the 24th of August, 2004. Equivalent sound levels during 5-minute intervals were registered. Microphone positions according to section 3.1 were used.

3.4.2 Logging of traffic noise AFTER mounting the sound absorbing screen top element

During the period from August 28th to September 1st, the sound reducing screen top element was mounted on a 60 m long section of the screen. Figure 8 shows the cross section with the microphone positions mounted in the middle of the test section.
Sound levels from road traffic have been logged from Friday the 3rd until Tuesday the 7th of September. By logging, equivalent sound levels during 5-minute intervals have been registered during the logging period of five days. Microphone positions according to section 3.1 have been used during the measurements.

3.5. LOUDSPEAKER MEASUREMENTS OF INSERTION LOSS 2005

The loudspeaker measurements performed in 2004 with and without screen top element mounted (see section 3.3) was repeated one year later (screen top elements had then been installed for a year) on the 31st of October and 9th of November. In addition to perpendicular, a number of skew angles of incidence were measured (30, 45, 58 and 67 degrees of incidence).

The reasons for performing these measurements were twofold:

- to investigate any possible deterioration of the insertion loss due to environmental impact such as clogging of the sound absorbing material by dust and dirt, influence by humidity from rain and snow or moisture accumulation due to condensation during sudden temperature fall.
- to study the insertion loss also for other angles of incidents than perpendicular.

3.6. LOGGING OF WEATHER CONDITIONS

The weather conditions were logged in 5-minute intervals: wind speed, wind direction and temperature including the temperature gradient.

4. CALCULATIONS

4.1. 60 M SCREEN TOP ELEMENT - INSERTION LOSS FOR TRAFFIC NOISE

A CadnaA® calculation of the Insertion Loss for traffic noise, based on the Nordic Prediction Model for road traffic noise, has also been performed. In stage 1, the calculation for the case that the sound reducing screen top element has a total elongation of 60 m (30 metres on both sides of the receiver positions).

4.2. SCREEN TOP ELEMENTS ALONG THE WHOLE ROAD SECTION WITH NORMAL SCREENS – INSERTION LOSS FOR TRAFFIC NOISE

A CadnaA® calculation has also been performed to establish which Insertion Loss would be at hand if the whole screen installation would have been equipped with the sound reducing screen top element.

5. RESULTS

5.1. LOUDSPEAKER MEASUREMENTS 2004/2005

The resulting Insertion Loss is in the interval of **3.5 to 4.5 dB(A) in 2004** and **4.0 to 5.0 dB(A) in 2005** for the different receiver positions. Figure 11 shows the Insertion Loss for the non-diffracting absorbing screen top in the three different receiver positions for the frequency range 315-2500 Hz. Table 1 contains a summary of the measured loudspeaker results for the screen top element.

Measured Insertion Loss of attached screen top element. Loudspeaker noise		
Measurement position	**Insertion Loss (IL) dB(A)**	
	2004	**2005**
Pos 1. 6 m from screen	3.5	5.0
Pos 2. 12 m from screen	4.5	4.0
Pos 3. 18 m from screen	3.9	4.8
Mean value	**4.0**	**4.6**

Table 1. Table that summarize the results from loudspeaker measurements (sound propagation path perpendicular to the screen) of Insertion Loss for the sound reducing screen top here expressed in dB(A).

- **Appendix 1** describes the measured Insertion Loss for the screen without the screen top element mounted.

- **Appendix 2** describes the measured Insertion Loss with screen top element. The three microphone positions at receiver side are shown in Figure 8,

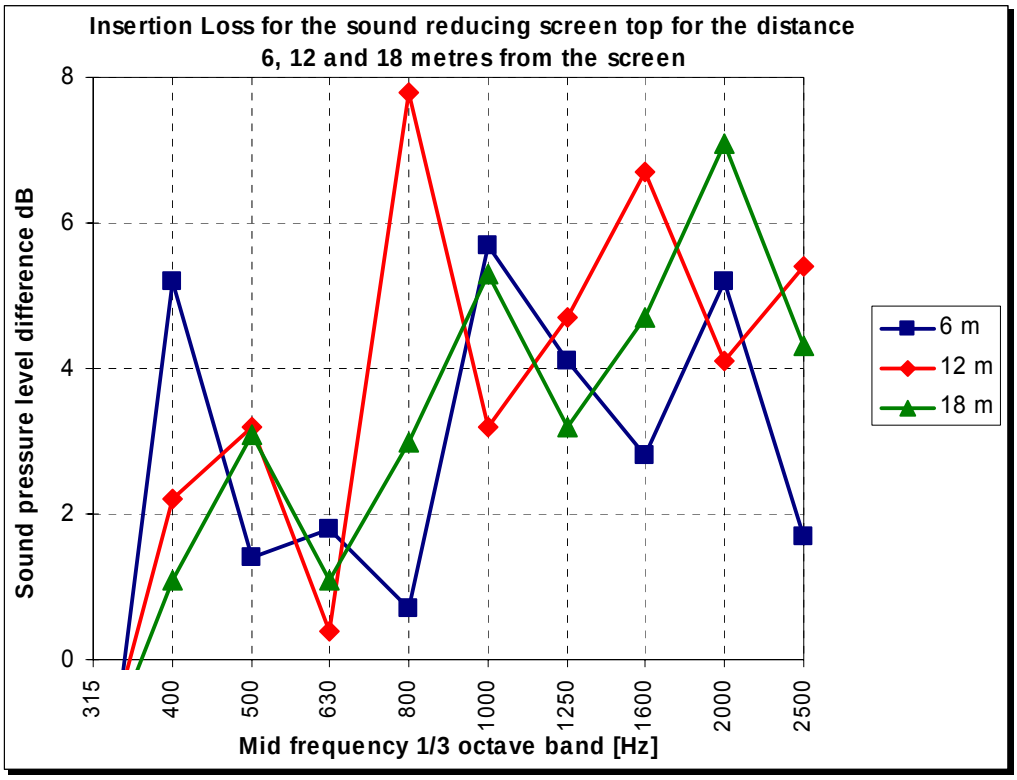


Fig. 11. Insertion Loss for microphone positions at 6, 12 and 18 metres from the screen determined by loudspeaker measurement. Transmission: Perpendicular relative to screen. The mean value of the Insertion Loss for all microphone positions is shown in Fig. 12.

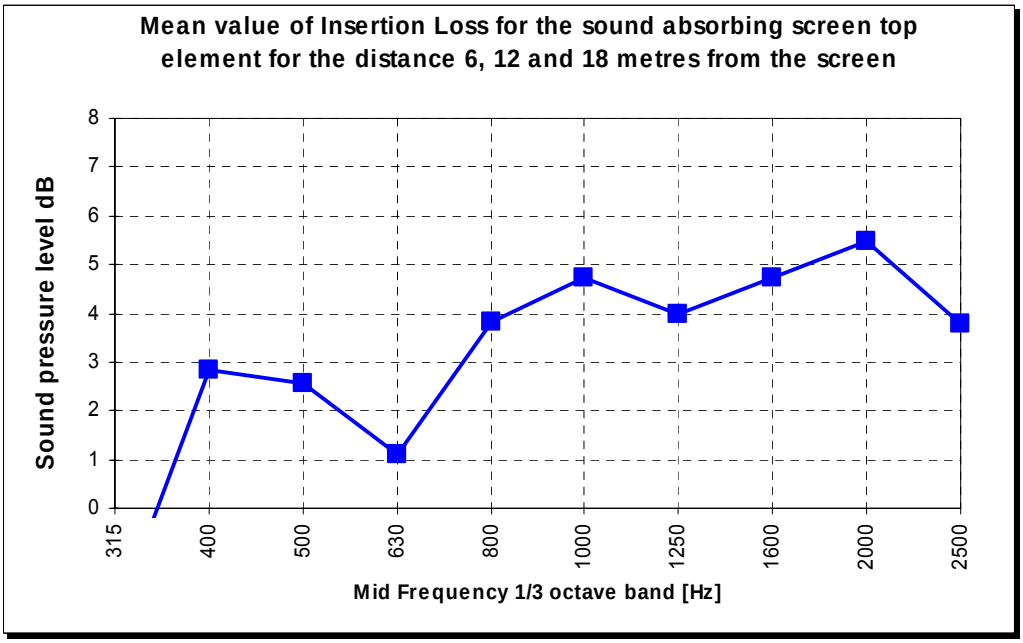


Fig. 12. Mean value of the Insertion Loss for the sound-reducing screen top element measured with loudspeaker noise. Transmission path: perpendicular relative to screen. Positions of microphones and loudspeaker: see sketch in Fig. 8.

5.2. MEASUREMENTS OF THE DEPENDENCE OF ANGLE OF INCIDENCE

We believed that the insertion loss for a point source with small angel of incidence (almost parallel to the screen) relative to perpendicular incidence could give increased insertion loss primarily due to the longer propagation path over the sound absorbing material and an experienced larger radius of the cylinder. To the best of our knowledge no studies of the angle dependence has been performed in previous studies.

As can be seen the results of this study was that a constant absolute value of the insertion loss for the screen top element was achieve independently of the angle of incidence. The measurement results thus reveal no strong and statistically secure angle dependence on the insertion loss for the screen top element.

However the relation (*insertion loss for the screen top element)/(total screen attenuation*) may be higher for small angels (almost parallel to the screen) compared to perpendicular incidence. This is due to the fact that the screen attenuation is less for small angles of incidence, because the small angels give a smaller path difference and thereby a smaller Fresnel number.

Figure 13 below presents the Insertion Loss for the non-diffracting absorbing screen top element as an average of the three receiving microphone positions and for five different angles of incidence (0 degree means that the path is perpendicular to the screen and 67 degrees is more parallel to the screen).

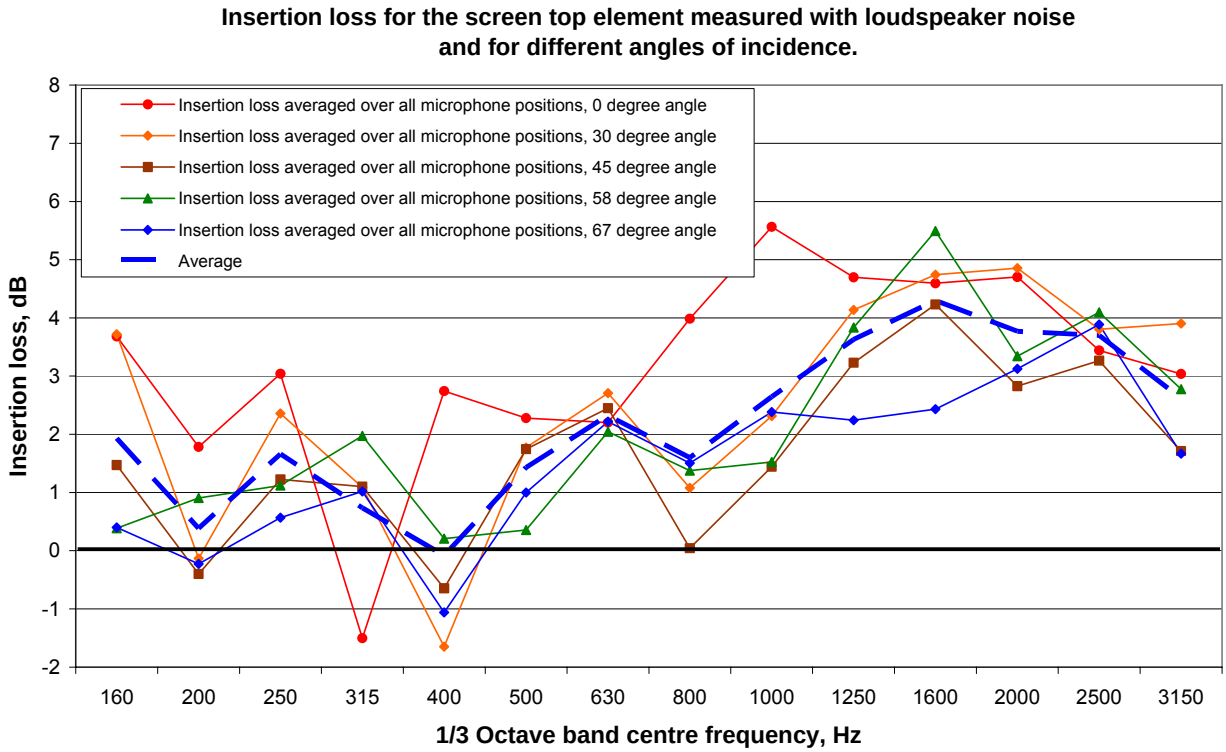


Fig. 13. Mean value of the Insertion Loss of all microphone positions for sound-reducing screen top measured for different angles of incidence.

The different angles of incidence for the loudspeaker noise are presented in Figure 14 below.

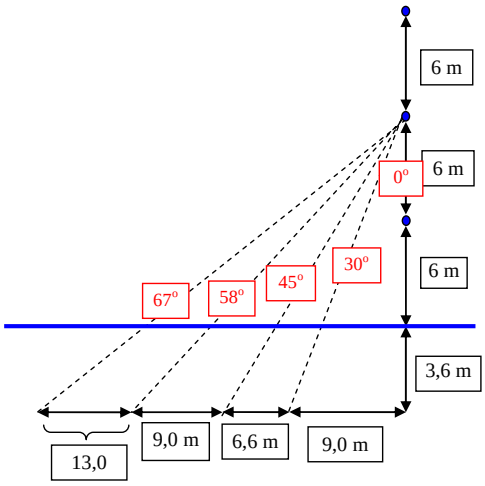


Fig. 14. Different angles of incidence for the loudspeaker noise.

5.3. TRAFFIC NOISE MEASUREMENTS 2004

The sound level difference between the reference microphone on the traffic side and microphones on the receiver side (residential areas) **without** mounted screen top has, as an average, been measured to **21.2 dB(A)**. The difference in sound level, between the reference microphone on the traffic side and receiver microphones **with** mounted screen top has, as an average, been measured to **23.1 dB(A)**.

The Insertion Loss for the non-diffracting absorbing screen top mounted on a section of 60 metres length can thus be established to ≈ **2 (1.9) dB(A)**, as an average, for all three receiver microphones (6 m, 12 m and 18 m from screen).

As the section with the attached screen top element was only 60 metres, the measured and calculated insertion loss for traffic noise is only about 2 (1.9) dB(A) about half of that measured with loudspeaker. This has been found to be due to leakage from the sections outside the test section not supplied with screen top element. Further comments could be found in section 6.

Figure 14 shows the Insertion Loss for the screen top for the 1/3 octave bands 160-3150 Hz. The shape of the spectrum for the Insertion Loss shows that the highest reduction of the sound pressure levels is achieved for the 1/3 octave bands 1000 Hz to 2000 Hz.

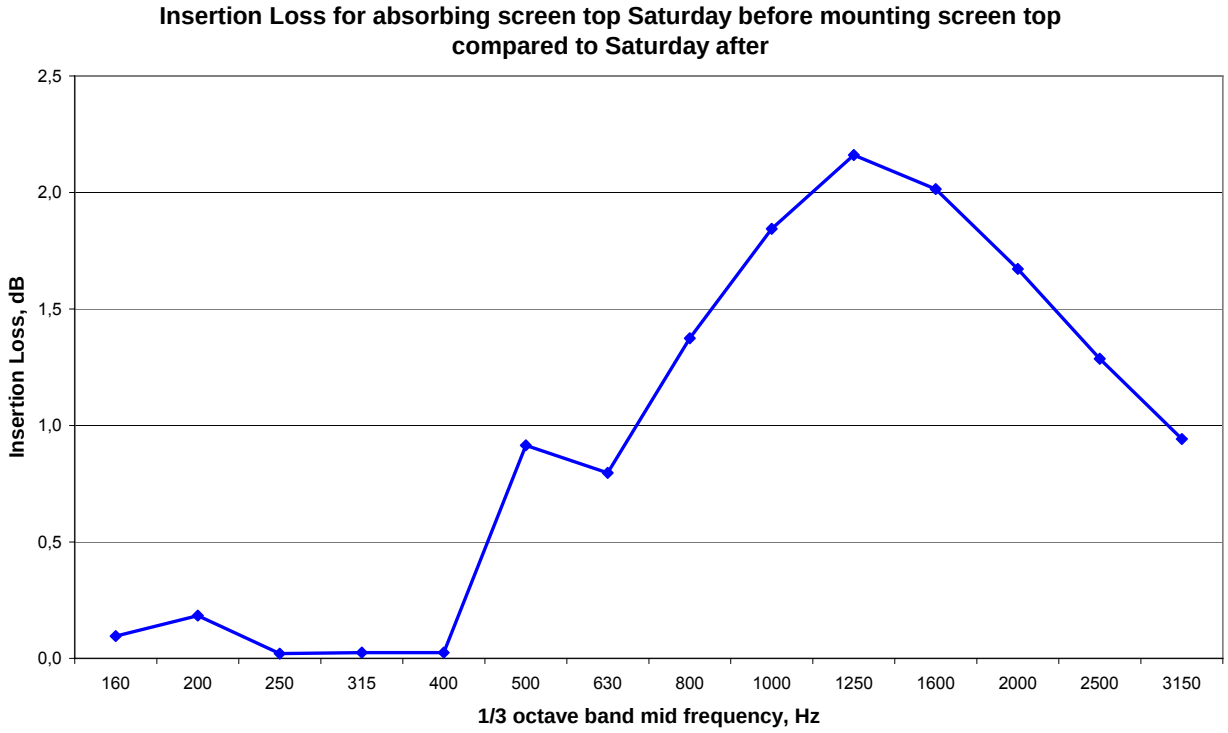


Fig. 14. Measured Insertion Loss of a 60 m long screen section equipped with sound reducing screen top element with actual traffic noise as source.

5.4. WEATHER CONDITIONS

Registered temperatures and wind speeds during the performed measurements are presented in Table 2 below.

Measurement	Date	Temperature Degree	Wind speed m/s
Logging of traffic noise, without screen top element	20/8 – 23/8 2004	20 C^0 during the days	0-5
Loudspeaker, without screen top element	28/8-2004	14 – 16 C^0	0-5
Loudspeaker, with screen top element	2/9-2004	14 – 16 C^0	0-5
Logging of traffic noise, without screen top element	3/9 – 7/9 2004	20 C^0 during the day	0-5
Loudspeaker, with screen top element	31/10-2005	8 C^0	3-5
Loudspeaker, without screen top element	9/11-2005	8 C^0	3-5 in average and peak wind speeds of about 7-8 m/s for short time periods

Table 2. Summary of the weather conditiopns during the performed measurements in 2004 and 2005.

5.5. CALCULATIONS USING CADNAA®

5.5.1 60 m sound reducing screen top element - Insertion Loss for loudspeaker noise

The CadnaA® calculations showed that the sound reducing screen top element is equivalent to increasing the screen height from 3.2 to 5.0 metres. A CadnaA® calculation of the Insertion Loss for loudspeaker noise is presented in table 3.

Calculated Insertion Loss, loudspeaker noise	
Measurement position	**Insertion Loss**
Pos 1. 6 m from screen	3.7
Pos 2. 12 m from screen	4.2
Pos 3. 18 m from screen	3.9
Mean value	**3.9**

Table 3. Table showing the results from **CadnaA®** regarding the calculated Insertion Loss for a screen hight of 5 m using a point source resembling the measurements with loudspeaker noise as source.

5.5.2 Insertion Loss for traffic noise

The calculated Insertion Loss for traffic noise, for a screen of 60 metres, is ≈2 (2.2) dB(A) and is presented in table 4. A CadnaA® calculation has also been performed to see what Insertion Loss would be at hand if the whole screen installation would have been equipped with the sound reducing screen top element. Calculation using line source resembling traffic noise as source and a prolonged section with screen top element, reveal that on an average Insertion Loss of 5.4 dB(A) will be achieved.

Sound reducing screen top element. Insertion Loss for traffic noise a) along 60 metres of the test track b) along the whole road section		
Receiving position	**a)**	**b)**
Pos 1. 6 m from screen	2.5	4.8
Pos 2. 12 m from screen	2.3	5.5
Pos 3. 18 m from screen	1.7	6.0
Mean value	**2.2**	**5.4**

Table 4. Table sumarising the results from **CadnaA®** regarding the Insertion Loss of the screen top element using normal traffic noise as source.

The master spectrum (sources spectrum, traffic noise), which has been used for the calculations, is shown in Figure 15. The digital 3D model is shown in Figure 16.

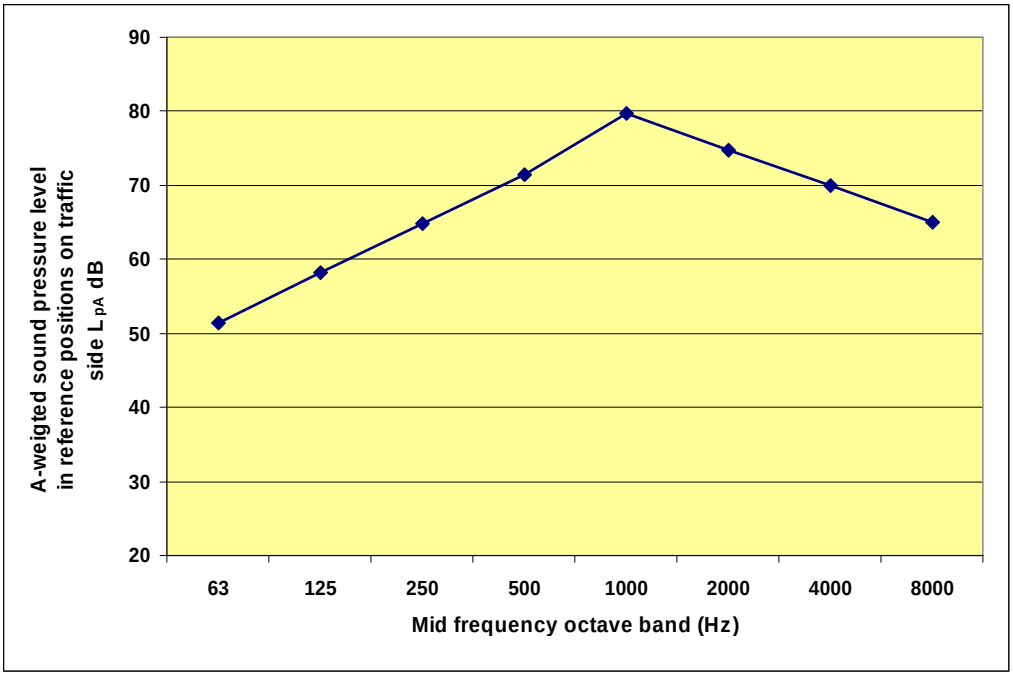


Fig. 15. Used master spectrum on the traffic side by calculation of the Insertion Loss of the sound reducing screen top for equivalent sound level L_{Aeq} [dB(A)]. By determination of the Insertion Loss of the screen top, the origin has always been the actual shape of the spectrum in each receiver position before mounting the screen top.

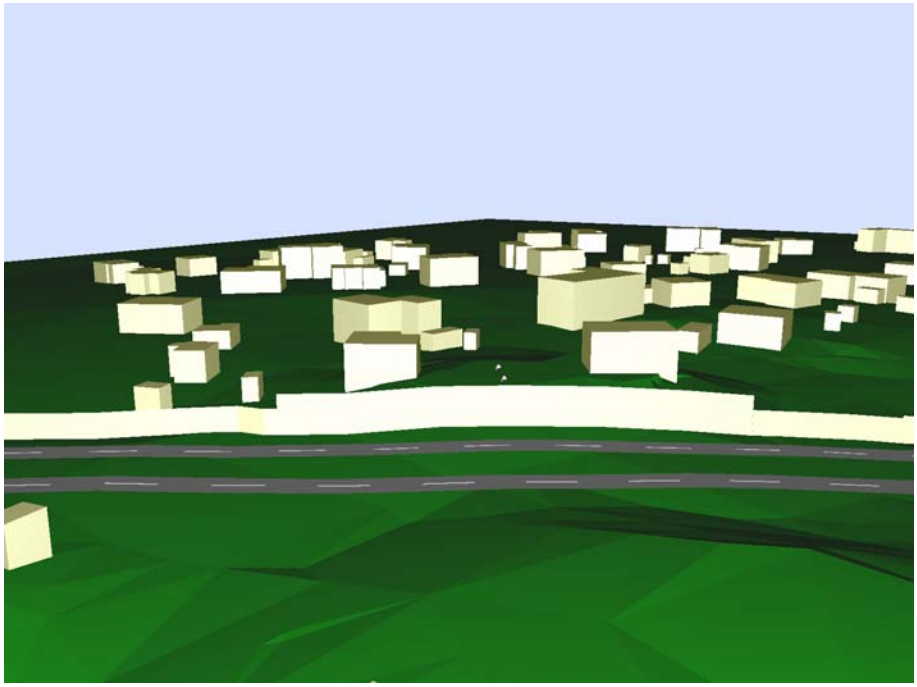


Fig. 16. Digital 3D model of the test section of E18 at Lahäll. The part of the screen which has an increased height of 1.8 metres, simulates the increased insertion loss of the screen (given by the sound absorbing screen top element).

6. DISCUSSION AND CONCLUDING REMARKS

The screen top element results in an increased insertion loss of the screen, which is equivalent to increasing the screen height from 3.2 to 5.0 metres. An alternative formulation could be that the insertion loss of the screen is increased by ≈ 4 dB(A). The new height of the screen has been determined by comparison of calculations in CadnaA®. With results from field measurements of insertion loss

After being installed one year, no negative long-term effect of the screen top element (the insertion loss is the same as at the time of mounting) has been found.

The screen top elements have not shown any pronounce influence from different angle of incident on the insertion loss. This may in effect be an advantage from calculation point of view since the same formulas can be used for all angles of incident.

By loudspeaker measurement, the transmission path is perpendicular to the screen (in Figure 17 marked with a solid blue arrow). For actual traffic noise expressed as equivalent sound level (L_{Aeq} [dB(A)]), the source is a line source which contributes along the whole length of the screen. In this latter case, the screen attenuation is unfavourable for small angles of incidence outside the section with screen top elements (marked with a dashed red line). This causes leakage effects coming from outside the test section equipped with the screen top elements. Thus the Insertion Loss measured for the screen top elements will be masked by contributions from the untreated part of the screen.

The Figure 17 below an attempt has been made to explain why the balance between propagation attenuation and screen attenuation results in a maximum contribution from a certain angle of incidence.

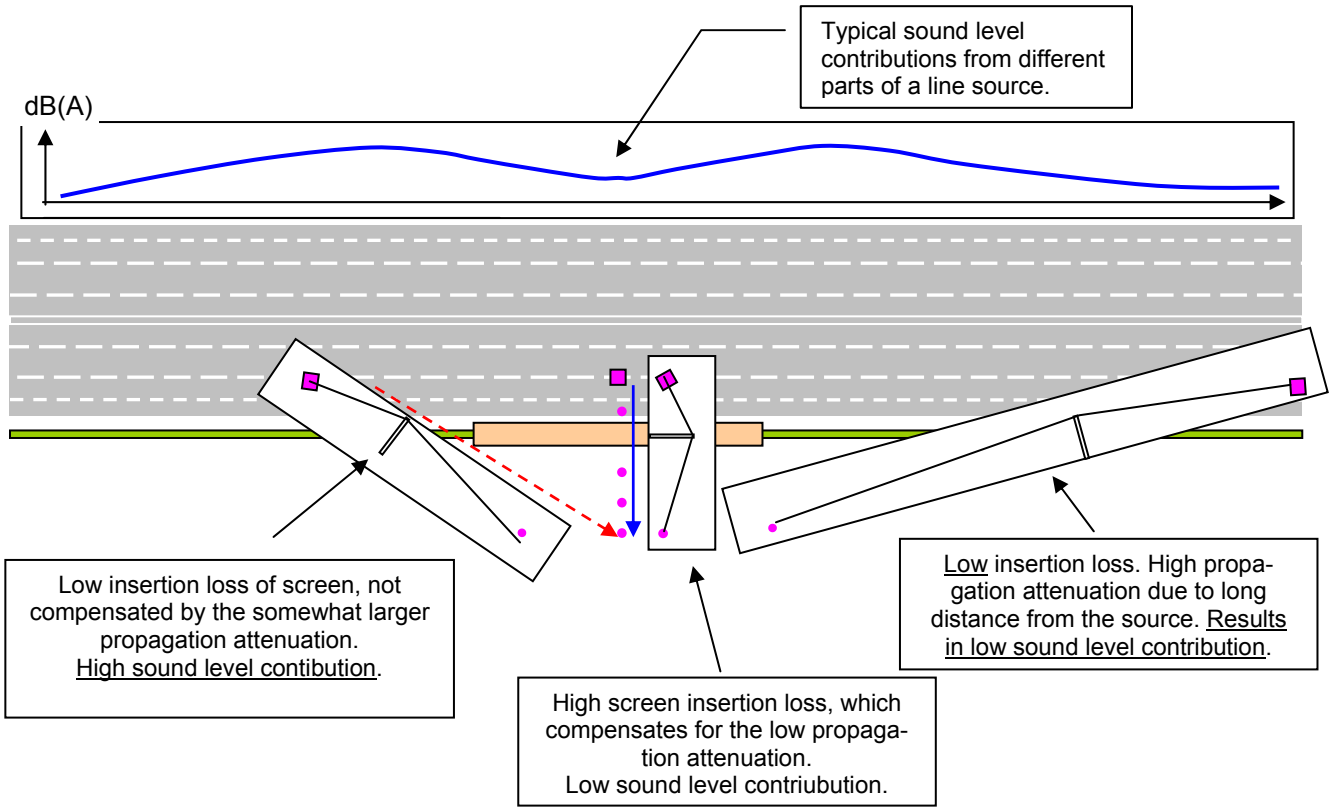
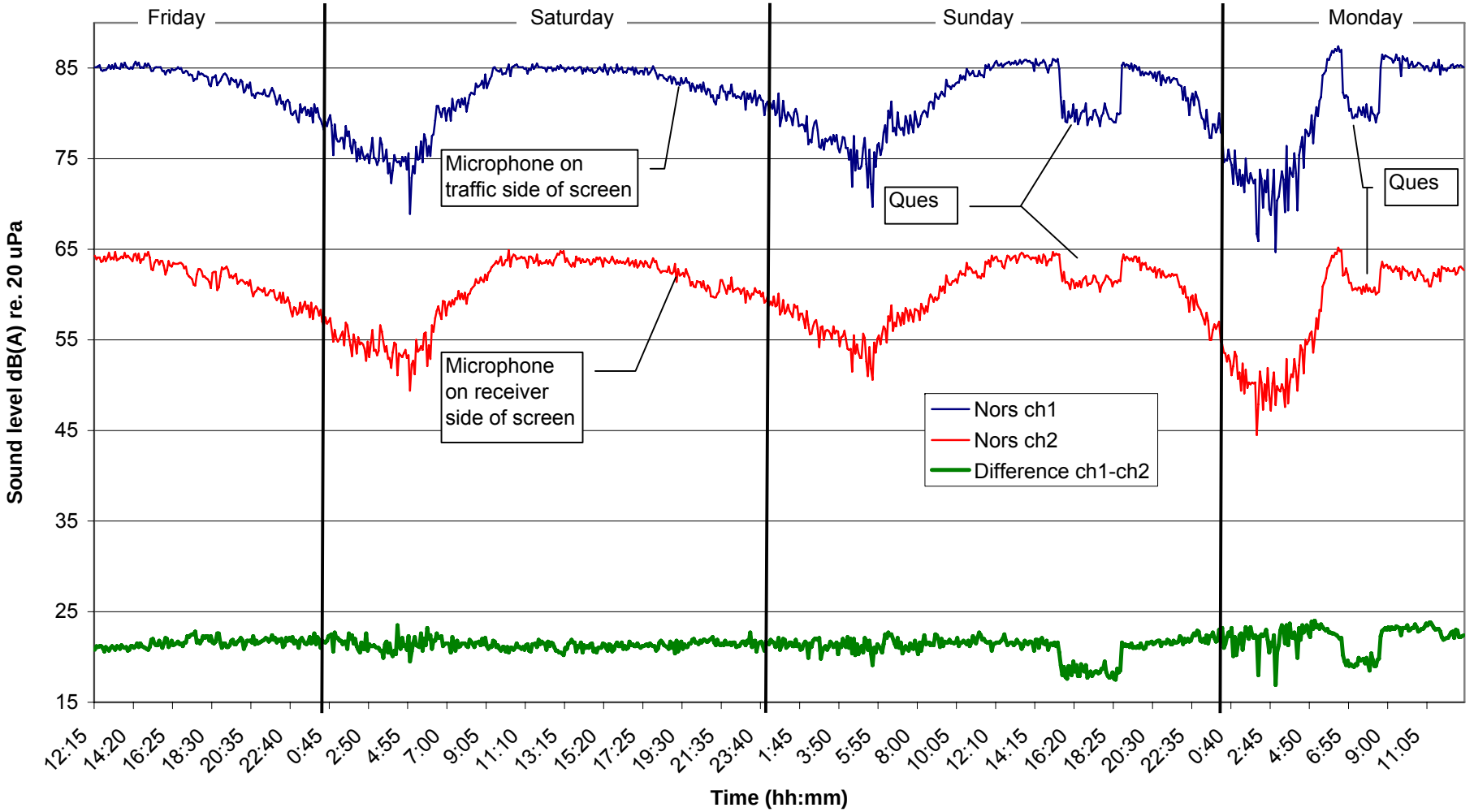
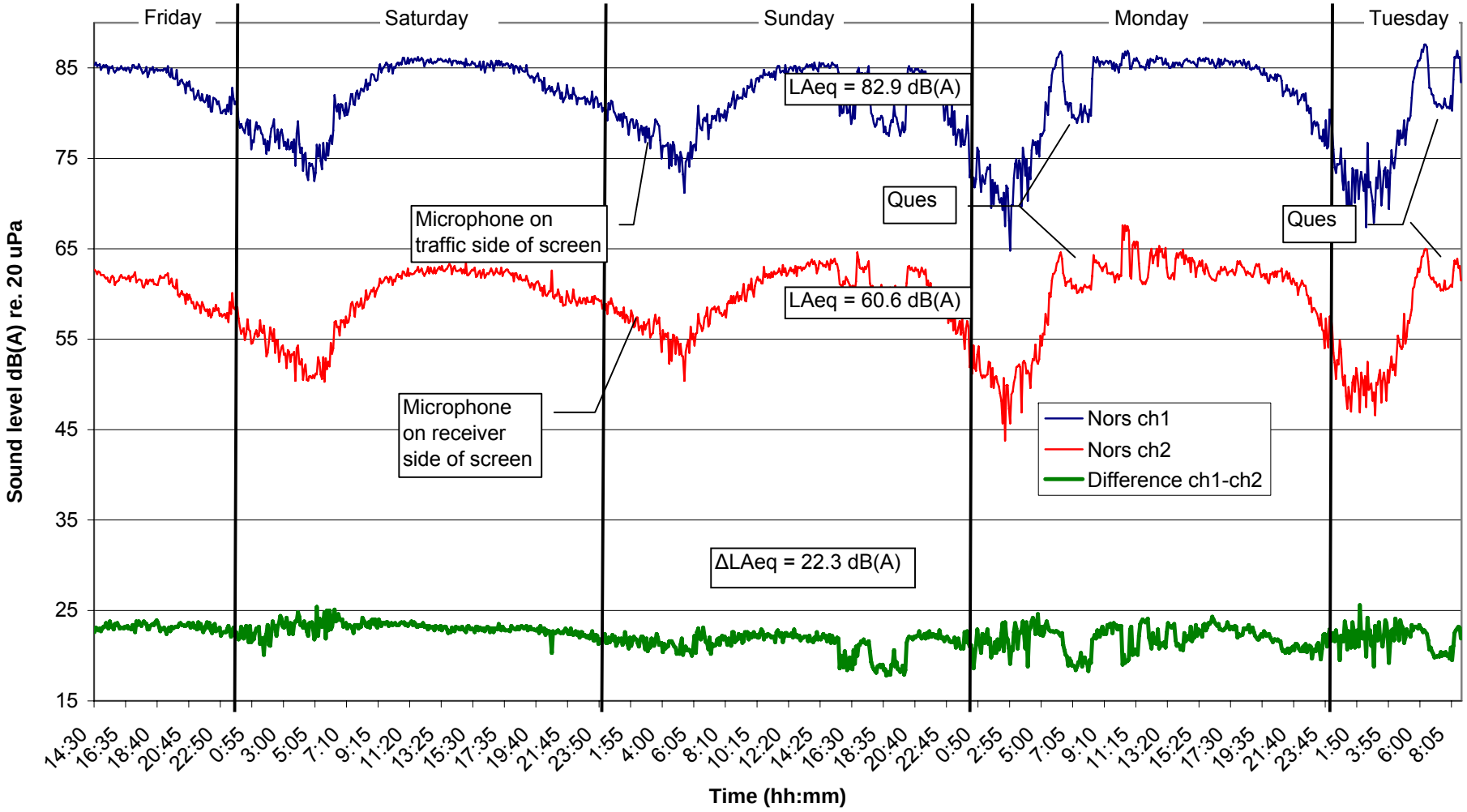


Fig. 17. Graphical explanation of how the maximum sound level for a point source will not occur at the perpendicular angle of incident but instead for an angle where the combination of low screen attenuation and low propagation attenuation will result in a maximum sound level contribution.

Appendix 1 Logged sound levels without screen top August 20th - August 23rd 2004



Appendix 2. Logged sound levels with screen top September 3rd - 7th 2004