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	Field studies of the poroelastic road surface
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EXECUTIVE SUMMARY

A recipe for a poroelastic[1] road surface has been developed partly through modelling and simulations in the FEM Software "Comsol Multiphysics" and partly by laboratory studies (including measurements of dynamic stiffness, sound absorption as well as various strength, durability and stability tests etc.). A method was also developed for impregnating the crumb rubber grains, used in the poroelastic road surface, with bitumen in order that the grains would be saturated with bitumen to prevent the rubber to soak up the binder that keeps the mix together. A test section 80 m long at Tagenevägen in Gothenburg was paved with the poroelastic road surface according to the developed recipe. Measurements with the aim to characterise the noise benefits from the poroelastic road surface, were performed on October 4, 2006.

External tyre/road noise from the poroelastic road surface, further developed and refined within the QCITY project, has been compared to standard road surfaces worn to various degrees. Comparisons, between the poroelastic road surface and standard reference road surfaces, reported here has been made to SMA11 and SMA16. SMA11 is an Asphalt Bitumen surface with maximum stone size 11 mm and with a high content of the bigger stones in the aggregate mix. SMA16 is the same type of surface but with 16 mm maximum stone size.

Both the Close Proximity (tyre/road noise is measured with aid of on-board carried microphones) and the Drive-by-method (the test vehicle is passing by a road side microphone 7.5 m from the centre of the vehicle track) has been performed to measure the sound reducing effect of the poroelastic road surface compared to conventional standard road surfaces.

Measurement results reveal a reduction in the external tyre/road noise for the poroelastic road surface of **6 dB(A)-units** (5.6-5.9 dB(A)) **compared to the SMA11** (see Fig A below) and **7.5 dB(A)-units** (7.3-7.6 dB(A)) **compared to the SMA16**.

By further increasing the void content from the current 15 % up to >20% it is expected that the noise reduction would increase to 7-9 dB(A) units relative to a newly paved SMA11 and 10-11 dB(A) units relative to an SMA16.

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[1] A Poroelastic road surface is a road surface that display the characteristics **sound absorption** (by communicating pores in the road surface) ***and*** **high elasticity** (by adding rubber granulate to the asphalt mix)

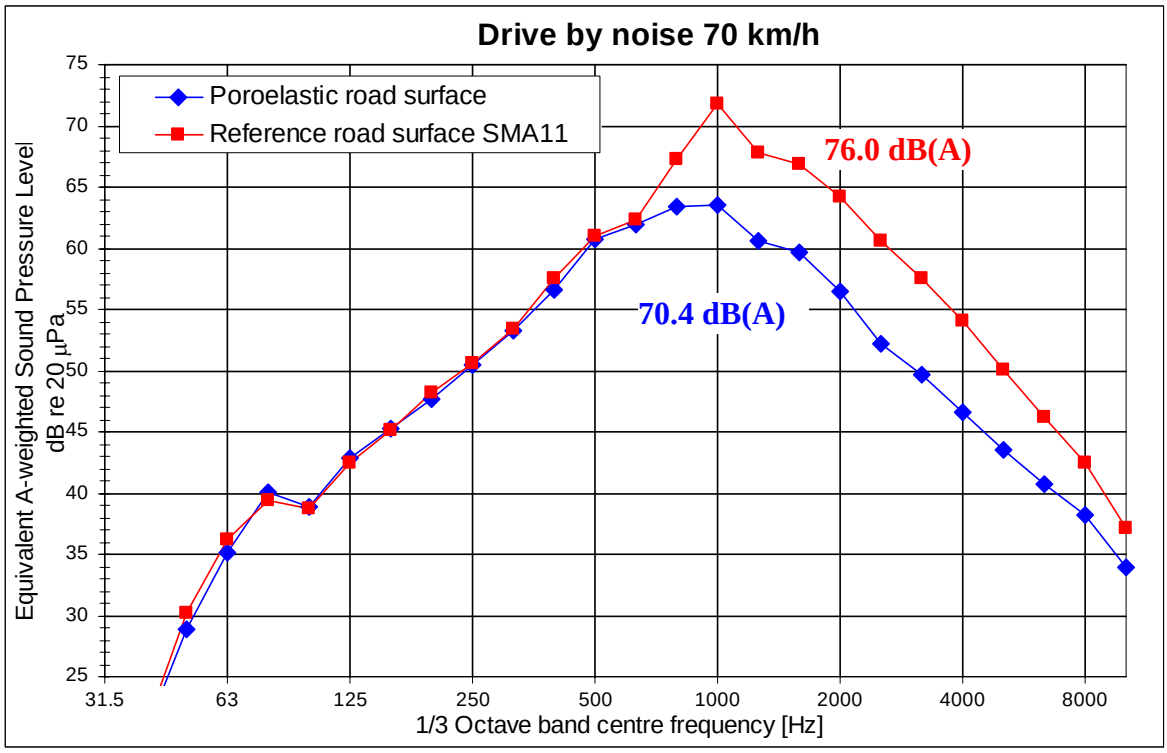

Fig A. Example of the reduction found for the reduction of a poroelastic road surface as compared to the new SMA11 (Asphalt Bituemen Stone max. size 11 mm. The reduction is presented as A-weighted sound pressure levels in third octave bands. Note the distinct reduction at higher frequencies from 800 Hz. The reduction as A-weighted broad band level L_{pA} in dB(A) is **6 dB(A) units**.

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1 OBJECTIVES AND SCOPE OF WORK

The objective of Work Package WP3.5 has been to develop a quiet road surface based on the poroelastic asphalt surface technique. A Poroelastic road surface is a road surface that display the characteristics **sound absorption** (by communicating pores in the road surface) ***and*** **high elasticity** (by adding rubber granulate to the asphalt mix)

A recipe for a poroelastic road surface has been developed through modelling and simulations in the FEM Software "Comsol Multiphysics" combined with laboratory studies (including measurements of dynamic stiffness, sound absorption as well as various strength, durability and stability tests etc.). The FEM-calculations resulted in certain conclusion of the rubber grain size and the elasticity and strength of the bitumen binder.

A method was also developed for impregnating the crumb rubber grains, used in the poroelastic road surface, with bitumen in order that the grains would be saturated with bitumen to prevent the rubber to soak up the binder keeping the mix together. A test section 80 m long at Tagenevägen in Gothenburg was paved with the poroelastic road surface according to the developed recipe. Measurements with the aim to characterise the noise benefits from the poroelastic road surface, were performed on October 26, 2006.

External tyre/road noise from the poroelastic road surface, further developed and refined within the QCITY project, has been compared to standard road surfaces worn to various degrees. Comparisons, between the poroelastic road surface and standard reference road surfaces, reported here has been made to SMA11 and SMA16. SMA11 is an Asphalt Bitumen surface with maximum stone size 11 mm and with a high content of the bigger stones in the aggregate mix. SMA16 is the type of surface but with 16 mm maximum stone size.

2 TEST SITE

The studied poroelastic road surface was applied on an approximately 80 m long road section of the Tagenevägen in Gothenburg, see Figure 1.

Figure 1. Photo showing the 80 m long test section, paved with the new type of poroelastic road surface.

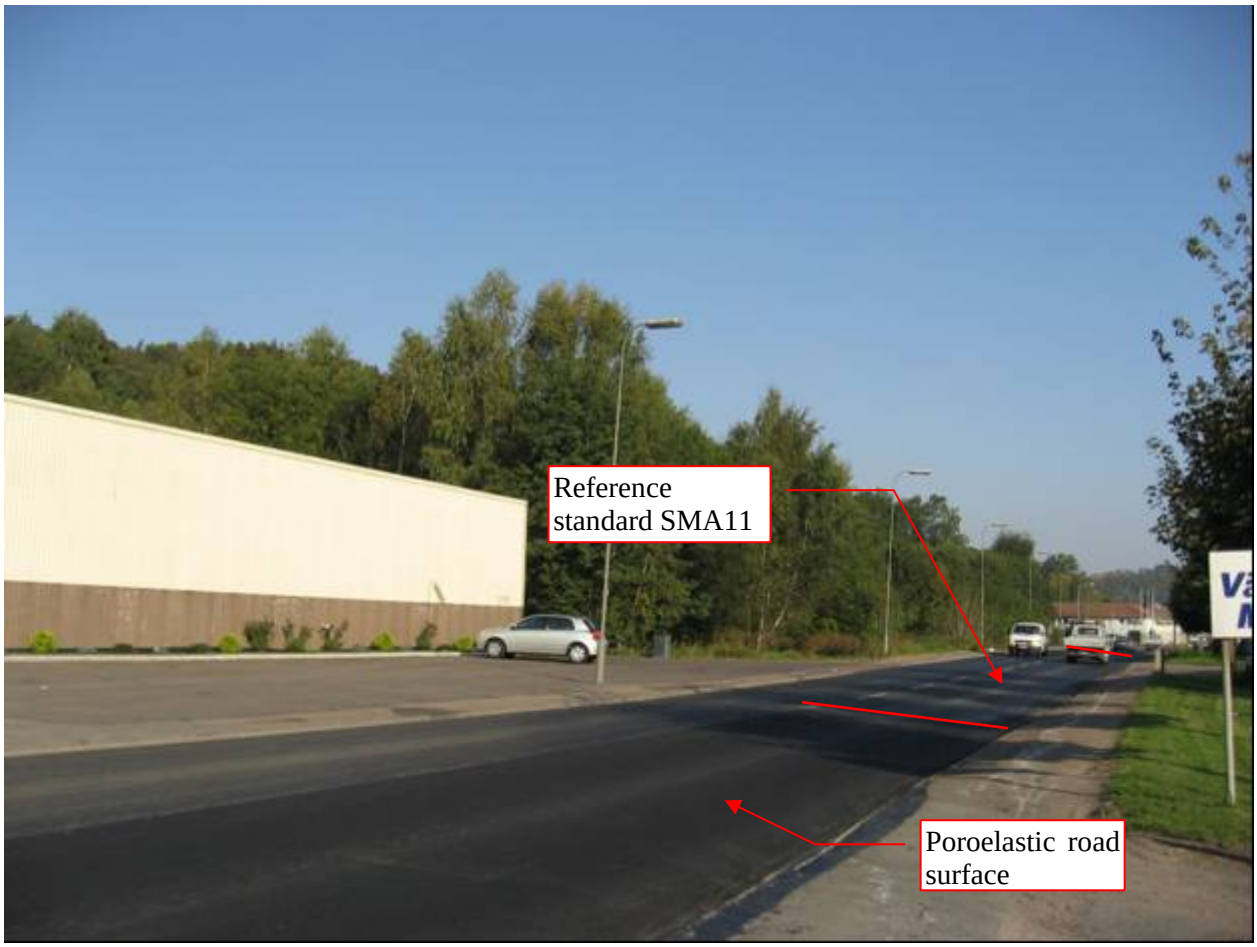

Figure 2. The end of the section with poroelastic road surface and the thereafter following standard SMA11 road surface used as reference at the test site.

3 TEST VEHICLE AND TEST TYRES

3.1 TEST VEHICLE

The test vehicle has been a Volvo V70 Bifuel manufactured in 2003. This car is representative for medium sized passenger car.

3.2 TEST TYRES

The test tires has been Goodyear Hydragrip, see Figure 3. The test tyre type and dimensions are **195/65R15** i.e. 195 mm wide; the height of the side rubber is 65 % of the width (127 mm). The rim diameter is 15". The total diameter of the tyre is 635 mm. The test tyre has been chosen in cooperation with the Acoustics Department at Goodyear in Luxembourg. The selected tyre Hydragrip 195/65R15 is representing an average tyre with respect to noise emission out of a typical modern tyre population.

Figure 3. Test vehicle Volvo V70 Bifuel used for both the Drive-by and CPX-tests. The test vehicle was supplied with test tyres of type Goodyear Hydragrip of type 195/65R15.

4 WEATHER CONDITIONS

Meteorological data was continuously logged during the measurement period with aid of a VAISALA monitoring system for wind speed, wind direction, temperature and humidity. The wind speed and wind direction was measured with aid of a new sensor technology based on ultra-sound. In Figure 4 below is the weather monitoring system shown.

Figure 4. The VAISALA weather transmitter. The sensor uses ultrasound to measure wind speed and wind direction.

The temperatures and wind speeds logged during the measurement period are presented in Figure 5 and Figure 6 below.

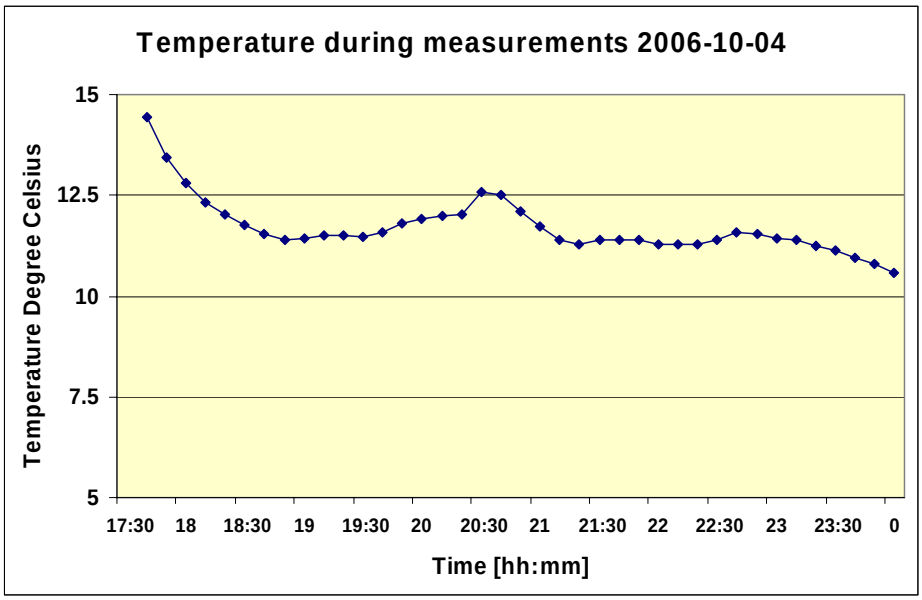

Figure 5. Logged temperatures in Degree Celsius during the measurements.

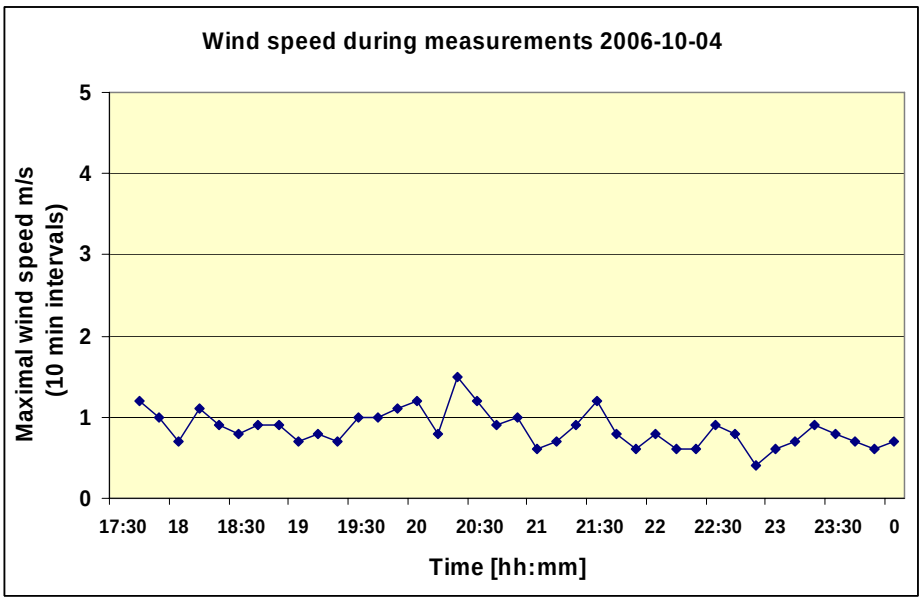

Figure 6. Logged maximum wind speeds in m/s during the measurement period.

5 MEASUREMENTS

Along with the measurements of the new poroelastic road surface at Gothenburg/Tagenevägen there were also measurements performed on a reference road surface of type SMA11. This reference surface was situated just adjacent to the poroelastic road surface.

The tyre/road noise has been measured with two different techniques, the Drive-by method and the Close-Proximity method.

In addition to the Drive-by and CPX tests of the studied road surface some stationary tests were also performed. The aim of these tests was to characterize the poroelastic road surface in relation to the standard road surface with respect to parameters influencing the tyre/road noise. Parameters that have been included in these measurements are

- The dynamic stiffness measured with aid of a special impedance head enabling the force transducer and accelerometer to be mounted in line.
- Sound absorption measured both as sound absorption in an impedance tube for perpendicular incidence and as measurements of sound propagation at the test site.
- the tyre horn amplification in different directions using the tyre mock-ups and reciprocity techniques

Table 1. Used equipment

Equipment	**Brand**	**Type**
12-channel signal analysis system	Brüel & Kjaer	Portable PULSE
Microphones	Brüel & Kjaer	4189 A21
Microphone wind shields	Brüel & Kjaer	
Sound level calibrator	Norsonic	
GPS speed and position logging system	Race Technology	DL1
Weather monitoring system	Vaisala	

5.1 TYRE/ROAD NOISE MEASURED WITH AID OF THE DRIVE-BY METHOD

The tyre/road noise has, to applicable extent, been measured according to the *Drive-by method* described in the standard ISO 7188:1994. The Drive-by method means that a test vehicle is driven along a measurement section of 20 m at constant speed and with

the engine on driving at an appropriate gear. The microphones were placed at a distance of 7.5 m from the middle of the test vehicle's driving path and 1.2 m above ground. The microphones were fitted with wind shields[2]. Figure 7 shows a sketch of the measurement set-up for measurements along the road track supplied with two microphones, one for each test section. Two road surfaces along the test road track have been tested. The poroelastic road surface is located just prior to the reference standard road surface of type SMA11[3]. The speed has been monitored during the whole measurement procedure with aid of a GPS-system that stores the speed and position together with a time code on a flash memory. The uncertainty of the speed measurement is ±0.2 km/h. Data is sampled every 10 milliseconds.

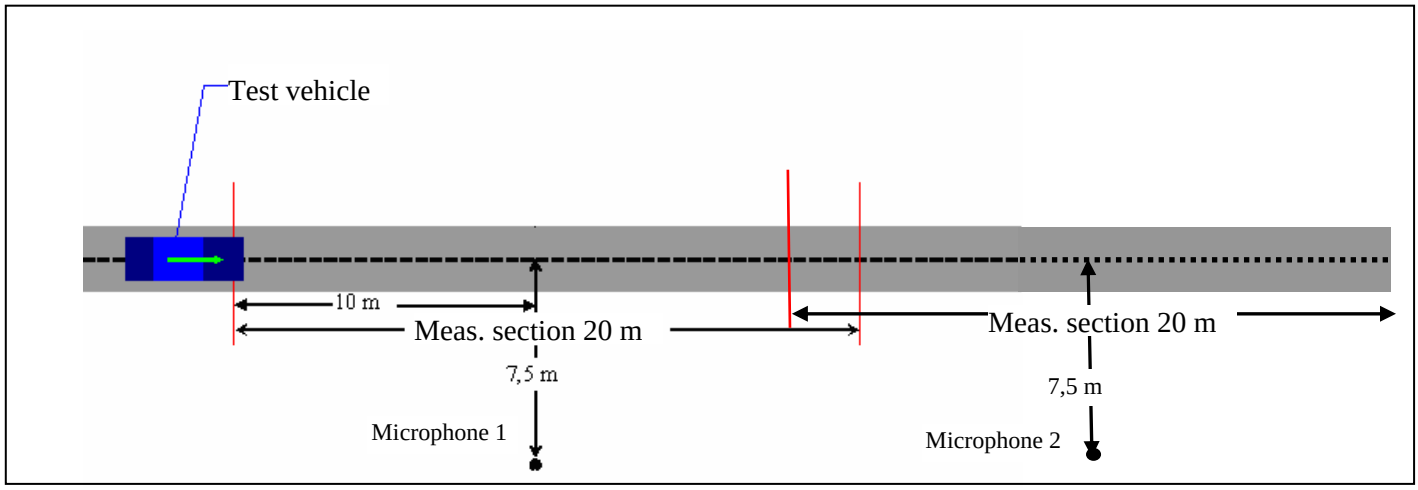

Figure 7. Sketch of the measurement set-up showing microphone positions etc. for measurements of tyre/road noise according to the Drive-by method (ISO 7188:1994).

5.2 TYRE/ROAD NOISE MEASURED WITH CLOSE-PROXIMITY METHOD (CPX)

The tyre/road noise has also been measured according to the Close Proximity-method (CPX-method) parallel to the Drive-by method. The CPX-method means that the test vehicle is supplied with microphones close to the tyre/road interface (see Figure 8). The result is presented as the average of the sound pressure level measured by the two microphones. The measurement section of the road shall be minimum 20 m. The vehicle speed shall be as constant as possible during the measurements. The test vehicle has been driven with aid of the cruise control to achieve as close as possible to constant

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2 The wind velocity during the measurements was less then 5 m/s, which is the requirement according to ISO 7188. The used wind shields are well equipped to reduce wind induced noise for these low wind speeds.

3 SMA11 means Asphalt Bitumen with Stone maximum size 11 mm. In SMA11 there is an excess amount of the bigger stones in the aggregate mix.

velocity. The speed has also been monitored with aid of a GPS-system that logs the speed, every 10 milliseconds with a measurement uncertainty of ±0.2 km/h. The measurement set-up and testing methodology is, to applicable extent, performed according to the draft proposal to a new standard, ISO CD 11819-2.

Figure 8. Microphone position in front of and behind the test tyre. The microphone positions that have been chosen to minimize the self induced wind noise (especially in the low to mid frequency range) and achieve maximum stability in the microphone mounting.

5.3 DYNAMIC STIFFNESS OF THE ROAD SURFACE

The dynamic stiffness of a structure is the ratio of the force divided by the responding vibration displacement (integrated vibration velocity or acceleration integrated twice), when the test object is excited with a force from e.g. a hammer impact. The dynamic stiffness has been analysed as a function of frequency (in the continuation called Frequency Response Function, FRF). Normally it is distinguished between point and transfer FRF. Point FRF is obtained when the force and response is measured in the same position. Transfer FRF is obtained when the response is measured at a greater[4] distance from the force excitation. The mechanisms involved with the sound generation at the tire/road are mostly local and occur close to the leading and trailing edge of the contact area. Therefore these measurements have been focused only on the point FRFs

[4] "great" should here be interpreted as "great" in relation to the wavelength of the studied frequency or frequency region

in order to as closely as possible measure parameters relevant for the excitation process.

The measurements have been performed with aid of a technique utilizing the impedance head concept. The impedance head for measurement of the Dynamic Stiffness of road surfaces was developed by ACL and was first presented at the ICSV conference in 2003 (see ref [1]). The impedance head concept was developed to measure the point FRF on elastic road surfaces thereby as closely as possible resembling the excitation process when a tyre tread element hits the road surface. Figure 9 below shows the impedance head developed by ACL.

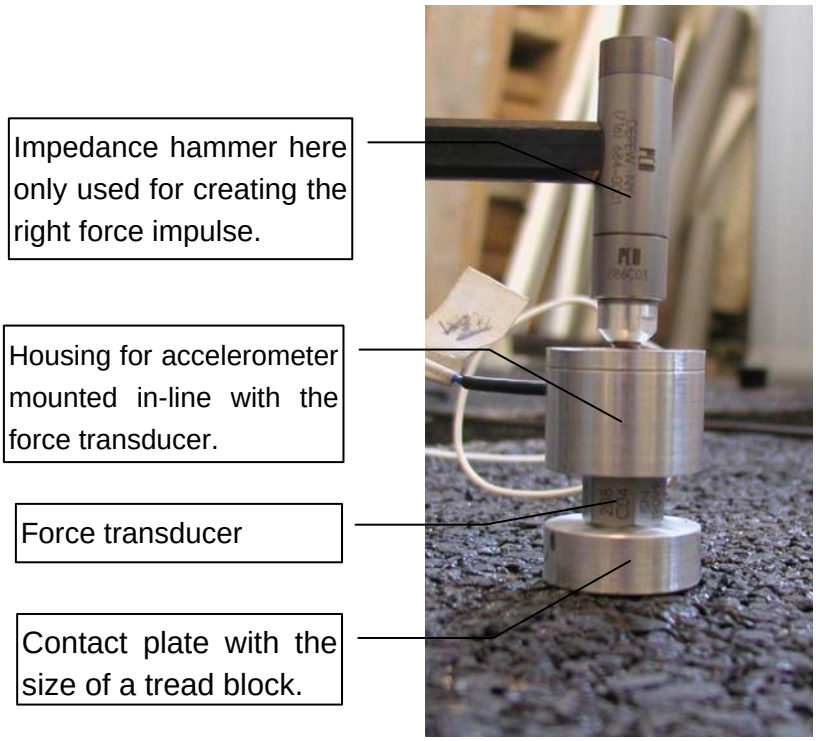


Figure 9 Impedance head for measurement of the dynamic stiffness of poroelastic road surfaces. The contact plate diameter is tuned to give relevant data for the dynamic process of a tire tread block in the contact patch.

The used measurement equipment is presented in Table 2 below.

Table 2 Used measurement equipment.

Equipment		**Type**	**Serial no.**
Multi Channel Signal Analyser System		Brüel&Kjaer PULSE 7 ch	2414019
Impedance head	Accelerometer	PCB 353B11	25541
	Force transducer	PCB 208C04	19099

In Figure 10 below one of the four measurement positions where the point Dynamic stiffness was measured on the poroelastic road surface at Tagenevägen in Gothenburg is shown.

Figure 10. Measurement of the Dynamic stiffness on the poroelastic road surface at Tagenevägen in Gothenburg.

5.4 SOUND PROPAGATION (SOUND ABSORPTION)

The sound absorption of the poroelastic road surface could be believed to give excess ground attenuation. The quantification of such excess ground attenuation due to the surface sound absorption relative the attenuation achieved for normal dense standard surface would give information of the effect directly in dB as a function of frequency. The sound propagation along the poroelastic road surface has therefore been measured. The measurement was carried out using an omni directional loudspeaker, positioned directly on the road surface. The sound pressure was measured at different positions from the loudspeaker according to Figure 11 below. The microphone positions were chosen along a line between the leading edge of the tyre (mock-up) and the receiver position at 7.5 m and 1.2 m above ground (resembling the sound propagation path when measuring drive-by noise with aid of a stationary roadside microphone), with an angle to the road surface of 9.1 degrees.

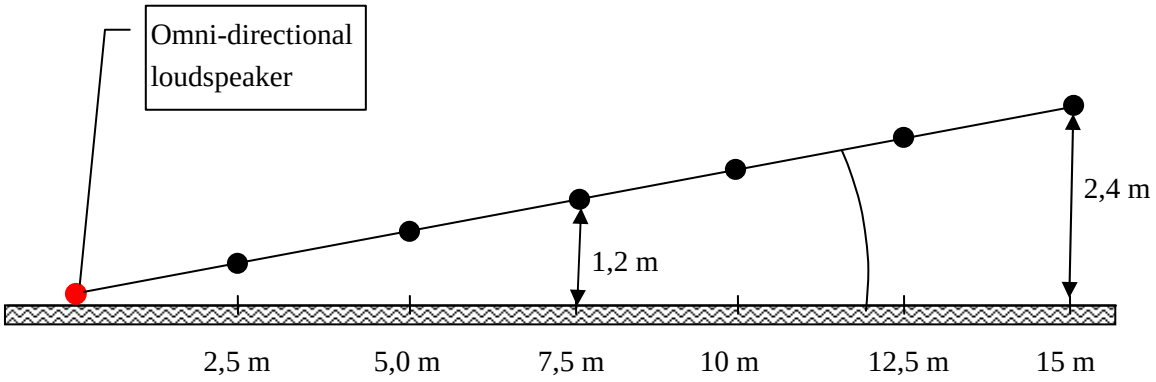


Figure 11. Path for microphone positions for sound propagation measurements.

5.5 DIRECTIVITY FOR THE TYRE/ROAD HORN EFFECT AMPLIFICATION ON DIFFERENT SURFACES

As reported in previous deliverables for the QCITY project, a sound absorbing road surface affects the tyre/road horn amplification properties. In order to investigate how the tyre/road horn is affected for different road surfaces a field study was performed. This field study utilized the reciprocity detachment method[5] using a 193 mm wide tyre mock-up. The measurement set-up is shown in Figure 12 below. A loudspeaker, omni-directional in the frequency range of 200-3150 Hz was located 2 m from the leading edge of the contact patch and 0.3 m above the road surface thereby using the same

[5] The reciprocity detachment method is a method where the transfer function is measured with the source at the receiver position and the microphone in the source position. The absolute value of the horn effect is determined by simply detaching the tyre mock-up still using the same microphone position while repeating the transfer function again. The difference between the FRFs will provide the horn amplification for the direction in which the measurements were performed.

angle to the road surface compared to drive-by noise tests. A small ¼"-microphone was located close to the leading edge of the contact patch.

Figure 12. Setup for measurement of the tyre/road horn amplification effects at different directions during the study of the poroelastic road surface. The reciprocal detachment method was used.

6 RESULTS

6.1 DRIVE-BY METHOD

Appendix 1 presents evaluated results for all the car passages as Drive-by noise spectra for the poroelastic road surface and the reference road surface, SMA11. Appendix 1 also presents the differences in Drive-by noise spectra between the poroelastic road surface and the reference SMA11 road surface. In Figure 13 below, the measured data points for the overall A-weighted Sound Level are presented for both the poroelastic and reference road surface. Least square curve fits are also shown for the two surfaces. It can be seen that the curve fit results in a straight line (as expected) when plotted as sound level vs. speed in logarithmic scale.

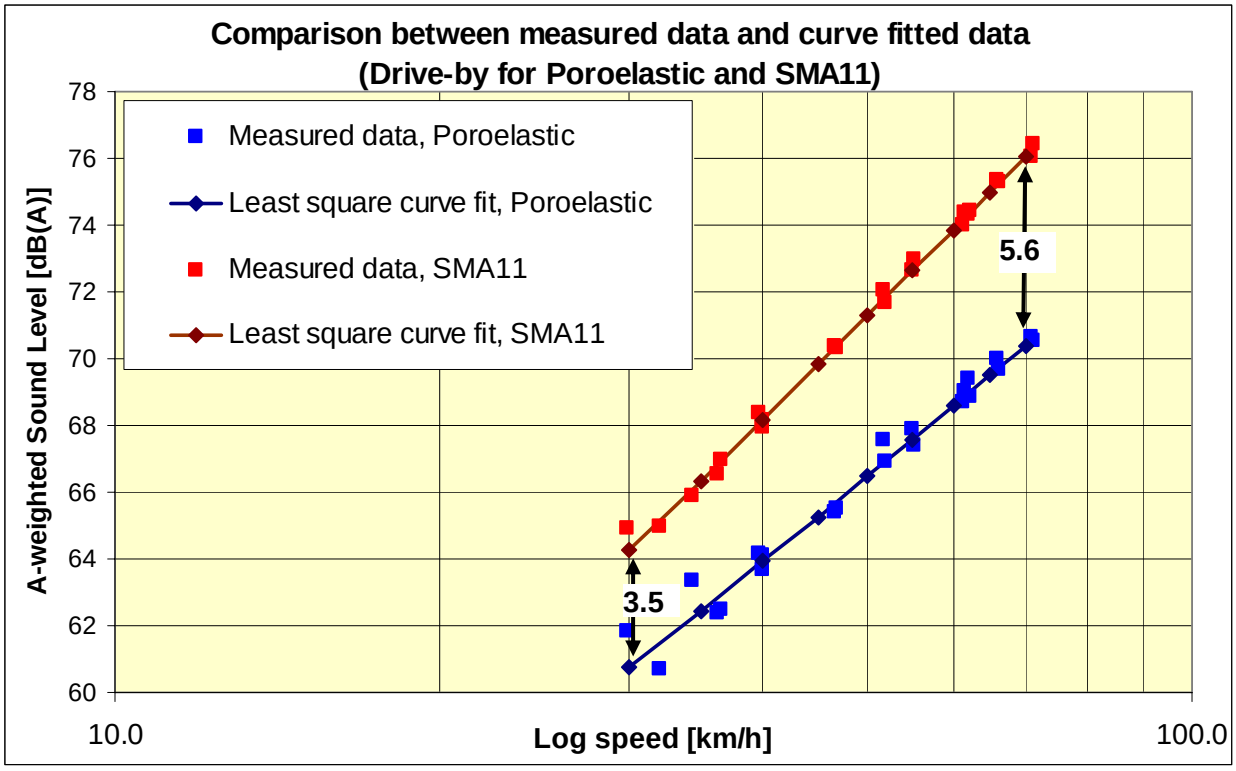


Figure 13. Measured external tyre/road noise here presented as broad band A-weighted sound pressure levels. Method: Drive-by according to ISO 7188:1994.
Note that all square symbols are actual data for sound level vs GPS-measured vehicle speed. **Note also** the small spread of measured data vs the least square curve fitting line, which provide a straight line in the sound level vs logarithmic speed diagram. The bigger difference between the poroelastic road surface and the SMA11 at higher speeds are probably due to less influence from drive-line background noise.

Note that the difference in A-weighted sound level is 6 dB(A) at 70 km/h, but only 3.5 dB(A) at 30 km/h. The difference in A-weighted Sound Level as a function of car speed is presented in Figure 14. The reduced effect of the poroelastic road surface for lower

speeds is due to masking of the tyre/road noise by engine noise. This conclusion is confirmed by the CPX-measurements presented in section 6.2.

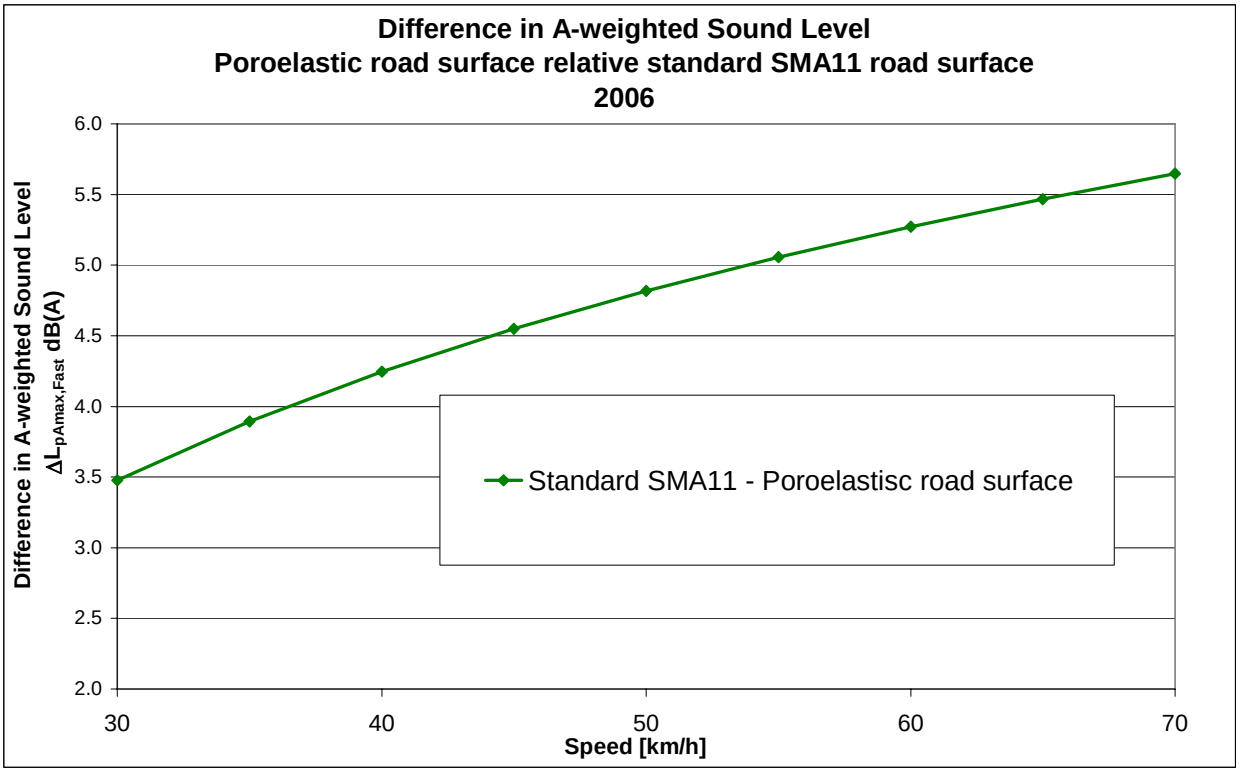


Figure 14. Difference in the broad band A-weighted Sound Level between the curve fitted data for the poroelastic road surface and the reference standard SMA11 road surface. Measurements was performed utlizing the Drive-by method according to the ISO 7188;1994.

Figure 15 presents the A-weighted Sound Pressure Level for the poroelastic road surface and the reference road surface SMA11 at a car speed of 70 km/h. It can be seen that the poroelastic road surface emits less noise for the higher frequencies compared to the reference SMA11 road surface. The sound reducing effect of the poroelastic road surface starts from the 1/3-octave band at 800 Hz and above.

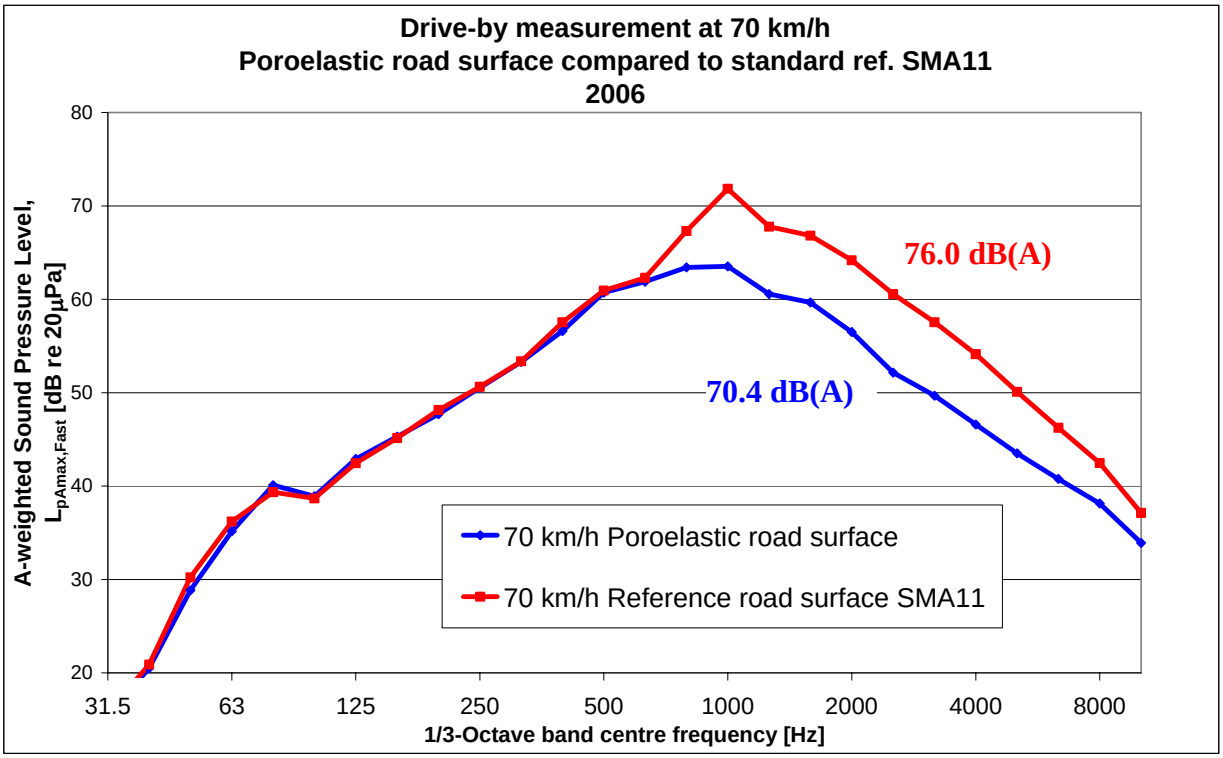


Figure 15. A-weighted Sound Pressure Level in third octave bands measured with aid of the Drive-by method (ISO7188:1994)for the poroelastic road surface and for the reference road surface SMA11. Speed 70 km/h.
Note that the difference in LpA is 6 dB(A) units and that the reduction occurs primarily from 800 Hz and upwards.

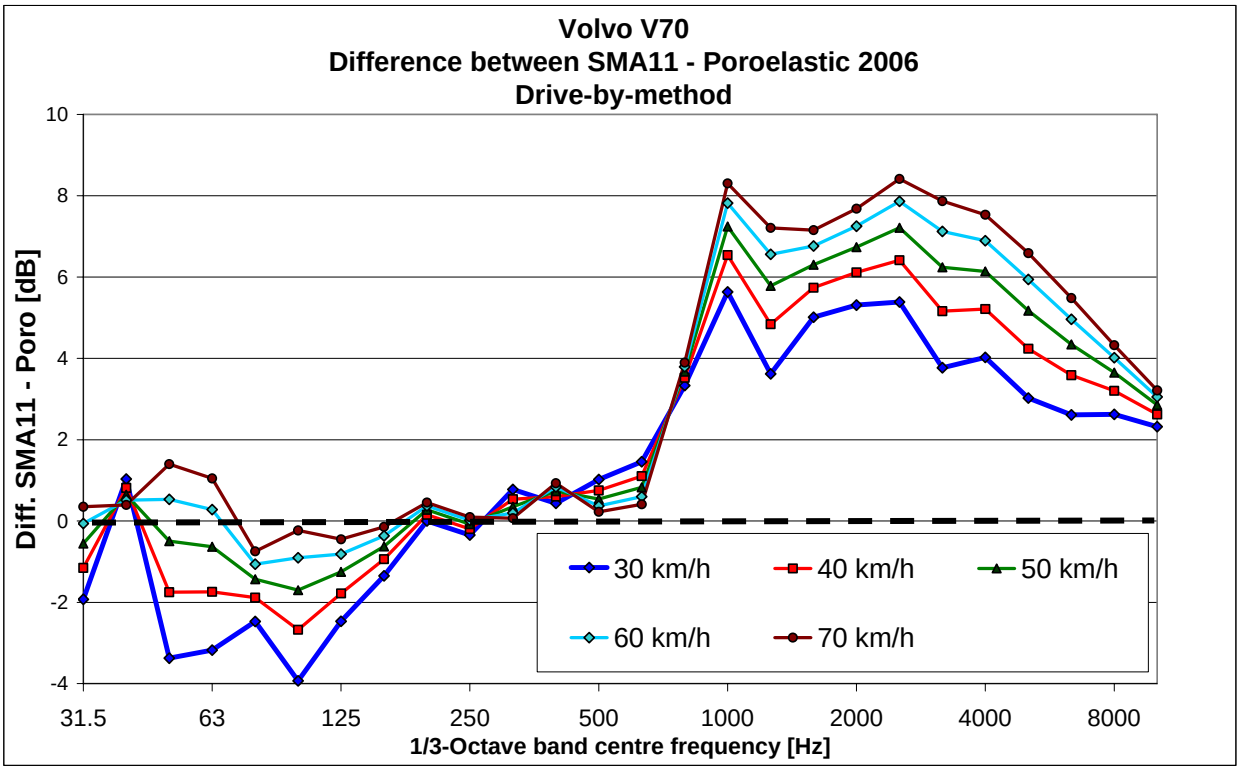


Figure 16. Difference in Drive-by Sound Pressure Level (ref. SMA11 – Poroelastic) for the different evaluated car speeds. Evaluation method: least square fit for each third octave band and presented values read from the fitted curve at the stated vehicle speed.

Notice that the difference is increased towards higher car speeds. This is believed to be due to the increasing dominance of tyre/road noise over the noise from the drive-line.

6.2 CLOSE-PROXIMITY METHOD (CPX)

All car passages on the poroelastic road surface and on the reference road surface (SMA11) are presented in Appendix 2., the velocity and level is registered every 0.125 ms. The undisturbed average sound pressure level during constant speed was evaluated for each car passage. Each 1/3-octave band is the presented as Sound Pressure Levels vs. velocity and a least square fit is performed to the data. The least square fit function then gives the sound pressure level at any given velocity. In Figure 17 below is presented the measured and evaluated data points (from the least square curve fit functions) as the broad band A-weighted Sound level vs. speed. Note that the least square fit gives a straight line when plotted as sound level vs. speed in logarithmic scale.

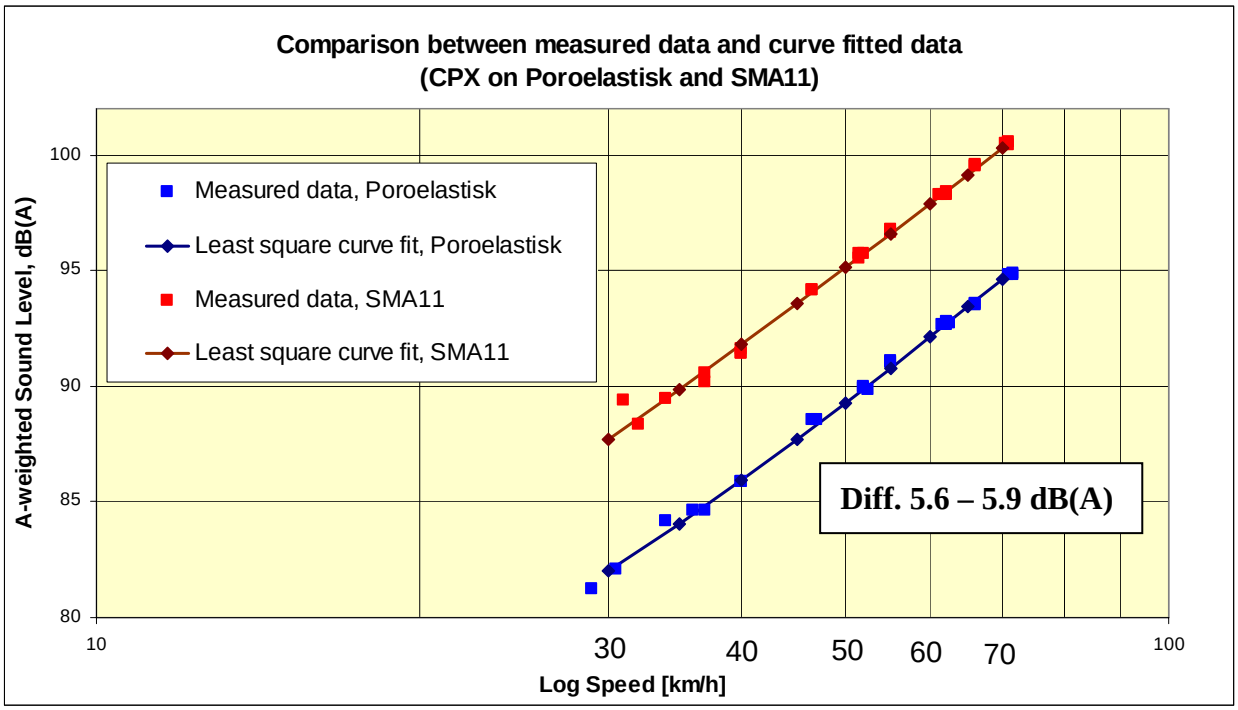


Figure 17. The CPX-measured and curve fitted A-weighted Sound Levels as a function of speed. The speed axis is presented in logarithmic scale.

It can be seen in Figure 17 that the measurement data points very well fit the least square curve fit and that it forms a straight line when the sound level is plotted as a function of speed in logarithmic scale. Therefore the measurement quality can be said to be good. Note that with the CPX-method the difference between the reference and poroelastic road surface is the same for low as for higher velocities. The difference between the poroelastic road surface and the reference road surface is presented in Figure 18.

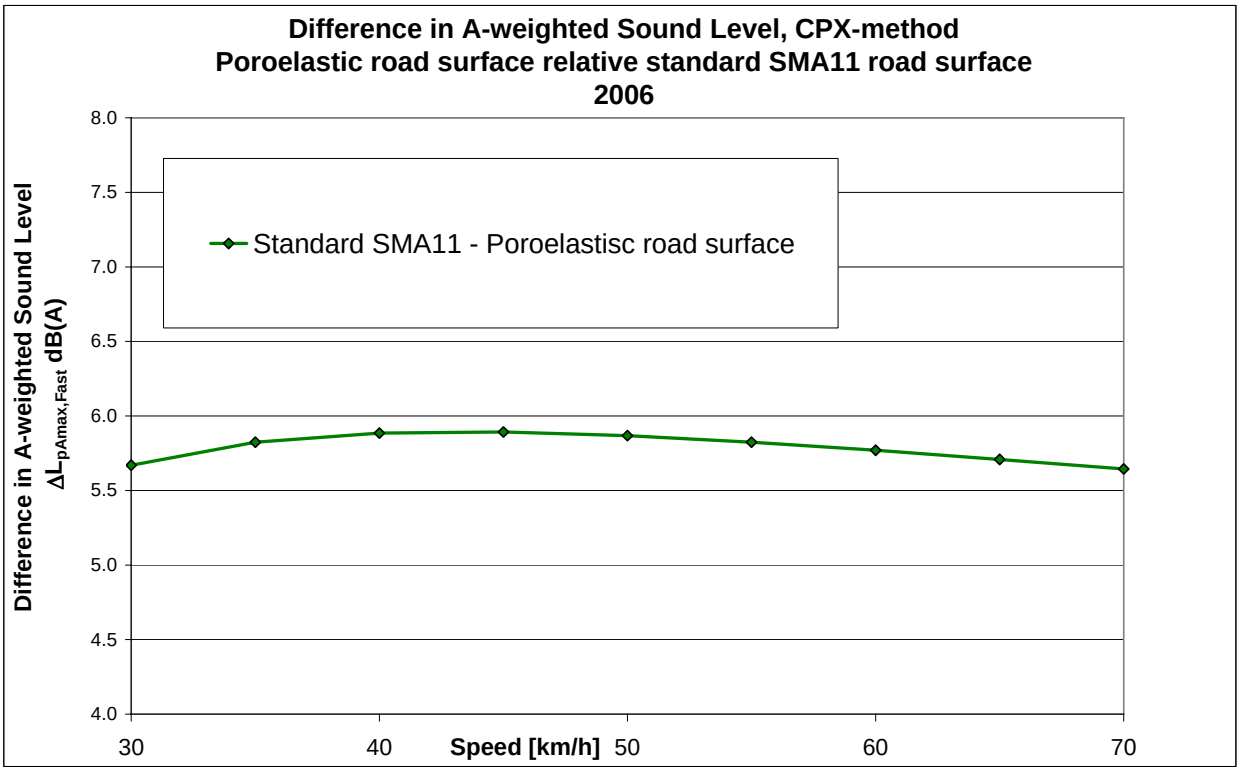


Figure 18. Difference in A-weighted Sound Level between the poroelastic road surface and the reference standard SMA11 road surface.
Note that the difference in sound level ΔLpA , as measured with aid of the CPX-method is almost constant throughout the speed range of 30 – 70 km/h.

From Figure 18 it can be seen that the poroelastic road surface has **5.6 to 5.9 dB(A)** less tyre/road noise compared to the reference road surface.

Below in Figure 19 the curve fitted (each 1/3-octave band separate) A-weighted Sound Pressure Level for the poroelastic road surface and the reference road surface evaluated at 70 km/h is presented. Figure 20 presents the difference between the two road surfaces for the speeds 30, 40, 50, 60 and 70 km/h. It can be seen that the poroelastic road surface is less noisy for frequencies higher than 500 Hz. For the lower frequencies there is no measurable difference between the two road surfaces. The frequency spectra evaluated at 30, 40, 50, 60 and 70 km/h are all presented in Appendix 2.

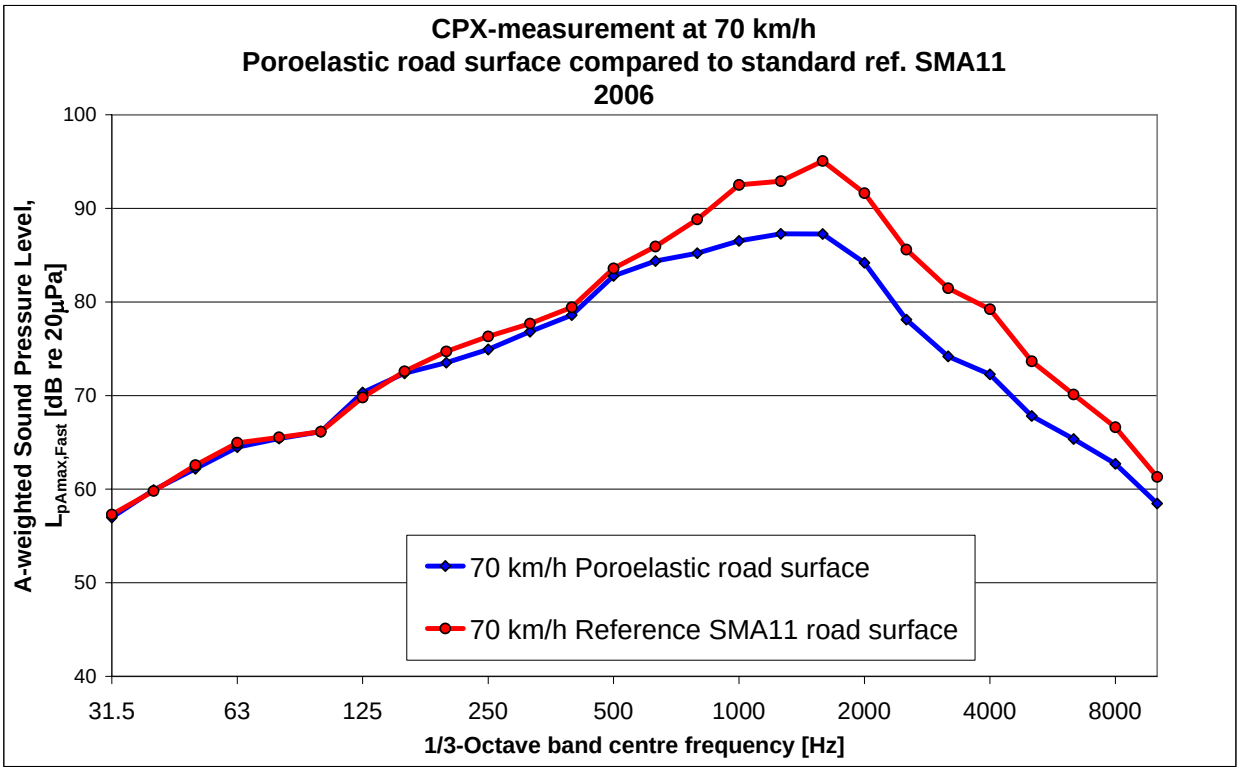


Figure 19. A-weighted Sound Pressure Level for the poroelastic road surface and the reference road surface SMA11 measured with the CPX-method at 70 km/h.

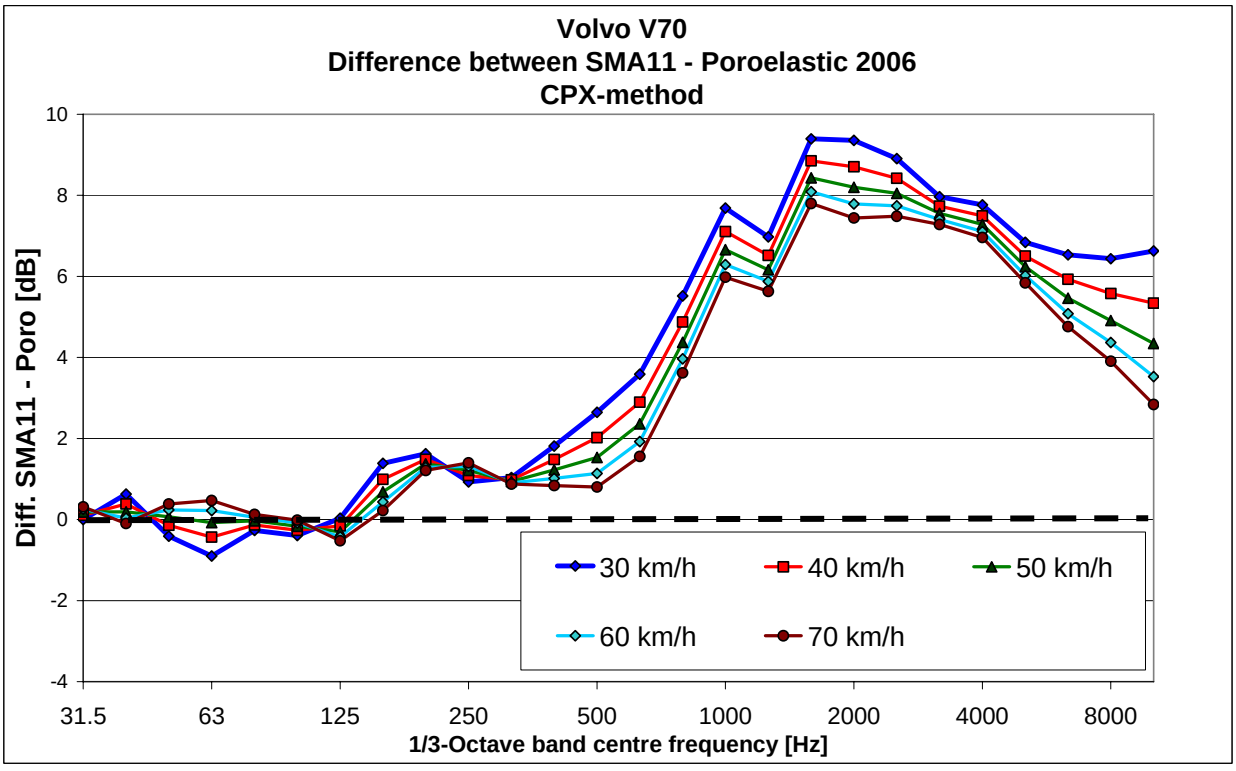


Figure 20. Difference in Sound Pressure Level (ref. SMA11 – Poroelastic) for the different evaluated velocities.

In connection to when measurements were carried out at Tagenevägen, measurements have also been carried out on other commonly used road surfaces in the Gothenburg area. The reference road surface at Tagenevägen is a newly installed road surface. Below in Figure 21 this newly installed reference road surface is compared to two normally worn road surfaces. Unfortunately the measurements were performed at different temperatures, but the reference at Tagenevägen is measured at both temperatures to show the temperature influence. Appendix 3 presents the CPX measurement results on the standard road surfaces for the speeds 50, 60 and 70 km/h.

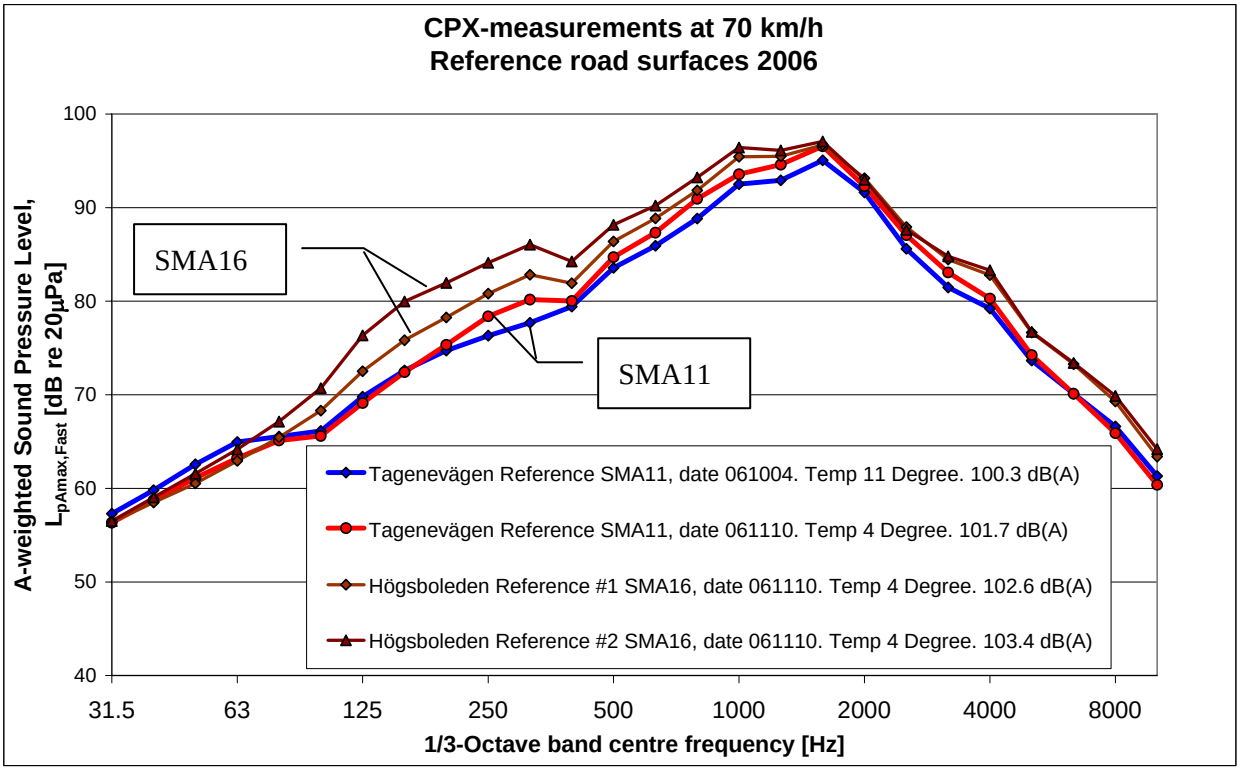


Figure 21. CPX-measurements on different standard road surfaces.

Notice the increased levels for lower frequencies on the road surfaces with lager stone size (i.e. rougher surface).

If the coarser road surface SMA16 is used to calculate the difference to the poroelastic road surface, the poroelastic road surface is found to be **7.3 – 7.6 dB(A)** quieter instead of 5.6 – 5.9 dB(A) quieter when compared to the newly installed reference SMA11 at Tagenevägen.

6.3 DYNAMIC STIFFNESS

Figure 22 presents the measured Dynamic Stiffness of the poroelastic road surface at Tagenevägen in Gothenburg compared to a reference road surface of the type

SMA11. It can be seen that the poroelastic road surface has approximately 10 dB lower Dynamic Stiffness (i.e. at least 3 times more flexible).

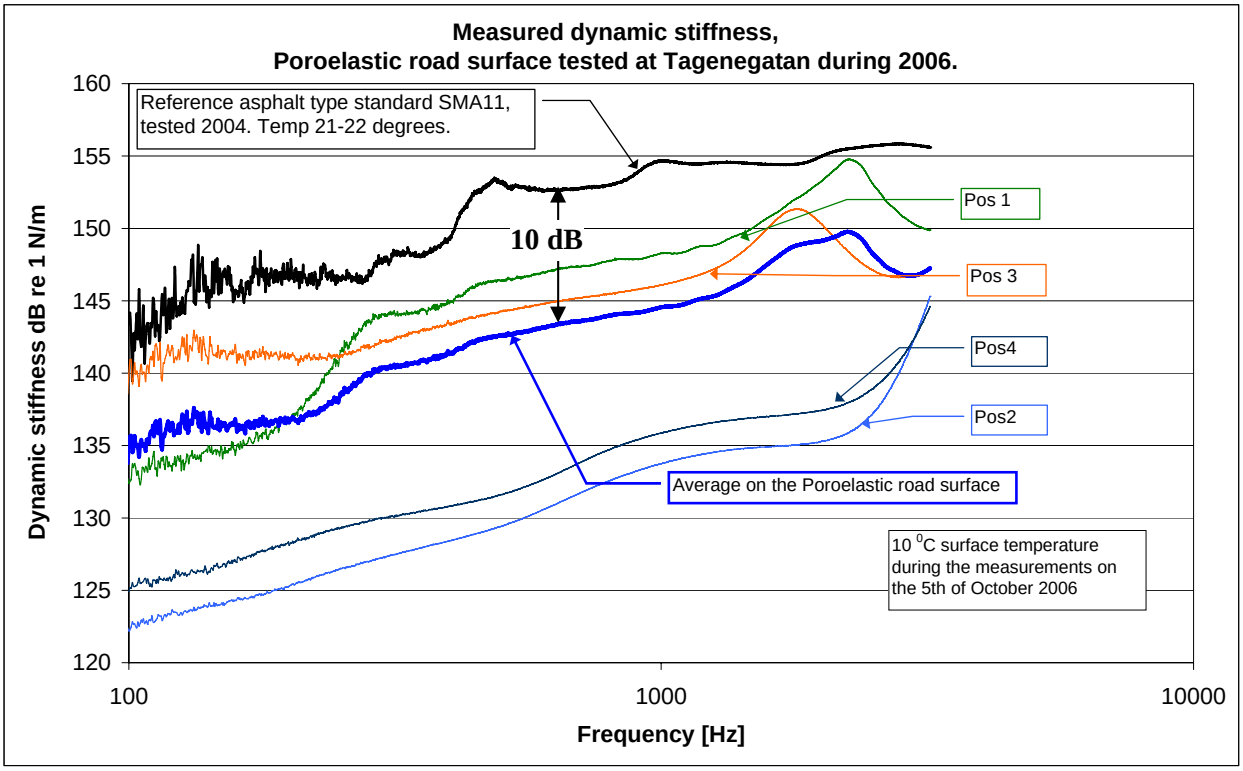


Figure 22. Measured Dynamic Stiffness on the poroelastic road surface laid at Tagenevägen in Gothenburg (**Blue** curve is the average) compared to a reference road surface of the type SMA11 (**Black** curve).
Note the great spread in impedance data for different spots of the surface.

6.4 SOUND ABSORPTION MEASURED IN AN IMPEDANCE TUBE.

6.4.1 Sound absorption of samples from laboratory manufactured test plates.

Sound absorption for perpendicular incidence of the sound field has first been determined for laboratory plates manufactured at NCC Road Lab in Upplands-Väsby/Stockholm. Test samples mounted in the socket fixture can be seen in Figure 23

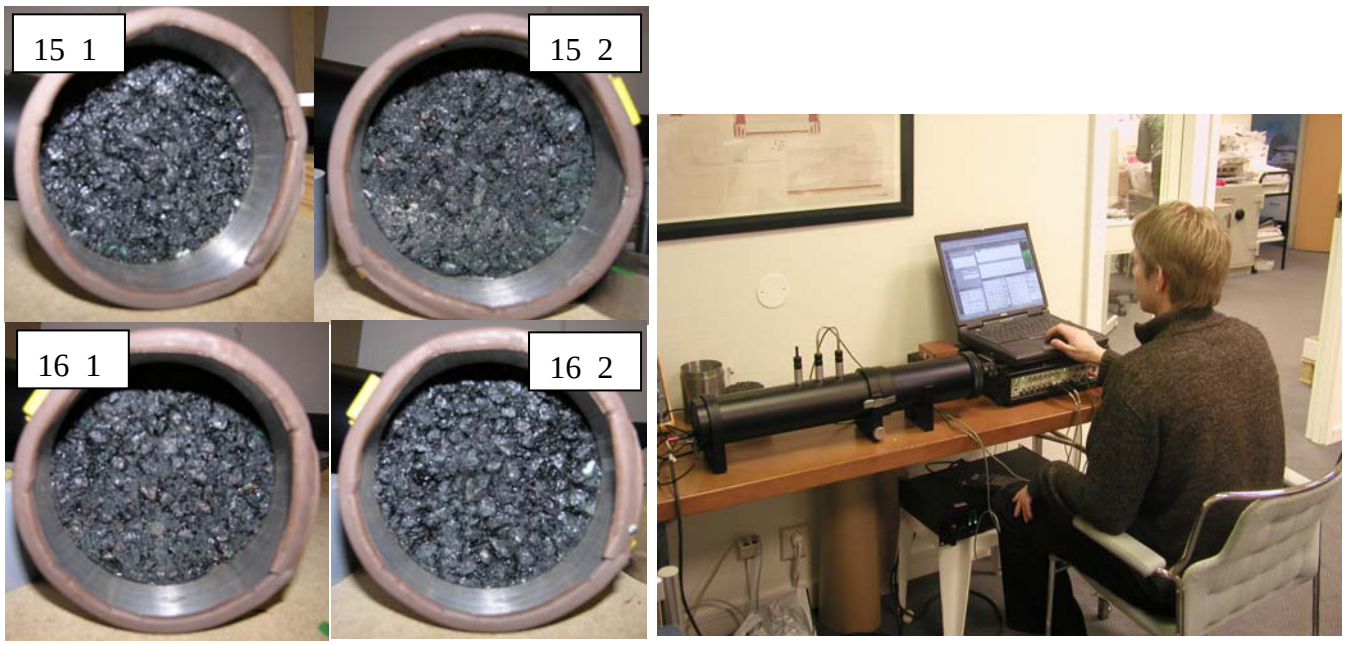


Figure 23. The test samples mounted in its socket fixture during measurements of sound absorption with aid of the impedance tube. The test samples were drilled out of laboratory manufactured test plates. To the right is also shown a measurement setup at ACL during the measurement with aid of the two channel impedance tube.

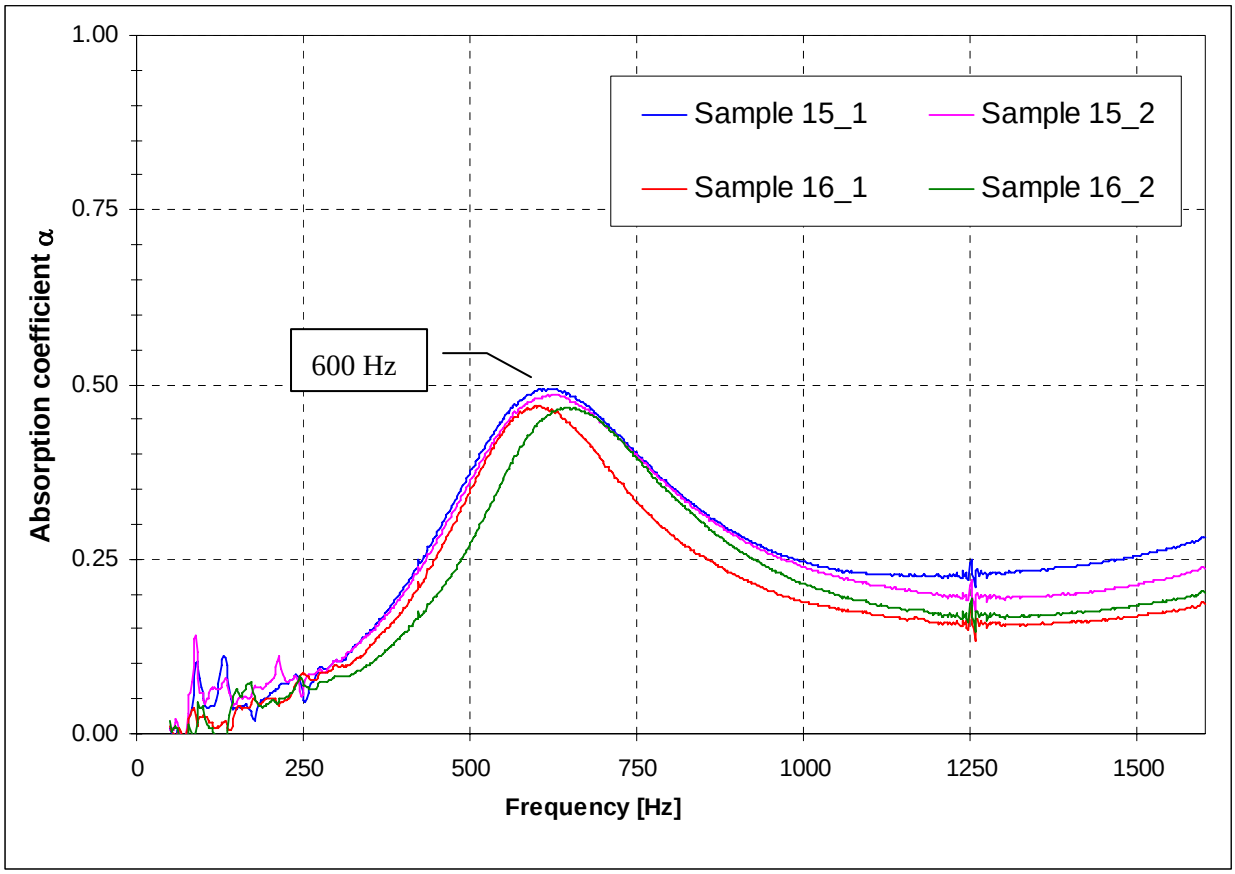


Figure 24. Sound absorption factors measured in the B&K impedance tube for the samples displayed in Figure 23.
Note the marked peak at about 600 Hz.
Note also the absorption factor that is increasing from about 1200 Hz and upwards.

6.4.2 Sound absorption of test samples drilled from the test road surface at Tagenevägen in Gothenburg.

The test road section at Tagenevägen was paved with poroelastic asphalt mix from the same recipe compared to the laboratory manufactured test plates for which sound absorption data are presented above. Figure 25 below presents the sound absorption data for samples drilled from the test surface at Tagenevägen.

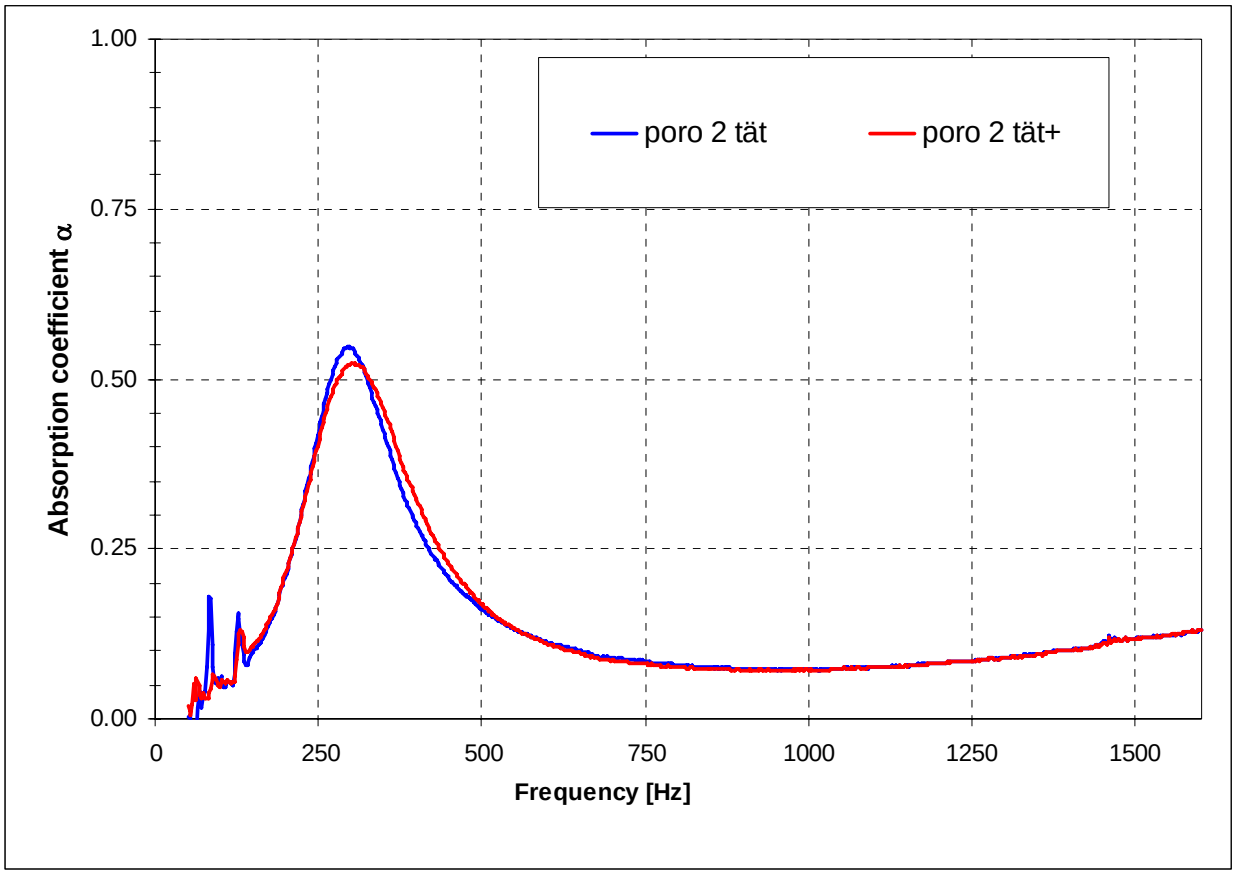


Figure 25. Sound absorption factor measured in the B&K impedance tube for the samples drilled out of the test road surface at Tagenevägen.
Note the low sound absorption at 1000 Hz (only 8 % compared to 20 % for samples from lab plates) and the low peak frequency (dropped from 600 Hz for samples from lab plates down to 300 Hz for the samples from Tagenevägen)

It can be seen that

1. The sound absorption coefficient at about 1 kHz is substantially lower compared to the data obtained from the laboratory plates. About 8 % was achieved at Tagenevägen compared to 18-25 % for the test plates.
2. The peak absorption due to the λ/4 resonator effect[6] is found to be substantially lower (≈ 300 Hz) compared to the peak absorption frequency obtained for the lab plates (≈ 600 Hz). The peak frequency was found to be about half the frequency for the lab plates.

---

6 The λ/4 resonator effect is typical for granular materials at lower frequencies. The unexpectedly low frequency for the peak shown in the diagram (sample is only 40 -45 mm thick) effect is partly due to that the wave speeds in the granular material are considerably lower compared to the wave speed in air. And it is partly due to that the open pores form a longer mean free path for the sound waves in the granular material.

6.5 DIRECTIVITY FOR THE TYRE/ROAD HORN AMPLIFICATION ON DIFFERENT SURFACES

The tyre/road horn amplification in different directions has been measured for the tyre mock-up located on both dense concrete as well as on the poroelastic road surface under test. In Figure 26 and Figure 28, the tyre/road horn directivities from the measurements are presented. Note that the horn amplification, for the poroelastic surface, at 1000 Hz is about 15 dB in the rolling direction of the tyre and only 4 dB at 90 degrees. All directivity measurements are performed using the detachment method.

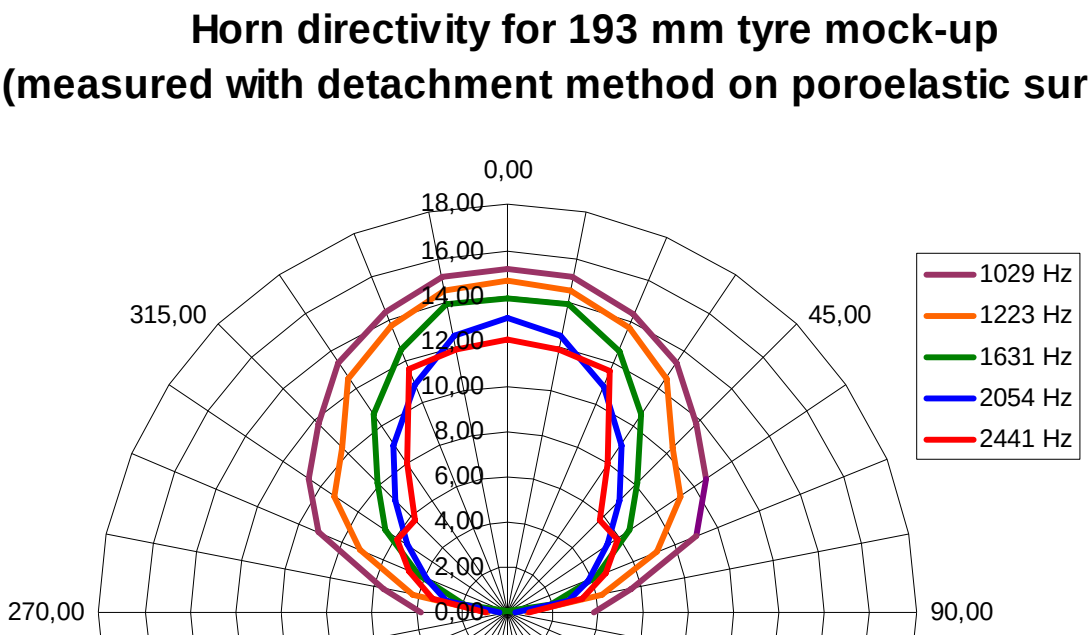


Figure 26. Tyre/road horn directivity measured on poroelastic road surface. Note that the amplification, in the rolling direction of the tyre, is 15 dB at 1000 Hz. At 90 degrees the amplification is only 4 dB.
The rather high tyre/road horn amplification in forward direction is assumed to be achieved due to the low sound absorption factor of the poroelastic road surface.

Below in Figure 27 the horn amplification is presented as a function of the frequency. Figure 27 presents the horn amplification vs. frequency for 9 different angles between 0 and 90 degree.

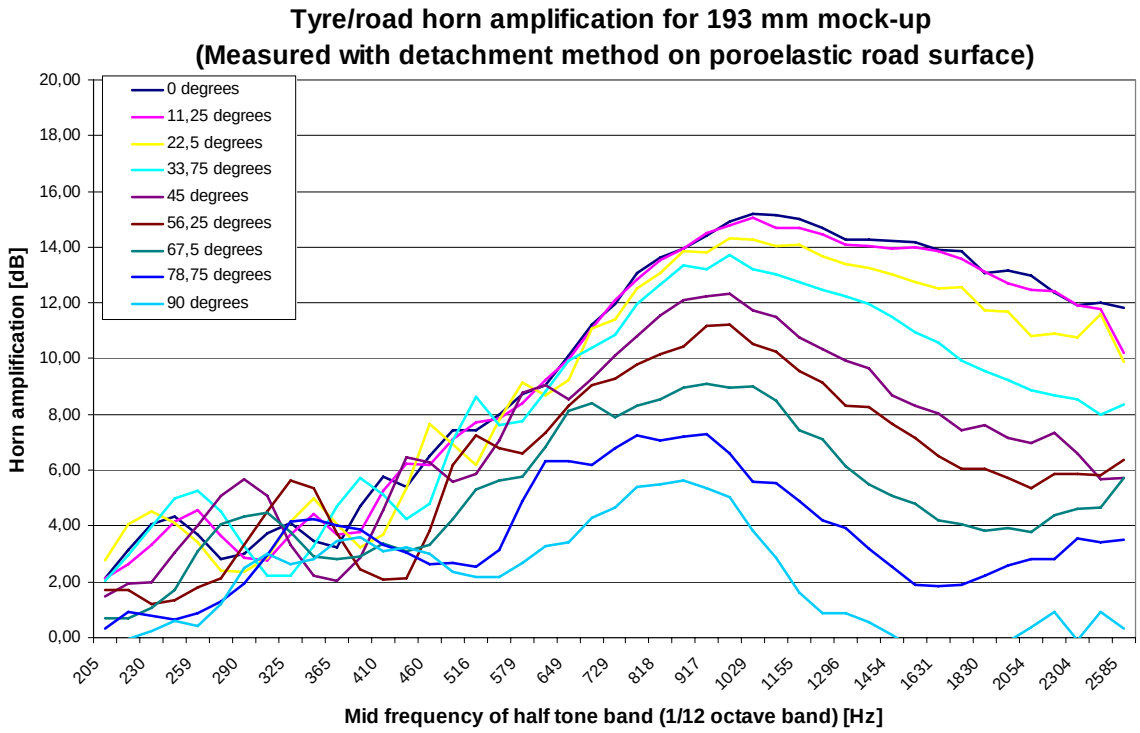


Figure 27. Tyre/road horn directivity measured on poroelastic road surface at Tagenevägen. Note that the amplification, in the rolling direction of the tyre, is 15 dB at 1000 Hz. At 90 degrees the amplification is only 4 dB. The rather high tyre/road horn amplification in forward direction is assumed to be achieved due to the low sound absorption factor of the poroelastic road surface.

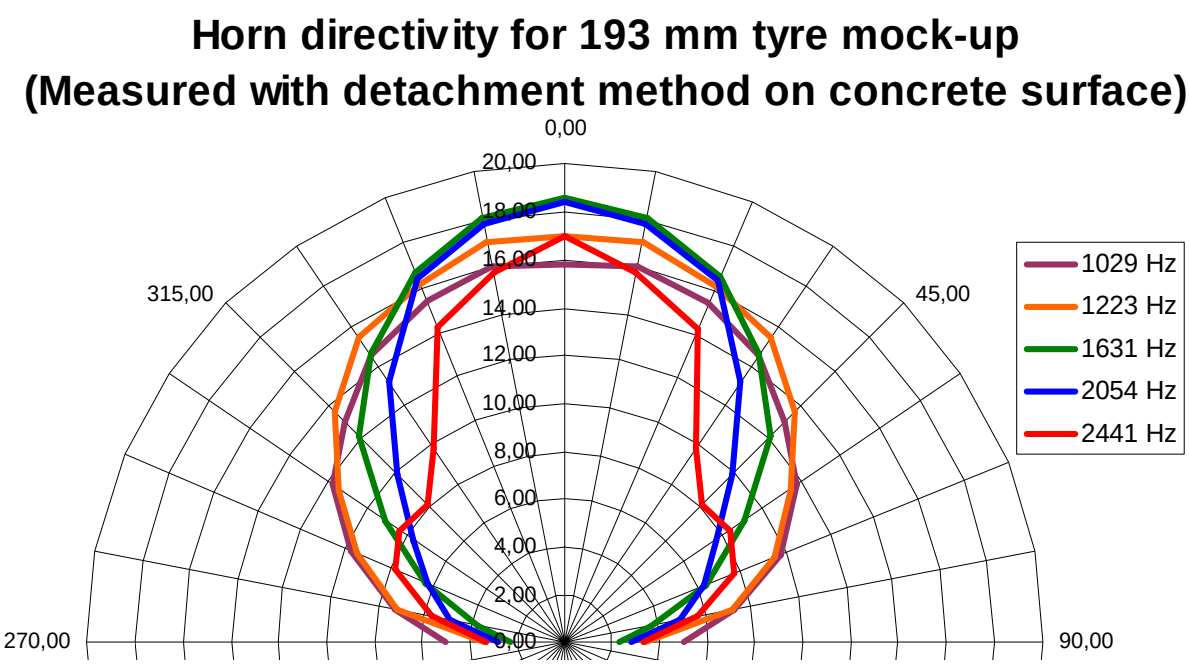


Figure 28. Tyre/road horn directivity measured on concrete road surface. Note that the amplification, in the rolling direction of the tyre, is 16 dB at 1000 Hz. Note the similarity in tyre/road horn amplifications in different directions

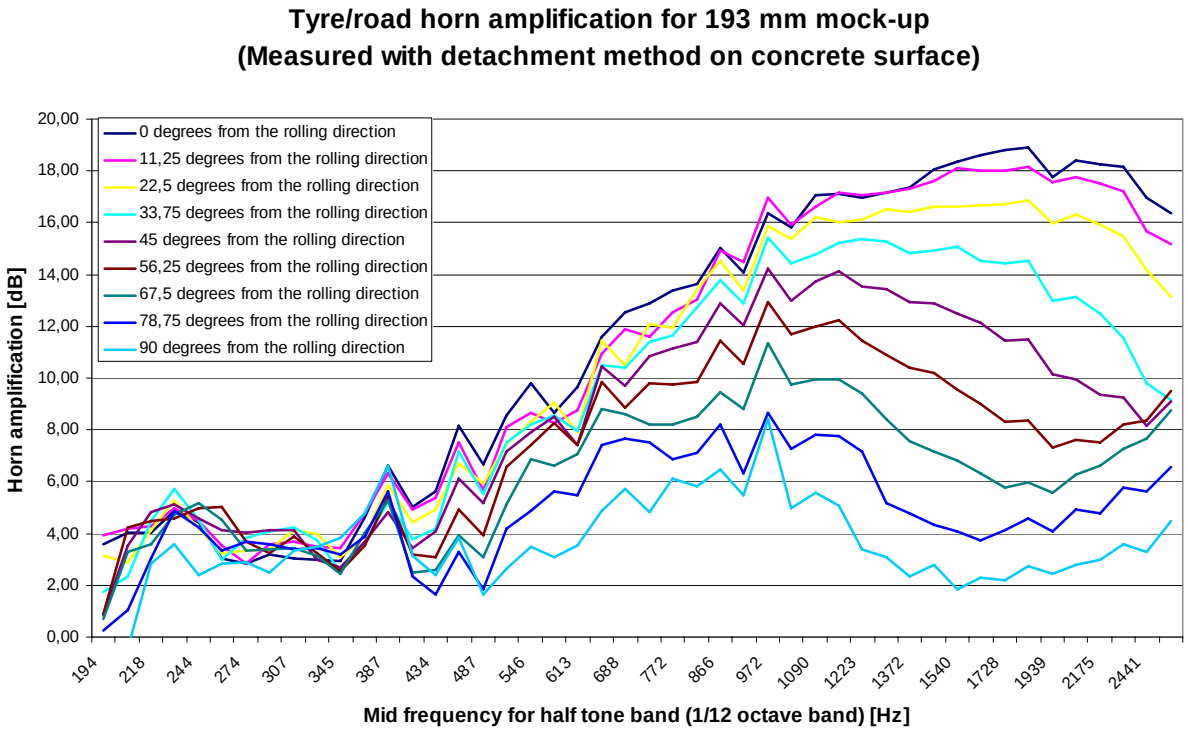


Figure 29. Tyre/road horn directivity measured on concrete road surface. Note that the amplification, in the rolling direction of the tyre, is 16 dB at 1000 Hz. Note the similarity in tyre/road horn amplifications in different directions

In Figure 30 below is shown, as a polar-plot, the difference in tyre/road horn amplification between concrete and poroelastic road surface. At 1000 Hz the difference between the two measured cases is about 1 dB in all directions. At 2000 Hz the difference is about 5.5 dB. This indicates that the absorption coefficient for the poroelastic road surface is low at 1000 Hz but higher at 2000 Hz. Since the tyre/road noise spectrum has its maximum magnitude near 1000 Hz this unfortunately means that the total noise reduction, due to the reduced horn amplification, is small. Still a noise reduction, due to the elastic properties of the road surface, can be expected.

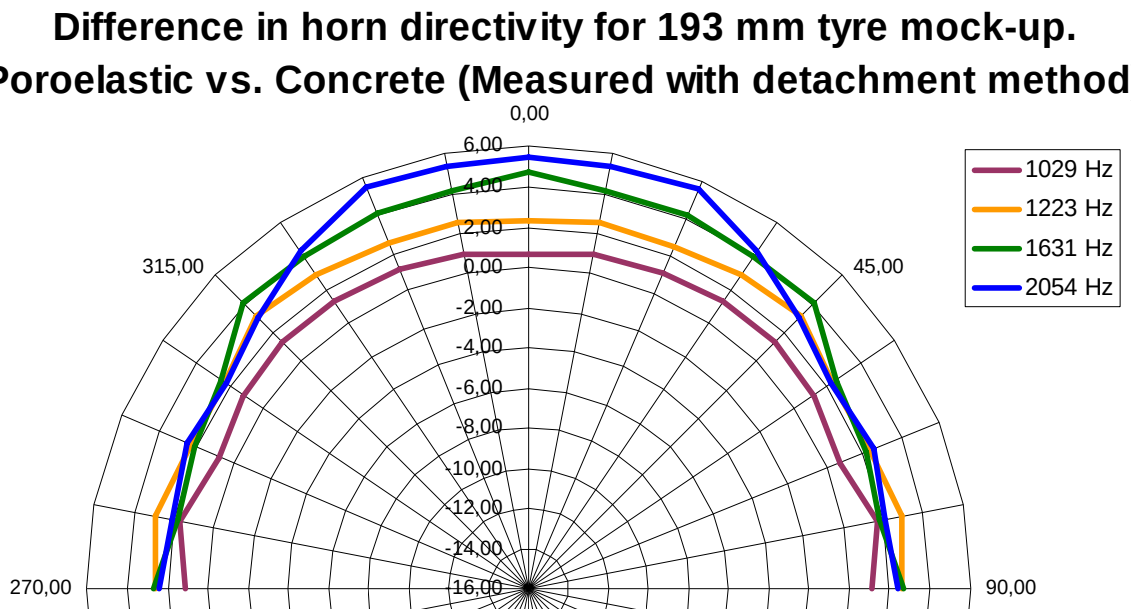


Figure 30. Difference in tyre/road horn amplification in different directions between poroelastic surface and concrete surface.
Note that the difference between dense concrete and the poroelastic surface are minor. The reason for this is the due to the unforeseen low sound absorption factor for both surfaces. The difference in horn amplification is only 1 dB at 1000 Hz. This indicates a low absorption coefficient at 1000 Hz. At 2000 Hz an increased difference of 5 dB has been achieved in forward direction (about 2 dB 90 ° to the direction of travel.

6.6 SOUND PROPAGATION

From Figure 32 below it can be seen that the sound propagation of the noise emitted by the loudspeaker, along the poroelastic pavement is almost exactly 6 dB for every doubling of the distance from the sound source. This is the same as the theoretical sound propagation of a spherical sound source which indicates that the road surface in this case has a low absorption coefficient, at least for this angle of incidence.

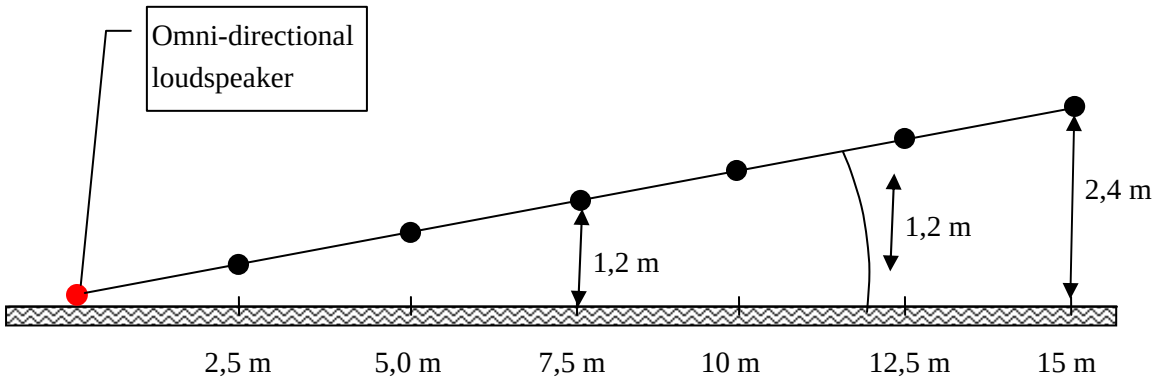


Figure 31. Measurement configuration for the measurements of excess sound attenuation due to propagation over a surface with high sound absorption factor.

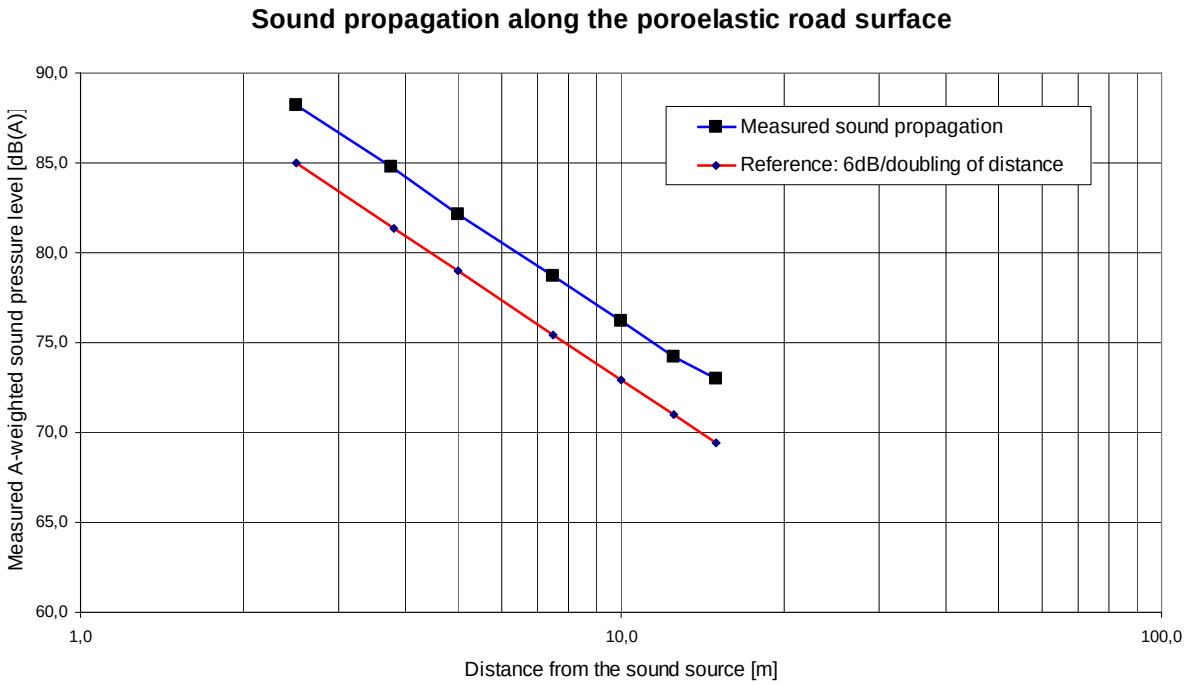


Figure 32. Sound pressure level decay for propagation over the poroelastic road surface
Note that the decay curve is very close to a decay of 6 dB/doubling of distance. This means that the road surface add a very small excess sound absorption to the sound propagating over the surface. This is consistent with measurement result on the horn amplificaiton and the sound absorption.

7 NOISE REDUCTION OF THE POROELASTIC ROAD SURFACE - CONCLUSIONS AND DISCUSSION

7.1 6 DB(A) LESS NOISE COMPARED TO A SMOOTH SURFACE AND 7.5 DB(A) COMPARED TO A ROUGH SURFACE

The measurement results both with the Drive-by and Close Proximity (which were found to be very similar) method has revealed that the poroelastic road surface at Tagenevägen in Gothenburg was **5.6 – 5.9 dB(A)** less noisy compared to a newly paved SMA11 adjacent to the poroelastic surface. Compared to worn SMA16 at Högsboleden in Gothenburg the poroelastic surface is **7.3 – 7.6 dB(A)** less noisy.

7.2 ELASTICITY WAS FOUND TO BE THE MAIN NOISE REDUCTION MECHANISM FOR THE STUDIED ROAD SURFACE

We think that the noise reduction mechanisms of the poroelastic road surface could be separated into

- noise reduction due to less roughness due to smaller stones in the poroelastic road surface (8 mm) compared to the reference surface (11 mm)
- noise reduction due to decreased dynamic stiffness
- noise reduction due to sound absorption
- combination effects of elasticity and absorption

The relative contributions to the total noise reductions from the different parameters have been estimated in the table below:

Factors influencing the noise reduction for the poroelastic road surface (8 mm max stone size) compared to an SMA11 (11 mm max stone size)	**Estimated relative contribution dB(A)-units**
Reduced roughness when using 8 mm max stone size in the poroelastic surface compared to 11 mm in the reference surface	**1.5** dB(A) units
Reduced dynamic stiffness of the poroelastic road surface due to the 8 % (weight) crumb rubber in the mix.	**2.5** dB(A) units
Sound absorption, which was limited by the low void content (15%) of the poroelastic road surface compared to virtually no absorption for the reference surface	**1.5** dB(A) units
Other effects	**0.5** dB(A) units
Total noise reduction of the tested poroelastic road surface	**6.0** dB(A) units

We believe that, for the currently studied poroelastic road surface, the elasticity is responsible for a substantial part of the found noise reduction presented above. The reason for this is that the measurements on sound absorption and the tyre/road horn amplification (1 dB less horn amplification compared to the dense and non-absorbing concrete surface at 1000 Hz and 5.5 dB at 2000 Hz) as well as the excess propagation attenuation reported above, all indicate that the porosity (void content) of the poroelastic surface became too low. The laboratory tests prior to the paving operation indicated that a void content in the range of 20 % should be achieved. However the compaction effeciency during the paving operation proved to be higher than expected, resulting in a void content of only 15 %. This lower void content will unfortunately adversely affect the sound absorption capability of the poroelastic road surface.

7.3 POTENTIAL EXISTS FOR A FURHTER DECREASED SOUND LEVEL FROM THE POROELASTIC ROAD SURFACE TESTED AT TAGENEVÄGEN.

The measurement results from the poroelastic road surface at Tagenevägen are of interest in two ways:

- It indicates that the potential of the surface relative to a worn SMA16 could be **8-10 dB(A) units** and relative to newly paved SMA11 about **7-9 dB(A) units** provided that the void content could be increased to > 20%.
- The fact that the elasticity of the surface is responsible for substantial part of the found noise reduction of the poroelastic road surface would point to that even a dense elastic road surface with a rubber content of about 8 % of the weight of the surface could result in a noise reduction of **3-4 dB(A) units**. Since a low noise non-porous surface would be attractive for inner city applications with low vehicle speed where open graded surfaces easily would clog the indicated noise reduction potential for a dense-elastic surface is interesting.

7.4 LOW INFLUENCE OF BACKGROUND NOISE FOR THE CPX-DATA

It was also found that the difference between poroelastic road surface and reference SMA11 road surface revealed different speed dependence when measuring with the Drive-by method compared to what was achieved when using the CPX method. The main difference was that in the low speed range the Drive-by method yielded a smaller difference between poroelastic and the SMA11 surface compared to the CPX method.

We believe that this is due to *an increased influence from drive-line noise for the Drive-by tests* compared to the CPX tests, where the microphones are located closer to the tyre/road contact edges and thereby less influenced by back-ground noise. Therefore the difference obtained by the CPX-method stays at around 5.5 dB(A) even at speeds as low as 30 km/h. The CPX-results seems to be practically unaffected by the driveline noise at all tested speeds.

Appendix 1

Measurement of tyre/road noise using the Drive-by-method

A-weighted Sound Pressure Level for the Poroelastic road surface and the reference road surface evaluated at specific speeds of 30, 35, 40, 45, 50, 55, 60, 65 and 70 km/h.

The difference spectra between Reference road surface and Poroelastic road surface for the speeds 30, 40, 50, 60 and 70 km/h.

Measurement of tyre/road noise using the drive-by method

CONTRACT N°	TIP4-CT-2005-516420
PROJECT N°	FP6-516420
ACRONYM	QCITY
WORK PACKAGE	5.5

Work task	Elaborator by	Date
Measurement of road/tyre noise	Martin Höjer	20061004

Applied measurement standard: ISO/CD 7188:1994 to applicable extent

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

30 km/h

Poroelastic road surface

L_{Aeq} = **61 dB(A)**

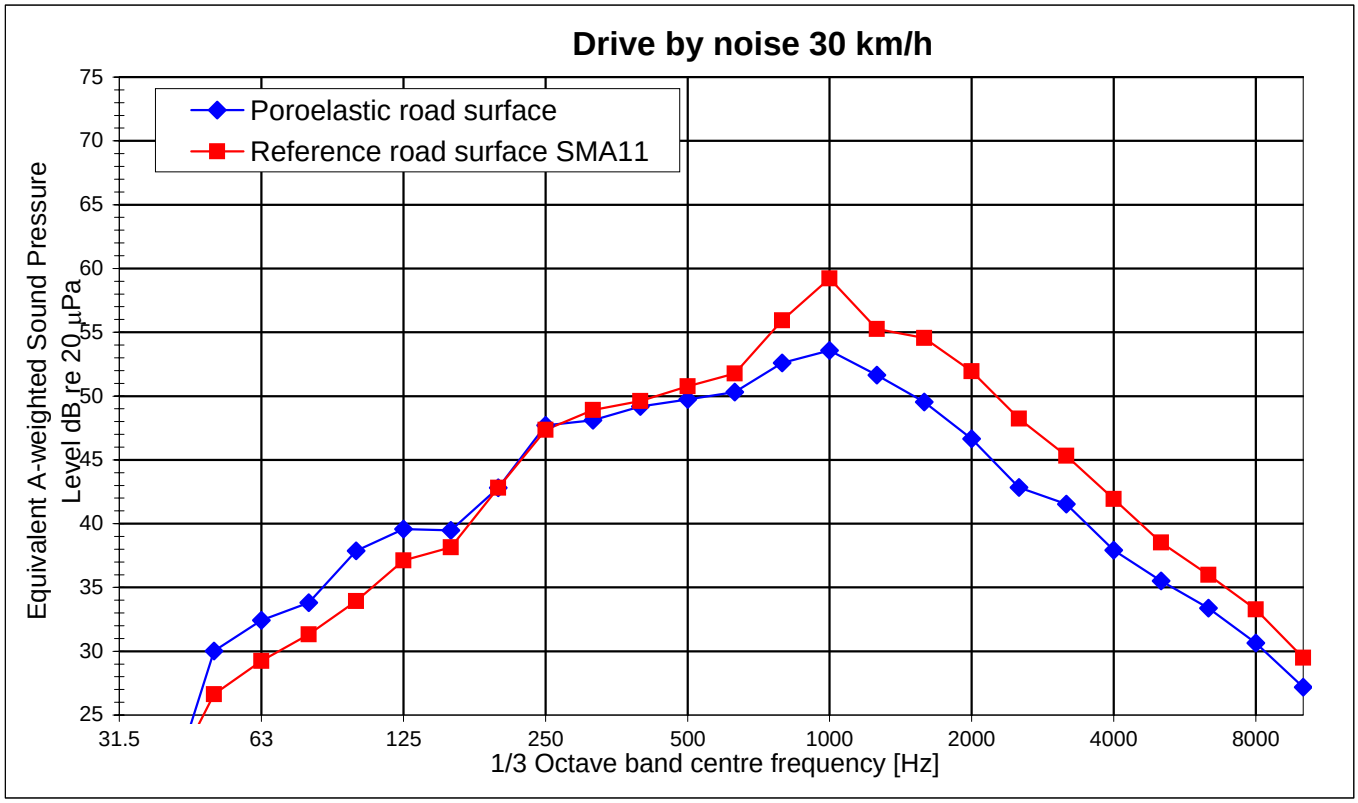
Reference road surface standard SMA11

L_{Aeq} = **64 dB(A)**

MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Drive by noise averaged using two microphones



ACOUSTIC CONTROL LABORATORIES

Measurement of tyre/road noise using the drive-by method

CONTRACT N°	TIP4-CT-2005-516420
PROJECT N°	FP6-516420
ACRONYM	QCITY
WORK PACKAGE	5.5

Work task	Elaborator by	Date
Measurement of road/tyre noise	Martin Höjer	20061004

Applied measurement standard: ISO/CD 7188:1994 to applicable extent

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

35 km/h

Poroelastic road surface

L_{Aeq} = **62 dB(A)**

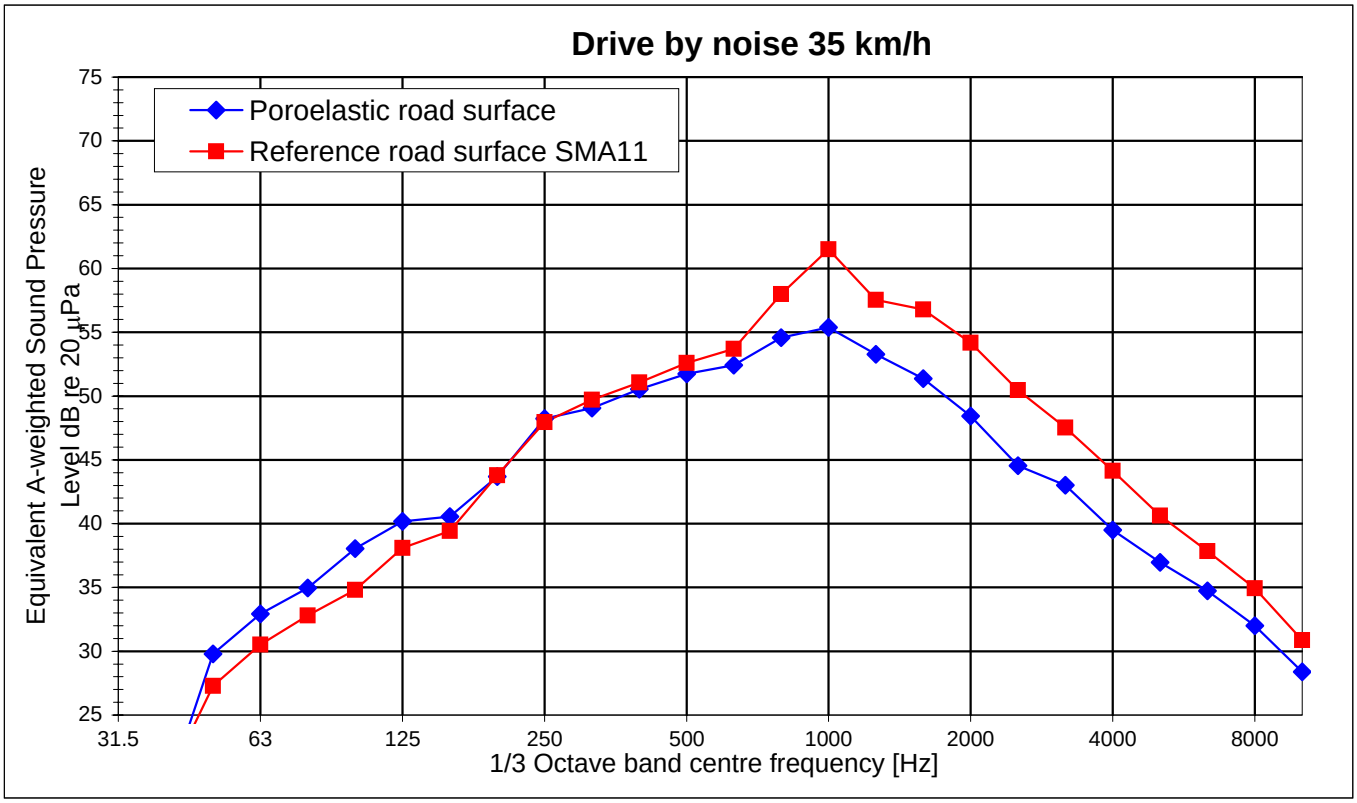
Reference road surface standard SMA11

L_{Aeq} = **66 dB(A)**

MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Drive by noise averaged using two microphones



ACOUSTIC CONTROL LABORATORIES

Measurement of tyre/road noise using the drive-by method

CONTRACT N°	TIP4-CT-2005-516420
PROJECT N°	FP6-516420
ACRONYM	QCITY
WORK PACKAGE	5.5

Work task	Elaborator by	Date
Measurement of road/tyre noise	Martin Höjer	20061004

Applied measurement standard: ISO/CD 7188:1994 to applicable extent

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

40 km/h

Poroelastic road surface

L_{Aeq} = **64 dB(A)**

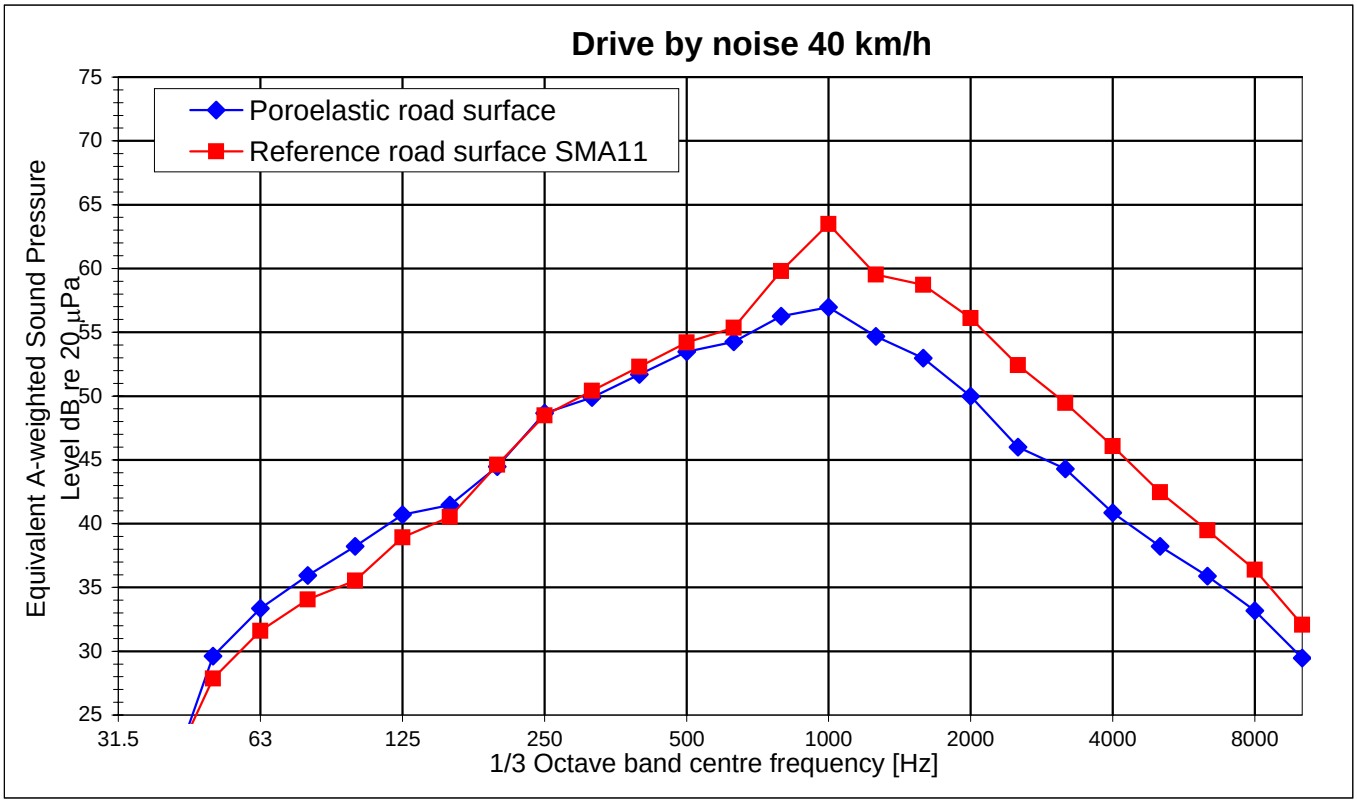
Reference road surface standard SMA11

L_{Aeq} = **68 dB(A)**

MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Drive by noise averaged using two microphones



ACOUSTIC CONTROL LABORATORIES

Measurement of tyre/road noise using the drive-by method

CONTRACT N°	TIP4-CT-2005-516420
PROJECT N°	FP6-516420
ACRONYM	QCITY
WORK PACKAGE	5.5

Work task	Elaborator by	Date
Measurement of road/tyre noise	Martin Höjer	20061004

Applied measurement standard: ISO/CD 7188:1994 to applicable extent

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

45 km/h

Poroelastic road surface

L_{Aeq} = **64 dB(A)**

Reference road surface standard SMA11

L_{Aeq} = **70 dB(A)**

MEASUREMENT EQUIPMENT

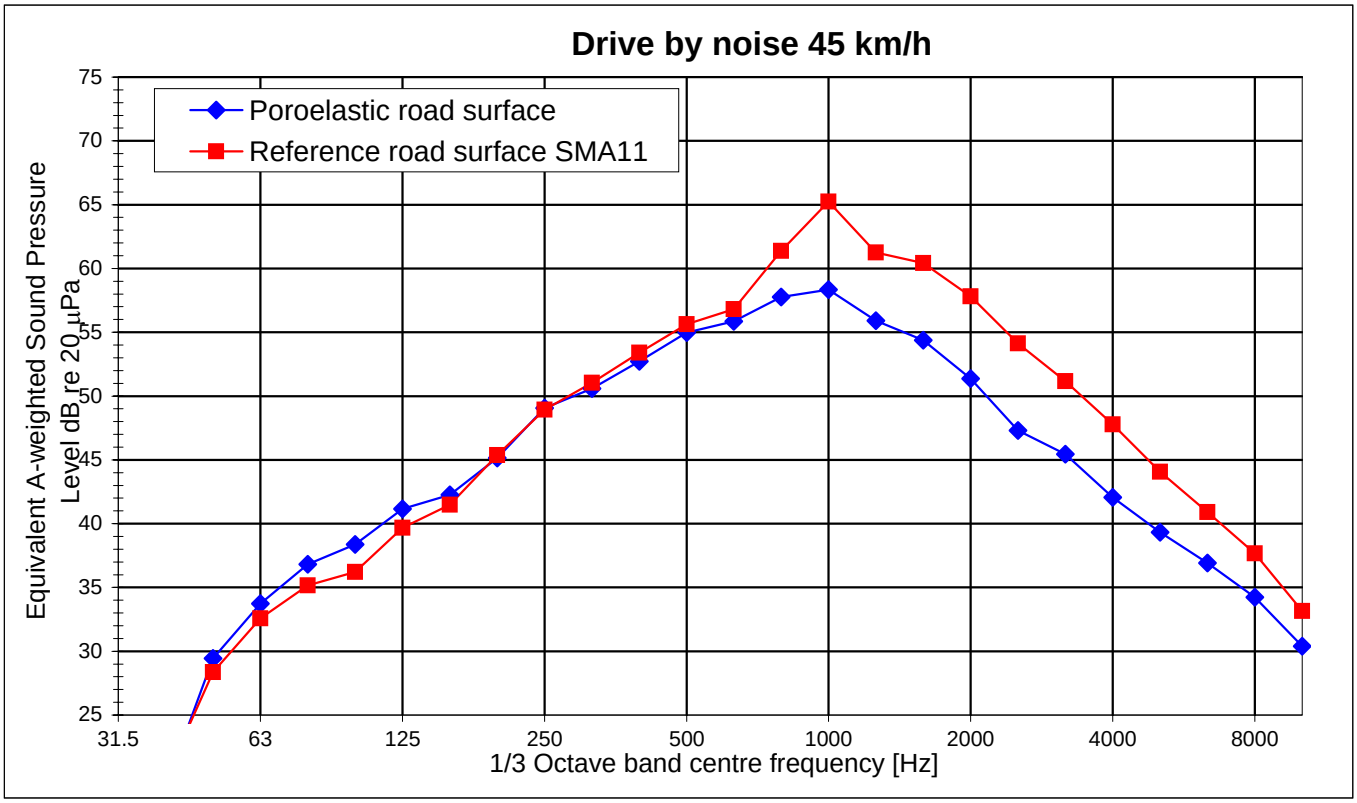
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE

Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT

Analysis: 1/3 Octave band
Drive by noise averaged using two microphones



ACOUSTIC CONTROL LABORATORIES

Measurement of tyre/road noise using the drive-by method

CONTRACT N°	TIP4-CT-2005-516420
PROJECT N°	FP6-516420
ACRONYM	QCITY
WORK PACKAGE	5.5

Work task	Elaborator by	Date
Measurement of road/tyre noise	Martin Höjer	20061004

Applied measurement standard: ISO/CD 7188:1994 to applicable extent

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

50 km/h

Poroelastic road surface

L_{Aeq} = **66 dB(A)**

Reference road surface standard SMA11

L_{Aeq} = **71 dB(A)**

MEASUREMENT EQUIPMENT

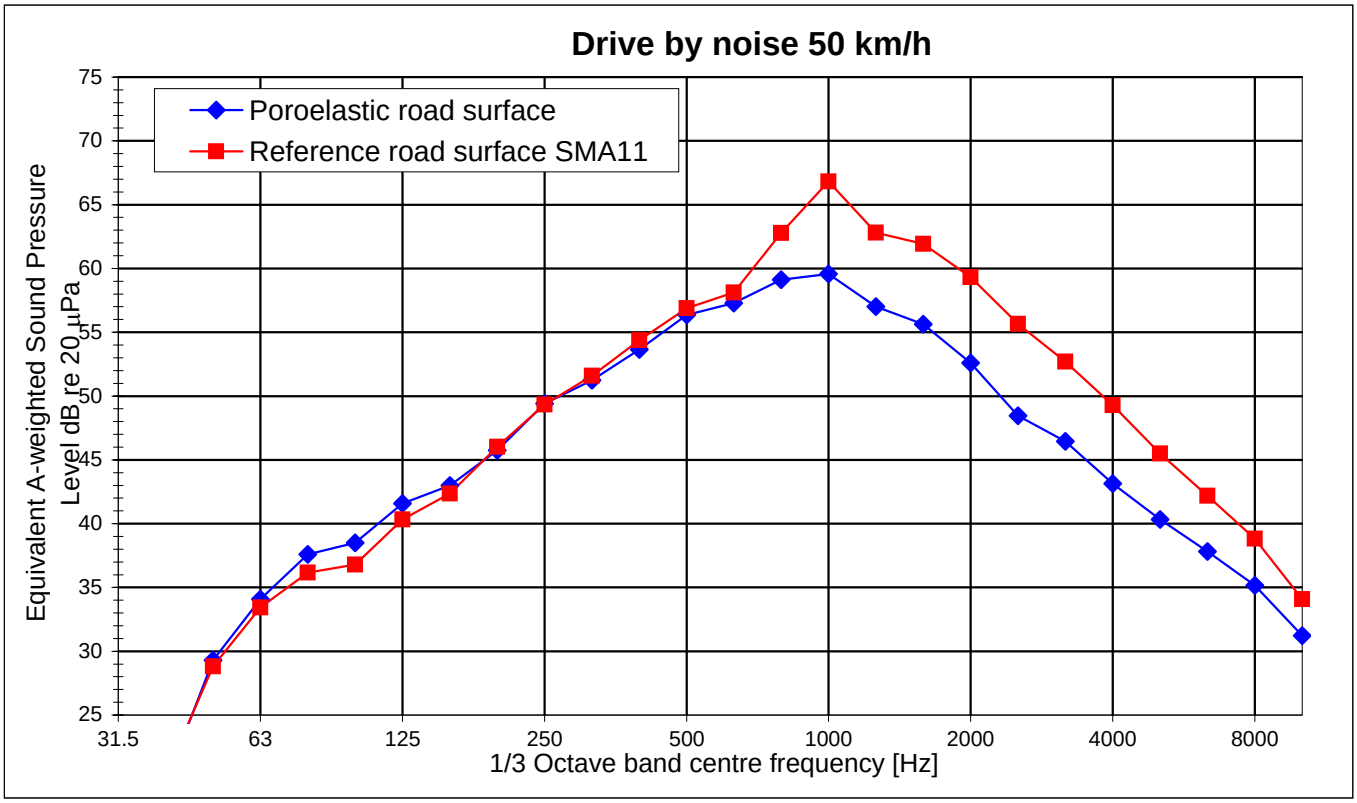
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE

Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT

Analysis: 1/3 Octave band
Drive by noise averaged using two microphones



ACOUSTIC CONTROL LABORATORIES

Measurement of tyre/road noise using the drive-by method

CONTRACT N°	TIP4-CT-2005-516420
PROJECT N°	FP6-516420
ACRONYM	QCITY
WORK PACKAGE	5.5

Work task	Elaborator by	Date
Measurement of road/tyre noise	Martin Höjer	20061004

Applied measurement standard: ISO/CD 7188:1994 to applicable extent

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

55 km/h

Poroelastic road surface

L_{Aeq} = **68 dB(A)**

Reference road surface standard SMA11

L_{Aeq} = **73 dB(A)**

MEASUREMENT EQUIPMENT

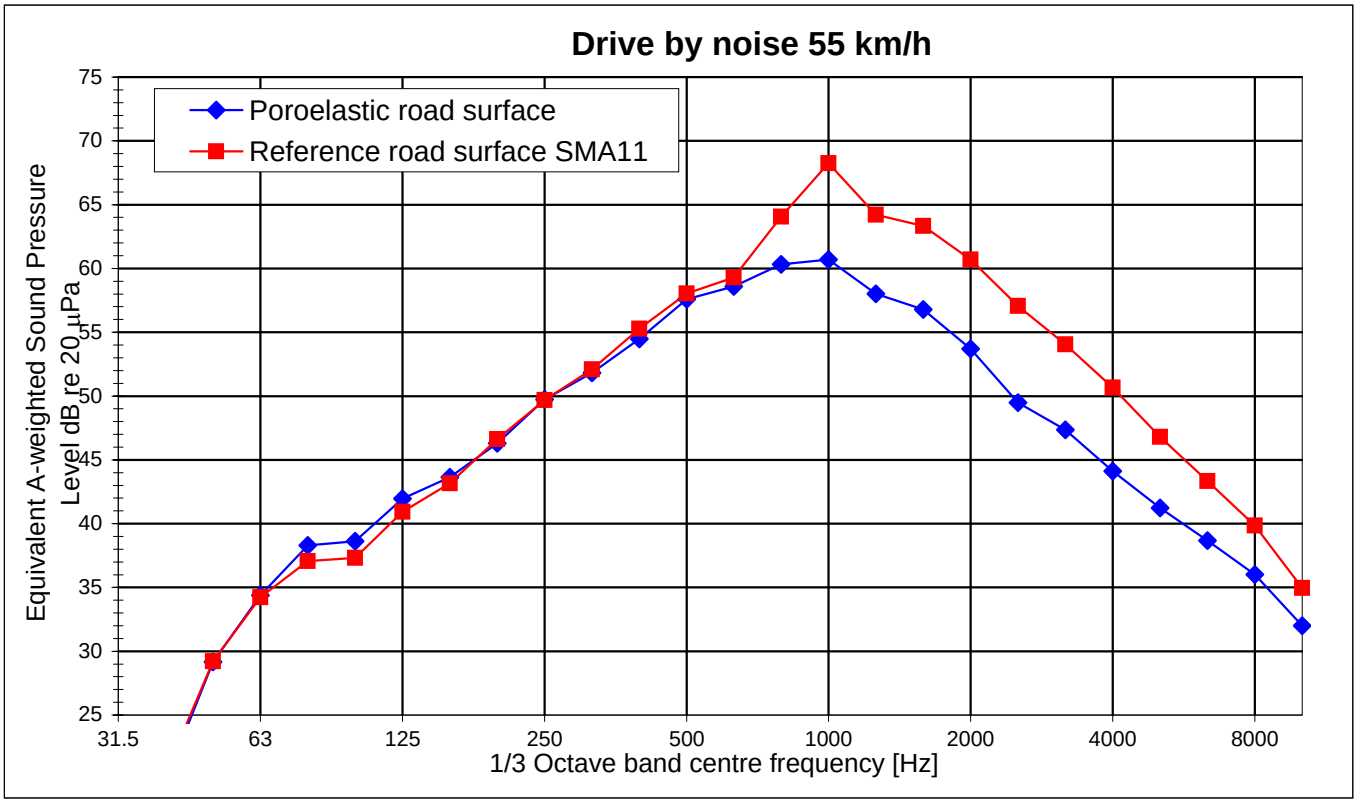
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE

Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT

Analysis: 1/3 Octave band
Drive by noise averaged using two microphones



ACOUSTIC CONTROL LABORATORIES

Measurement of tyre/road noise using the drive-by method

CONTRACT N°	TIP4-CT-2005-516420
PROJECT N°	FP6-516420
ACRONYM	QCITY
WORK PACKAGE	5.5

Work task	Elaborator by	Date
Measurement of road/tyre noise	Martin Höjer	20061004

Applied measurement standard: ISO/CD 7188:1994 to applicable extent

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

60 km/h

Poroelastic road surface

L_{Aeq} = **69 dB(A)**

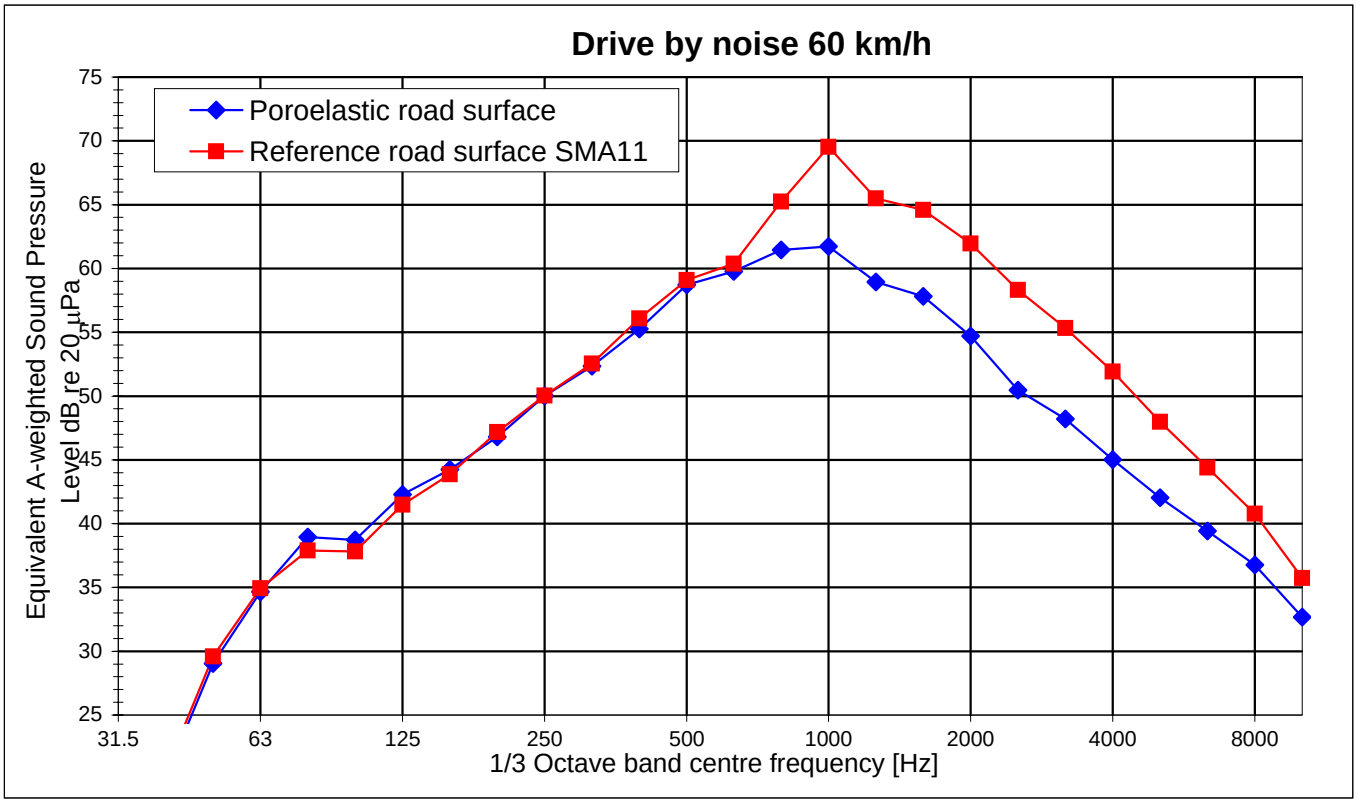
Reference road surface standard SMA11

L_{Aeq} = **74 dB(A)**

MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Drive by noise averaged using two microphones



ACOUSTIC CONTROL LABORATORIES

Measurement of tyre/road noise using the drive-by method

CONTRACT N°	TIP4-CT-2005-516420
PROJECT N°	FP6-516420
ACRONYM	QCITY
WORK PACKAGE	5.5

Work task	Elaborator by	Date
Measurement of road/tyre noise	Martin Höjer	20061004

Applied measurement standard: ISO/CD 7188:1994 to applicable extent

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

65 km/h

Poroelastic road surface

L_{Aeq} = **70 dB(A)**

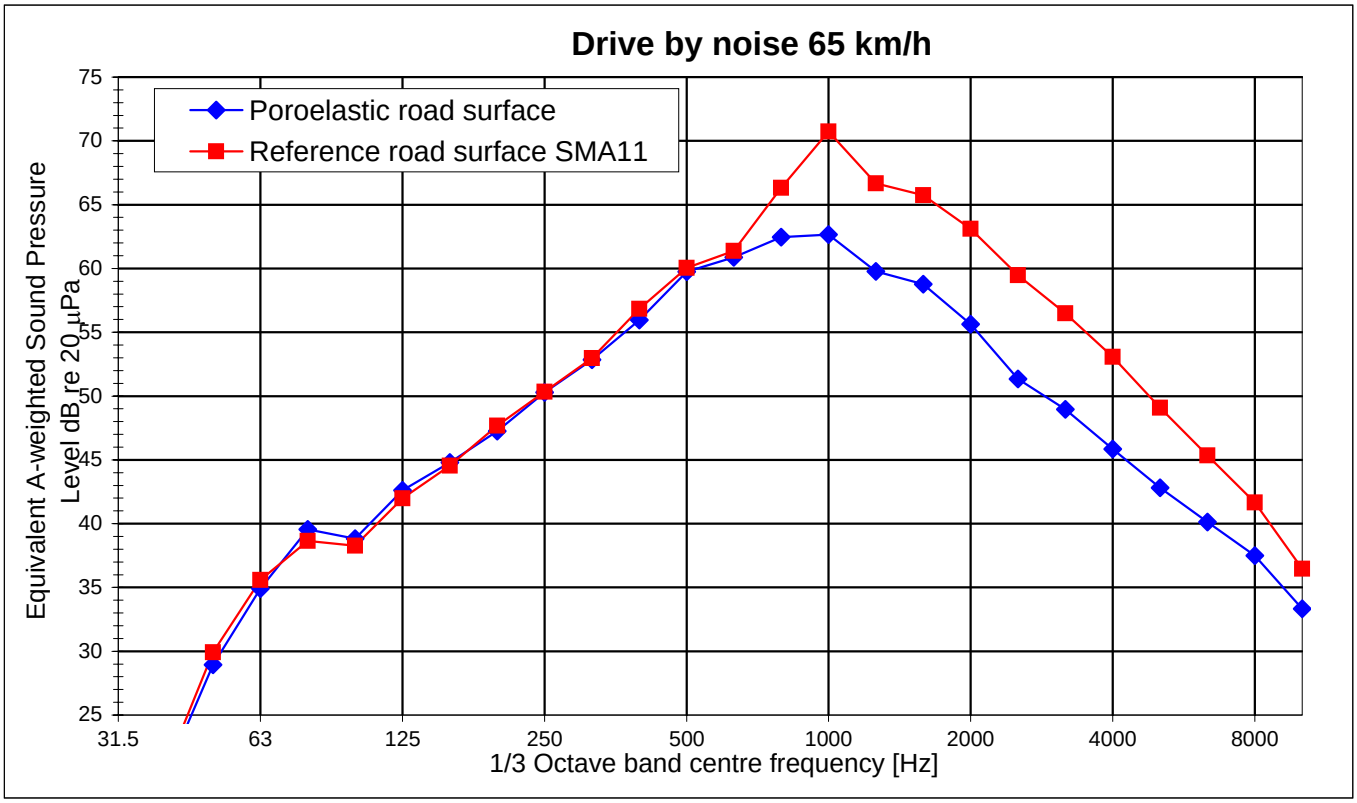
Reference road surface standard SMA11

L_{Aeq} = **75 dB(A)**

MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Drive by noise averaged using two microphones



ACOUSTIC CONTROL LABORATORIES

Measurement of tyre/road noise using the drive-by method

CONTRACT N°	TIP4-CT-2005-516420
PROJECT N°	FP6-516420
ACRONYM	QCITY
WORK PACKAGE	5.5

Work task	Elaborator by	Date
Measurement of road/tyre noise	Martin Höjer	20061004

Applied measurement standard: ISO/CD 7188:1994 to applicable extent

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

70 km/h

Poroelastic road surface

L_{Aeq} = **70 dB(A)**

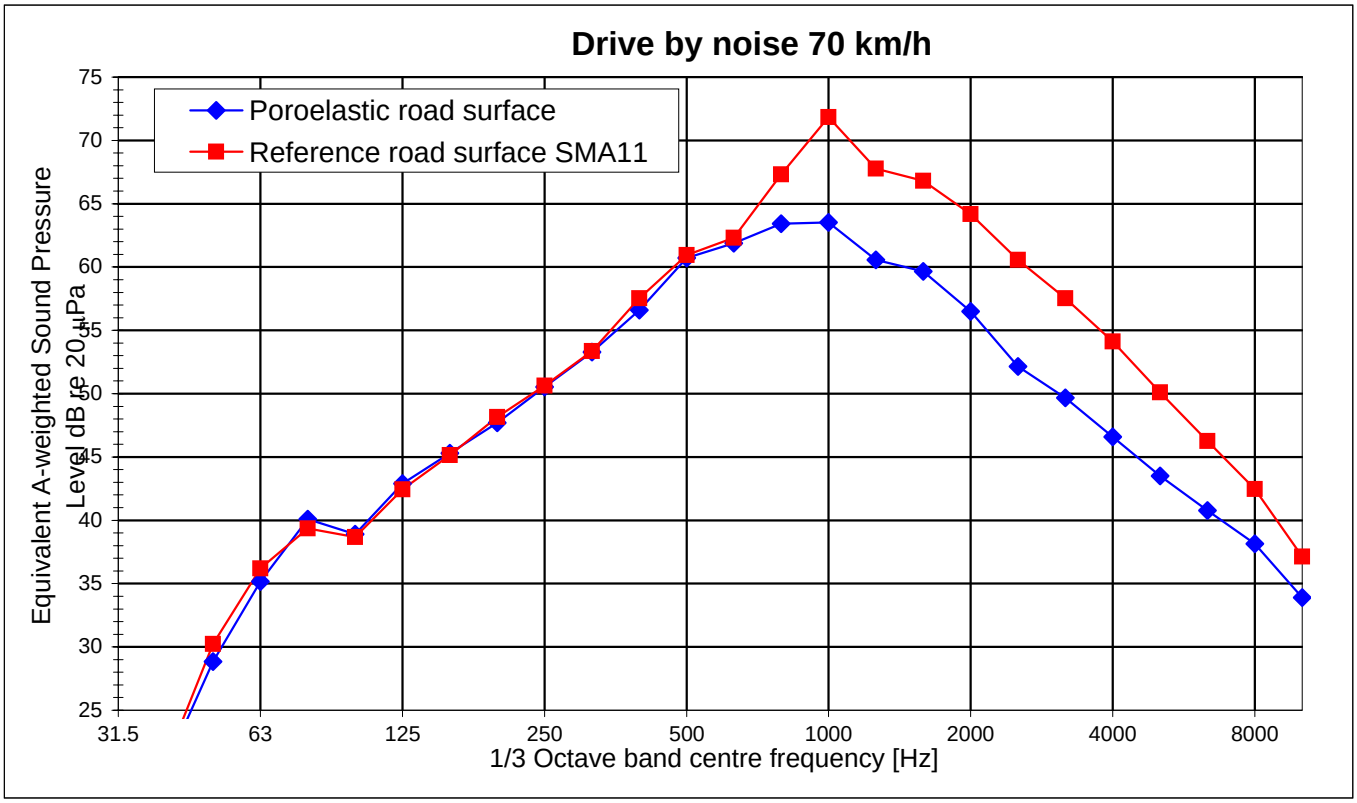
Reference road surface standard SMA11

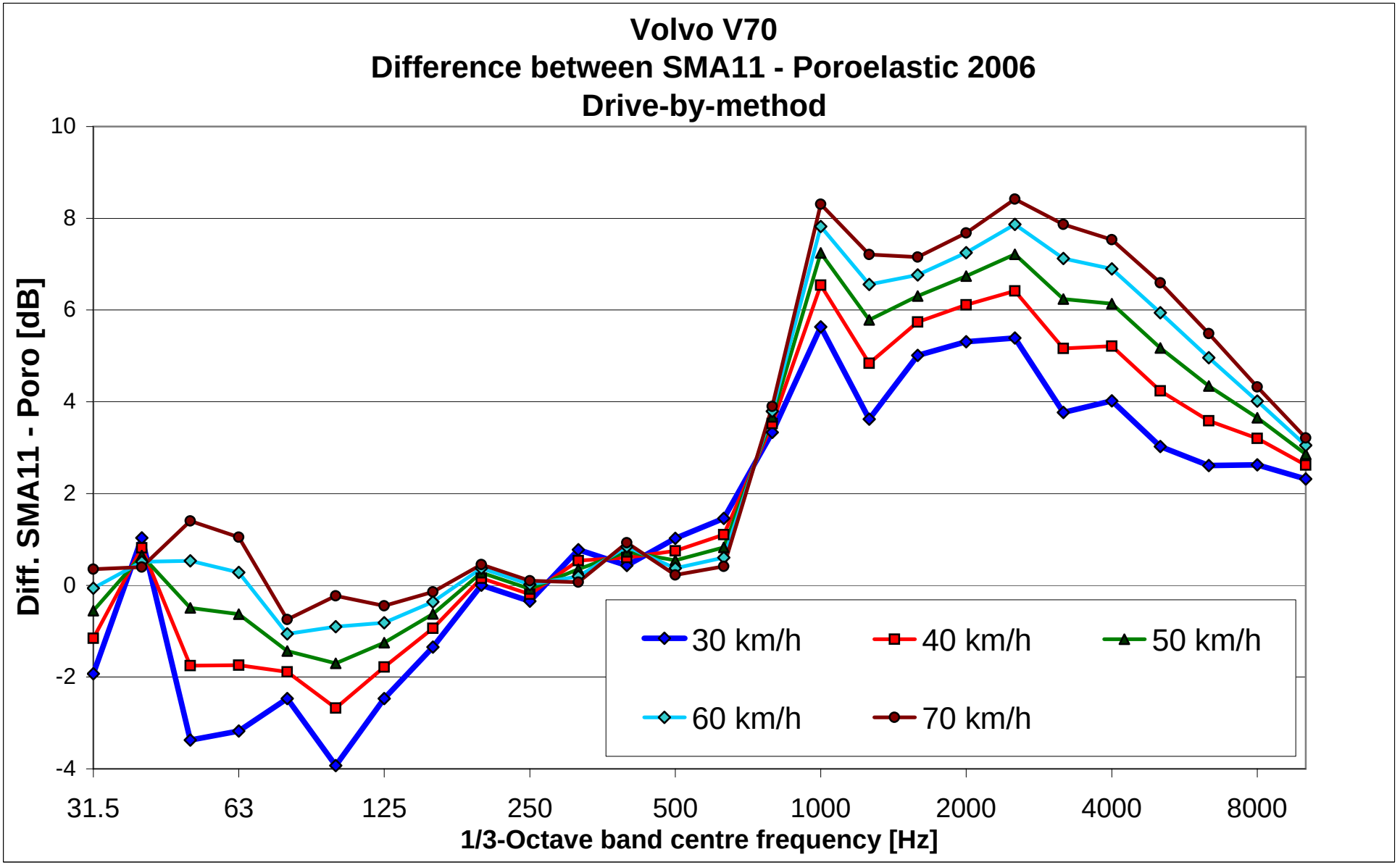
L_{Aeq} = **76 dB(A)**

MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Drive by noise averaged using two microphones




Volvo V70
Difference between SMA11 - Poroelastic 2006
Drive-by-method
Diff. SMA11 - Poro [dB]
10
8
6
4
2
0
-2
-4
31.5
63
125
250
500
1000
2000
4000
8000
1/3-Octave band centre frequency [Hz]
30 km/h
40 km/h
50 km/h
60 km/h
70 km/h

Appendix 2

Measurement of tyre/road noise using the CPX-method

Car passage 1 - 3	30 km/h
Car passage 17 - 18	35 km/h
Car passage 4 - 6	40 km/h
Car passage 19 - 20	45 km/h
Car passage 7 - 9	50 km/h
Car passage 21 - 22	55 km/h
Car passage 10 - 13	60 km/h
Car passage 23 - 24	65 km/h
Car passage 14 - 16	70 km/h

A-weighted Sound Pressure Level for the Poroelastic road surface and the reference road surface evaluated at specific speeds of 30, 40, 50, 60 and 70 km/h.

The difference spectra between Reference road surface and Poroelastic road surface for the speeds 30, 40, 50, 60 and 70 km/h.

Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**1**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

30-38 km/h

Poroelastic road surface

L_{Aeq} = **84 dB(A)**

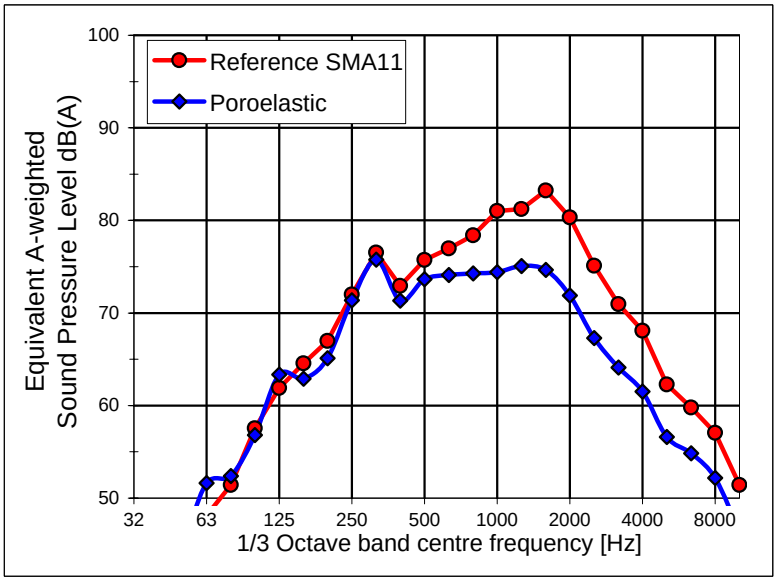
Reference road surface standard SMA11

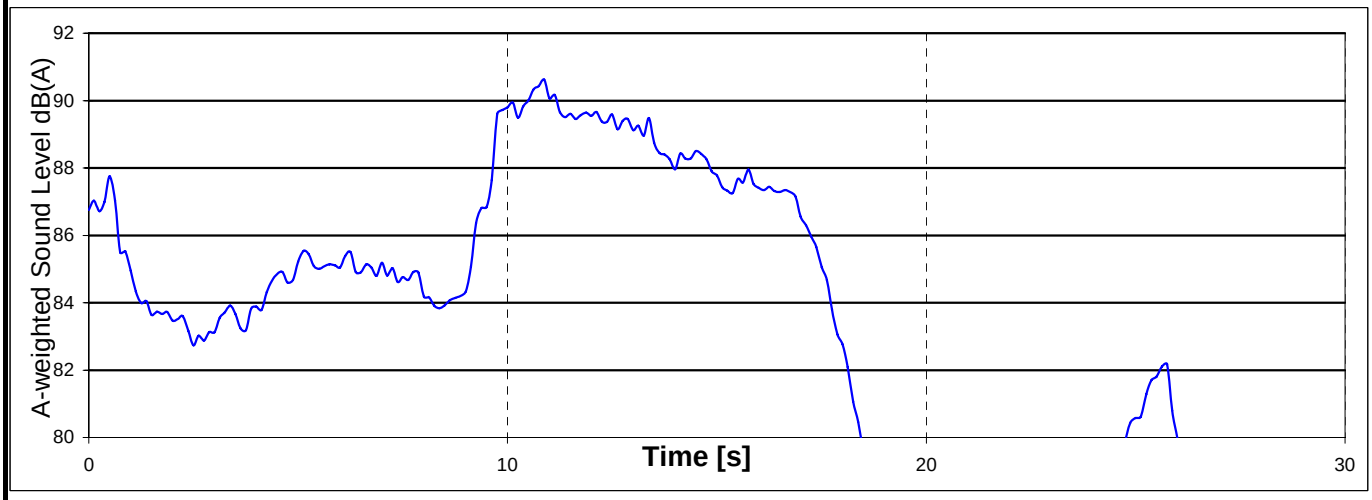
L_{Aeq} = **90 dB(A)**

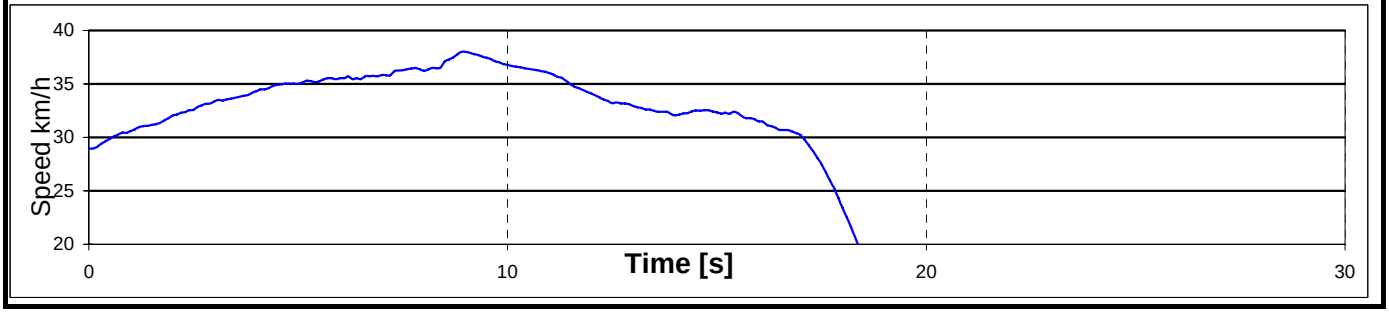
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**2**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

28-32 km/h

Poroelastic road surface

L_{Aeq} = **81 dB(A)**

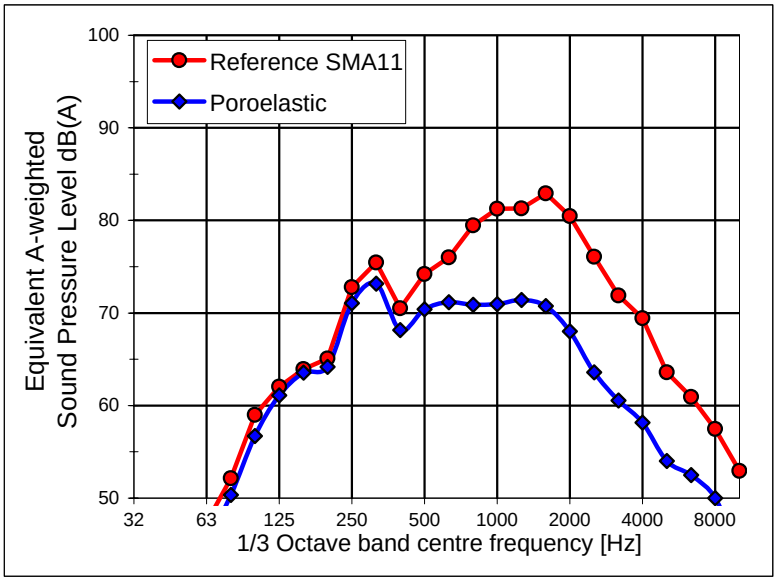
Reference road surface standard SMA11

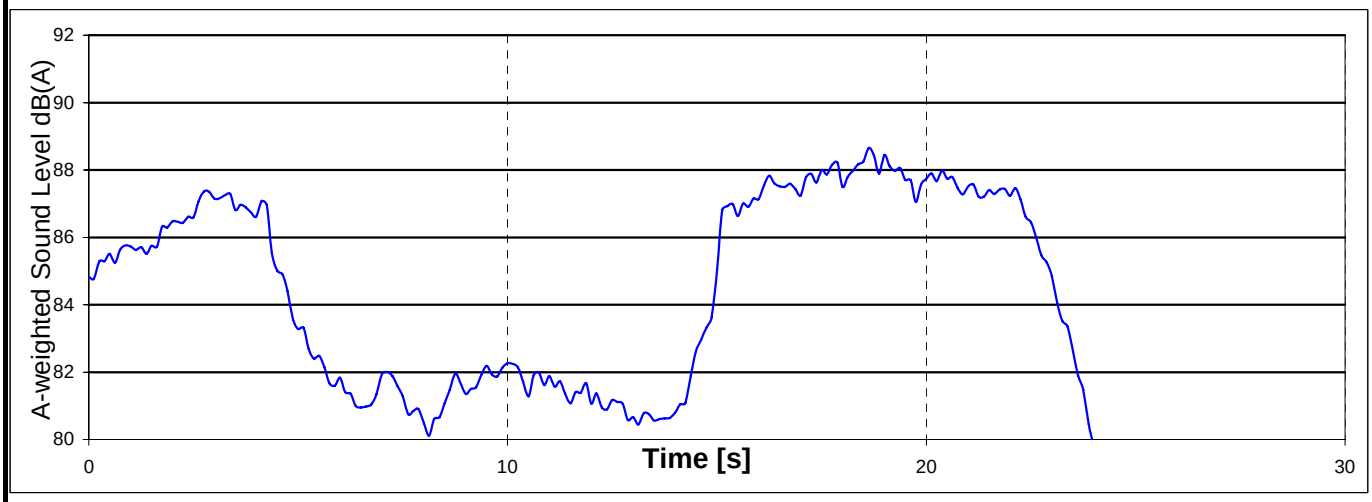
L_{Aeq} = **88 dB(A)**

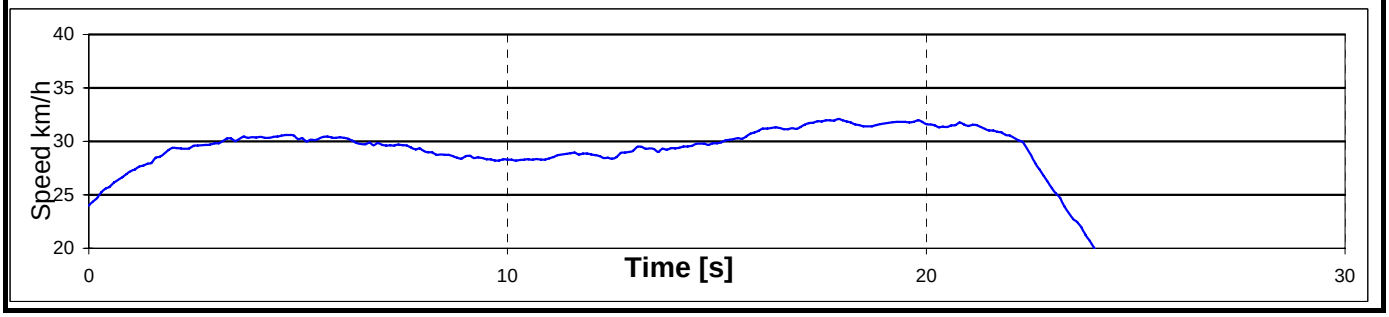
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**3**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

30-33 km/h

Poroelastic road surface

L_{Aeq} = **82 dB(A)**

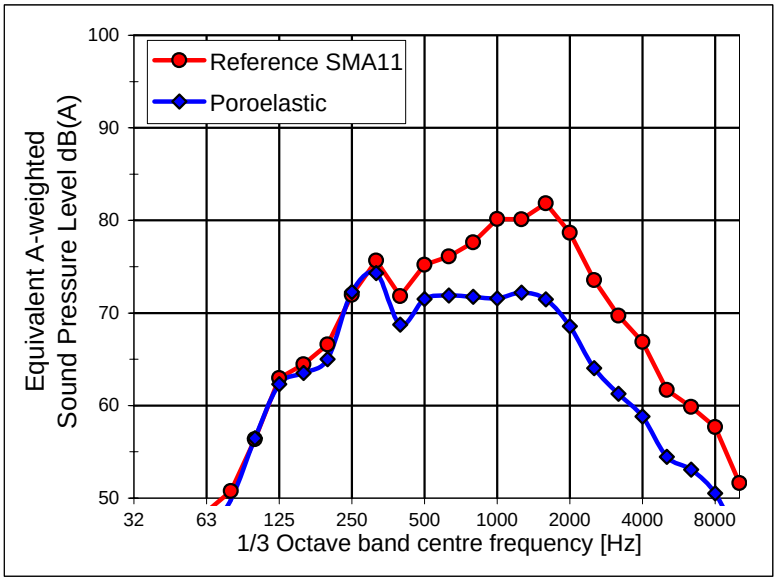
Reference road surface standard SMA11

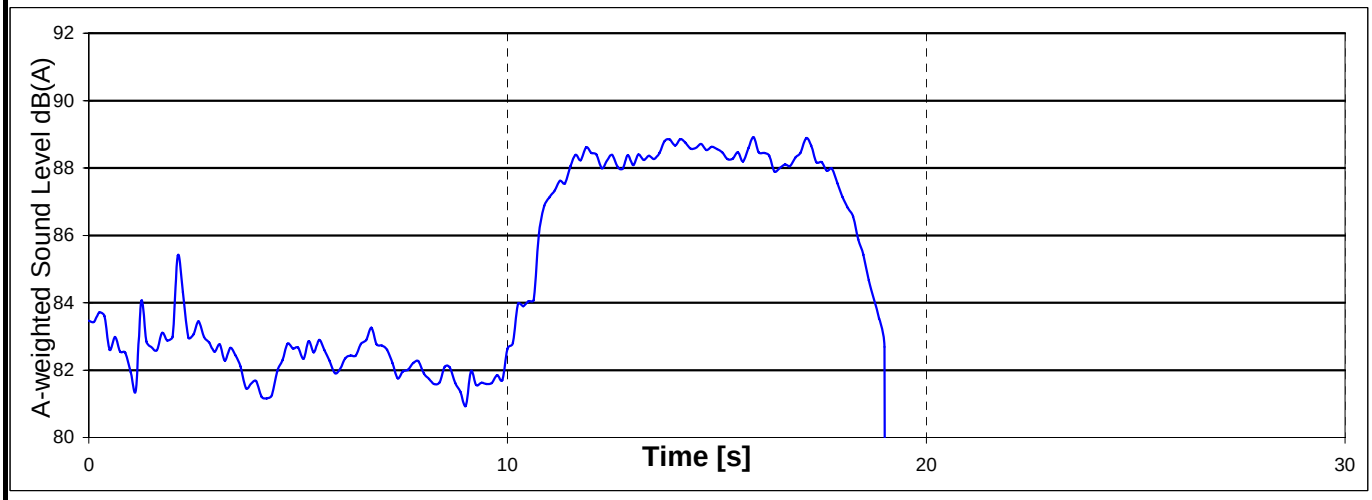
L_{Aeq} = **88 dB(A)**

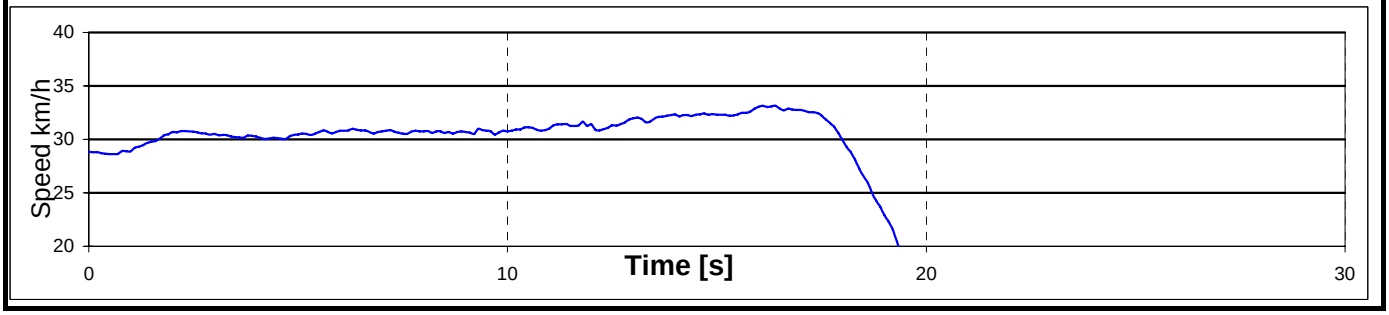
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**17**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

35-37 km/h

Poroelastic road surface

L_{Aeq} = **85 dB(A)**

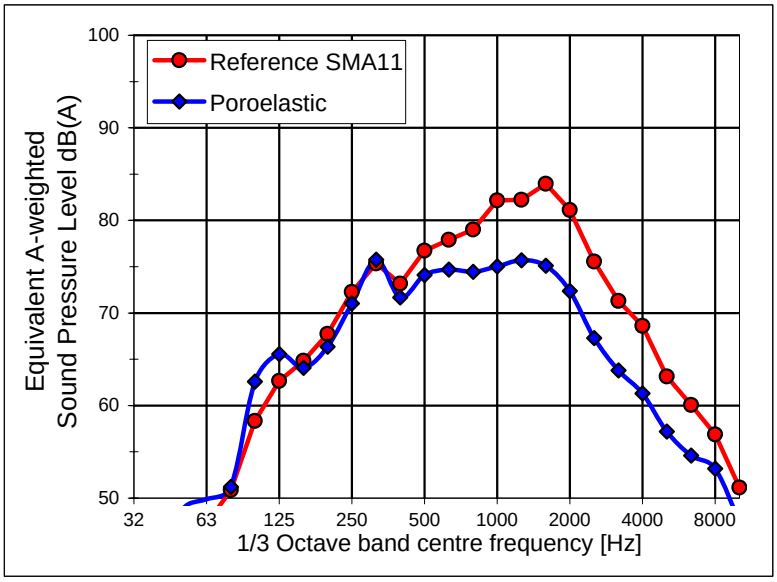
Reference road surface standard SMA11

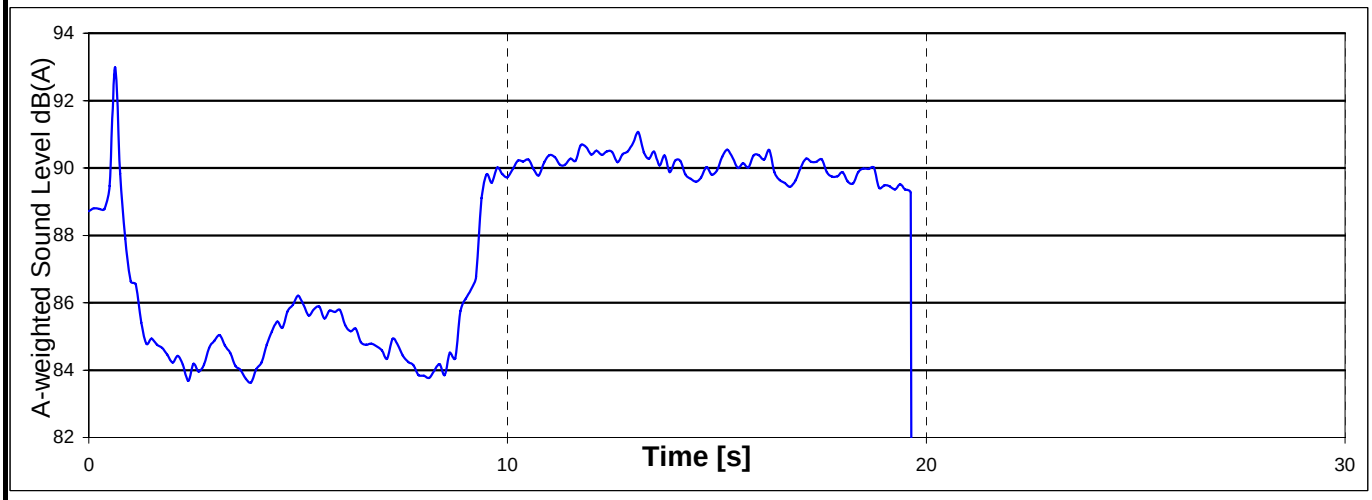
L_{Aeq} = **90 dB(A)**

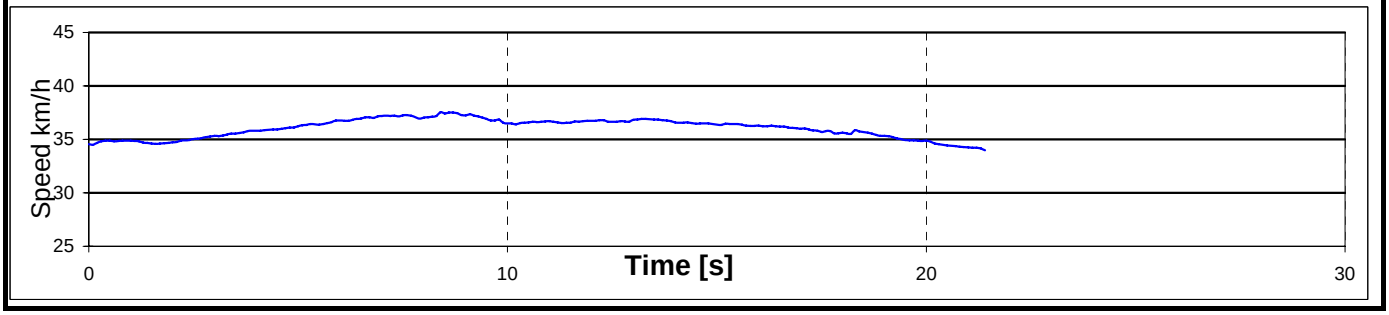
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**18**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

36-38 km/h

Poroelastic road surface

L_{Aeq} = **85 dB(A)**

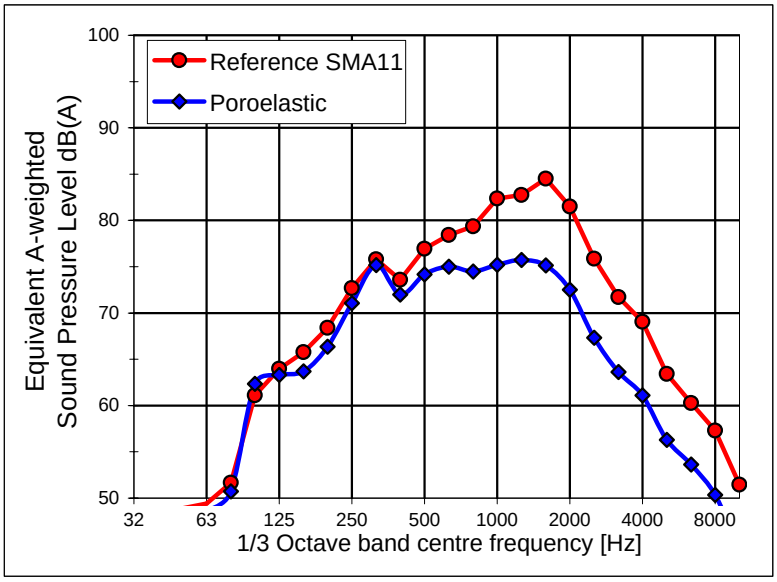
Reference road surface standard SMA11

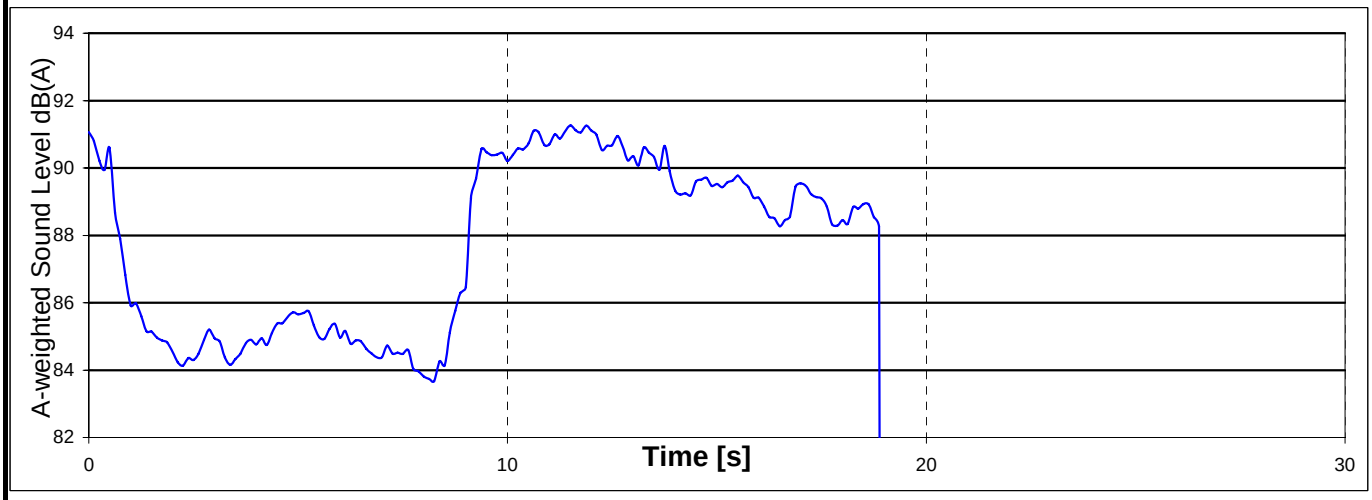
L_{Aeq} = **91 dB(A)**

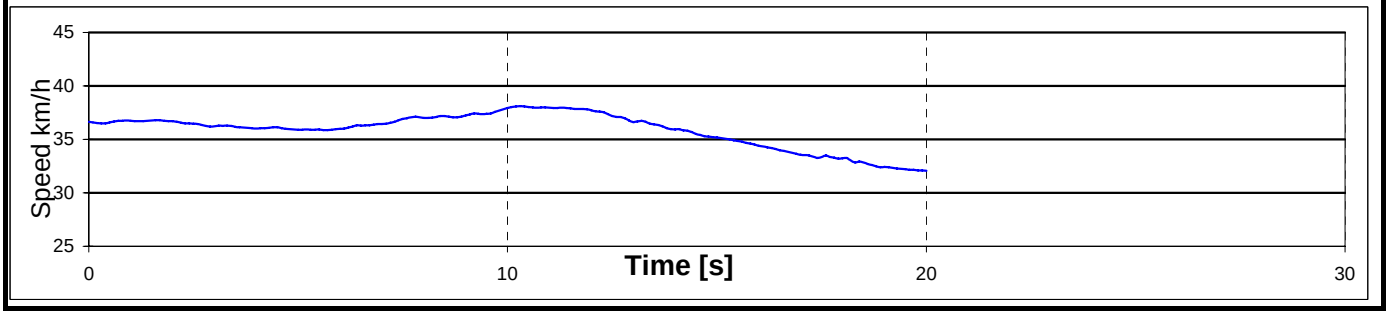
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**4**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

40 km/h

Poroelastic road surface

L_{Aeq} = **86 dB(A)**

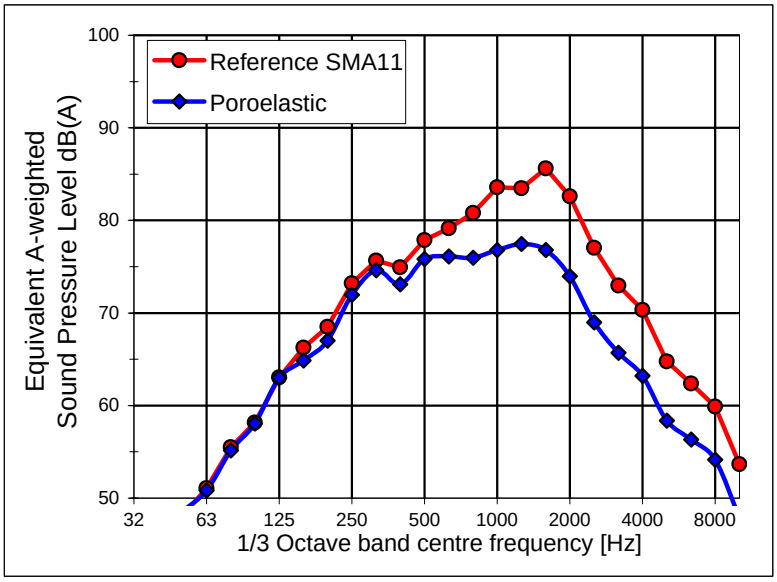
Reference road surface standard SMA11

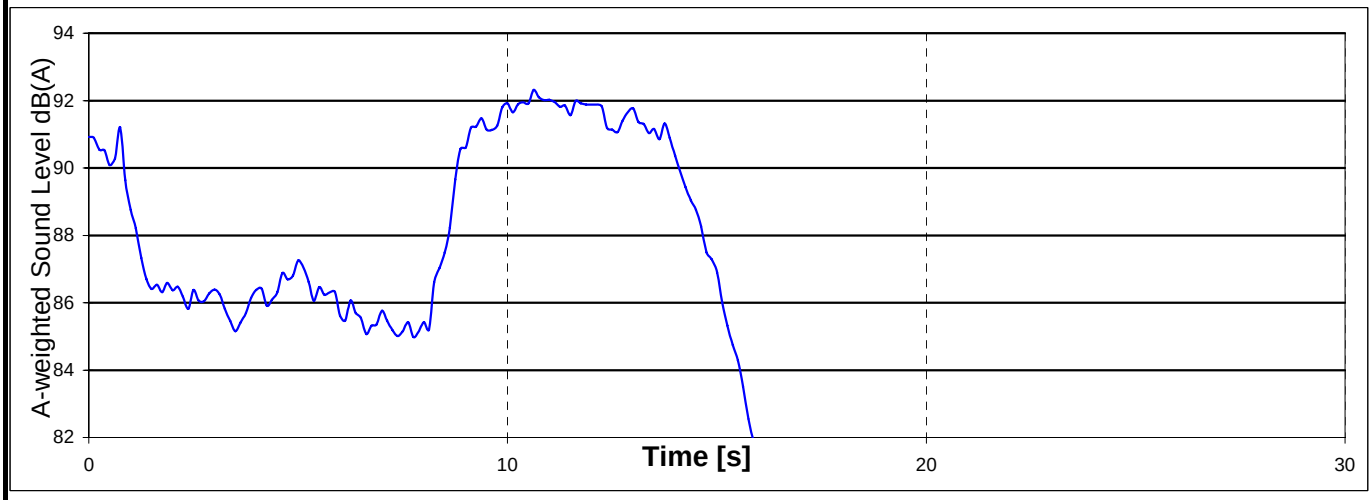
L_{Aeq} = **92 dB(A)**

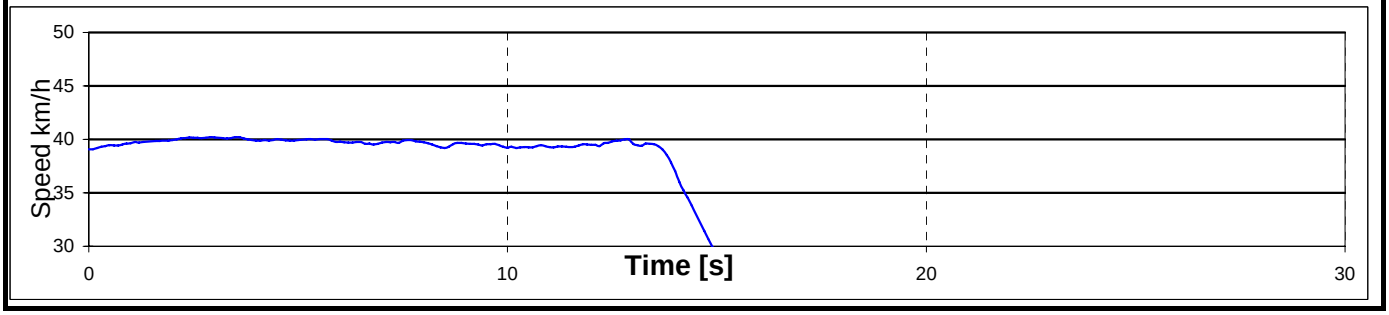
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**5**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

40 km/h

Poroelastic road surface

L_{Aeq} = **86 dB(A)**

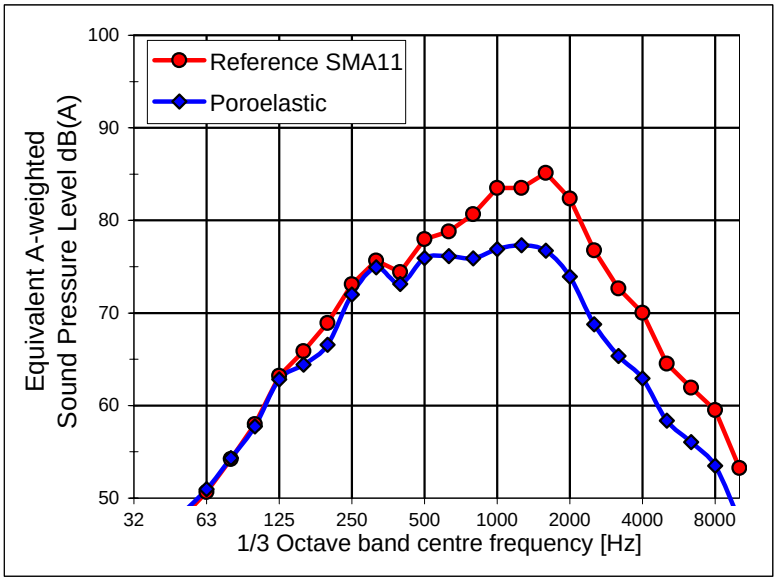
Reference road surface standard SMA11

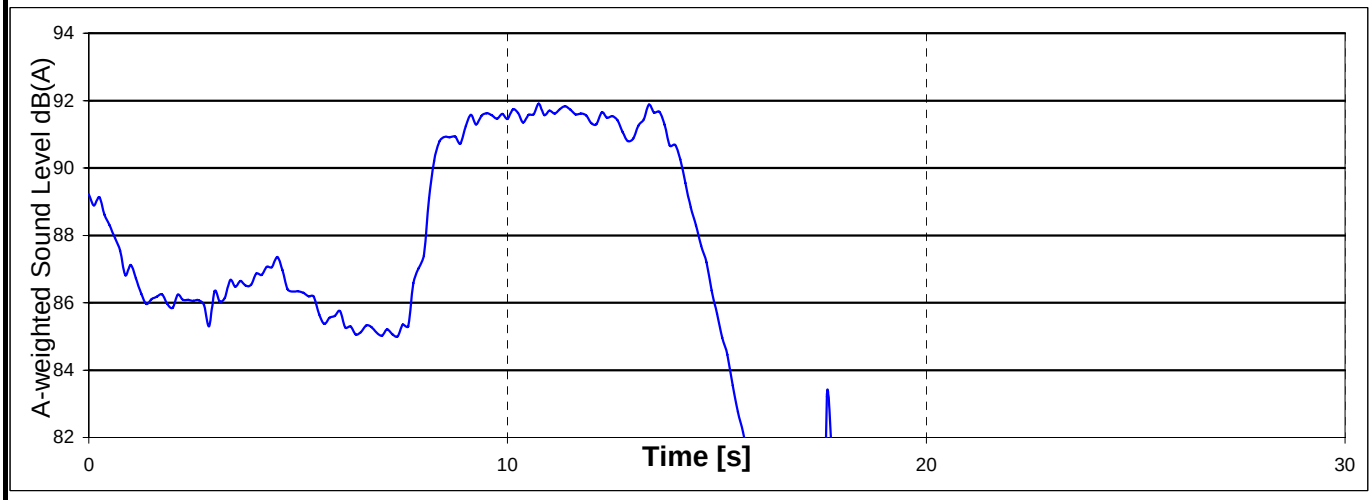
L_{Aeq} = **91 dB(A)**

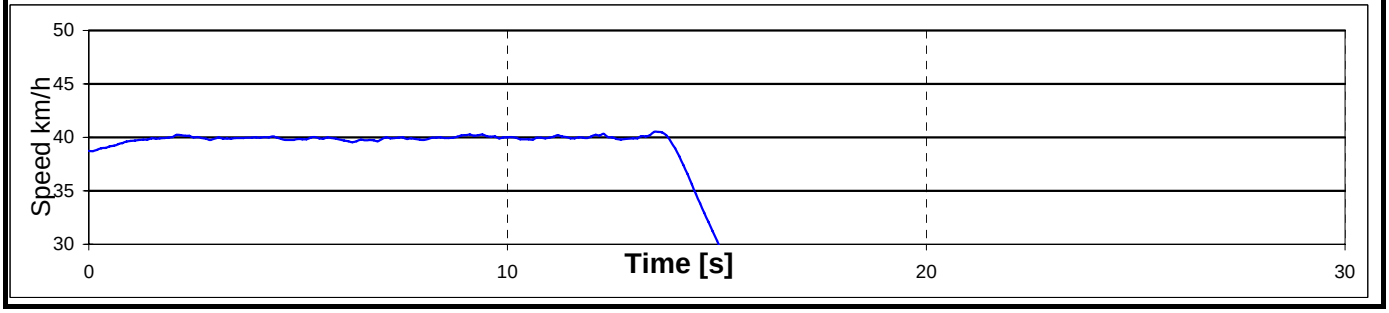
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**6**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

40 km/h

Poroelastic road surface

L_{Aeq} = **86 dB(A)**

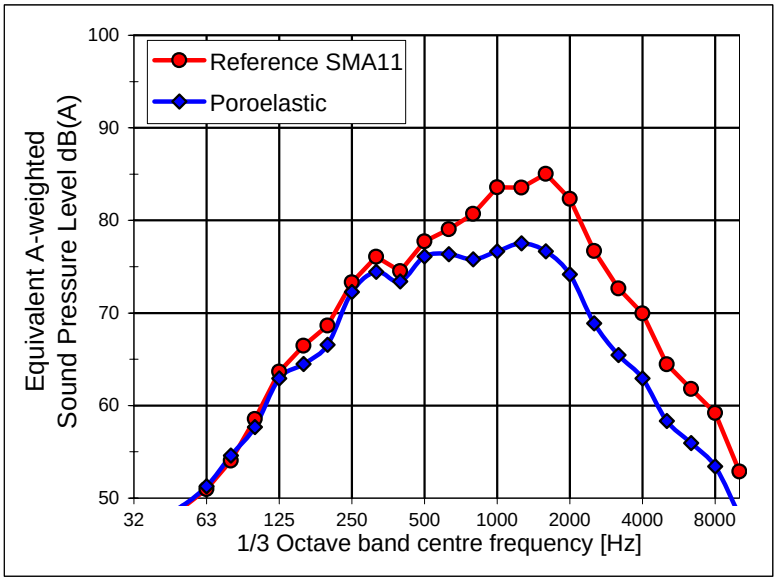
Reference road surface standard SMA11

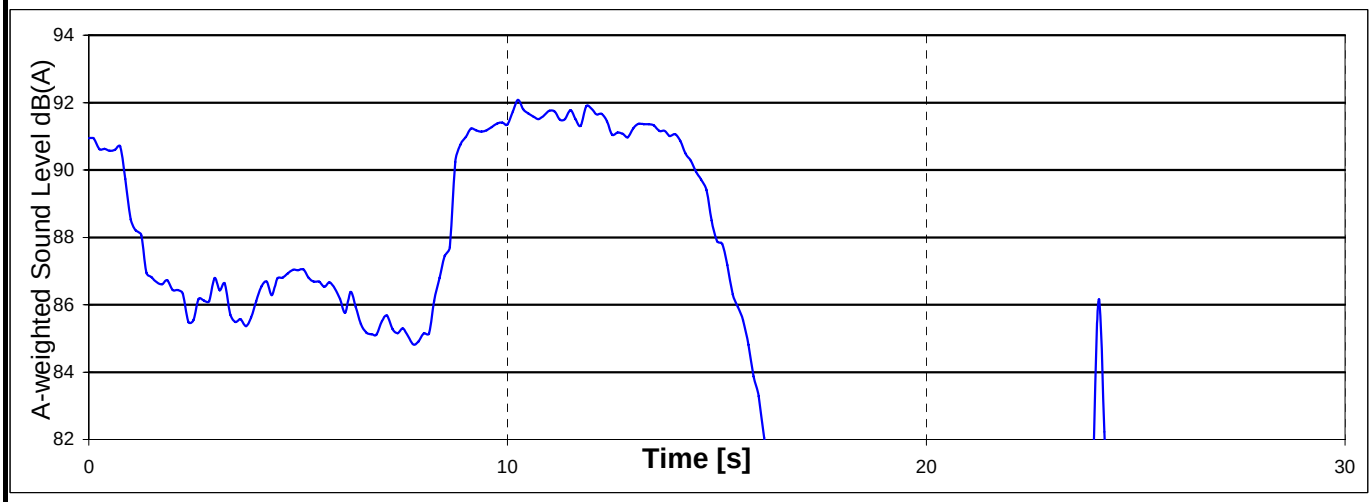
L_{Aeq} = **91 dB(A)**

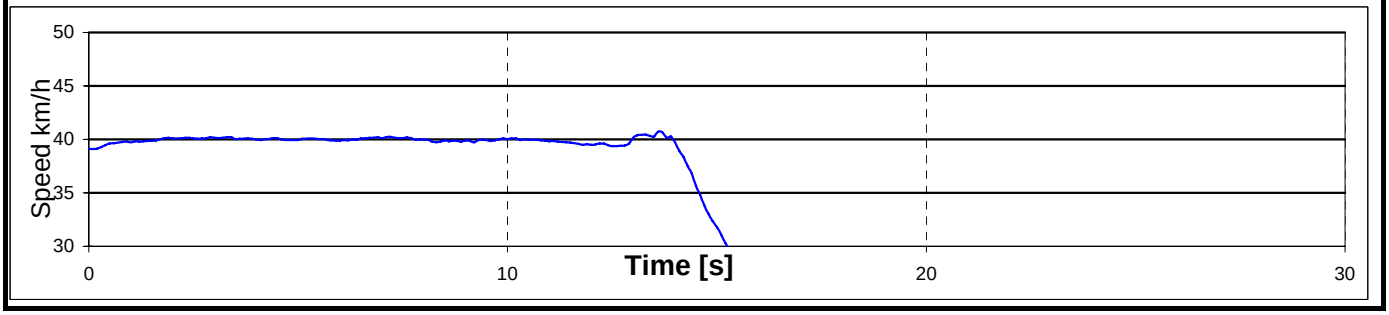
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**19**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

46-47 km/h

Poroelastic road surface

L_{Aeq} = **89 dB(A)**

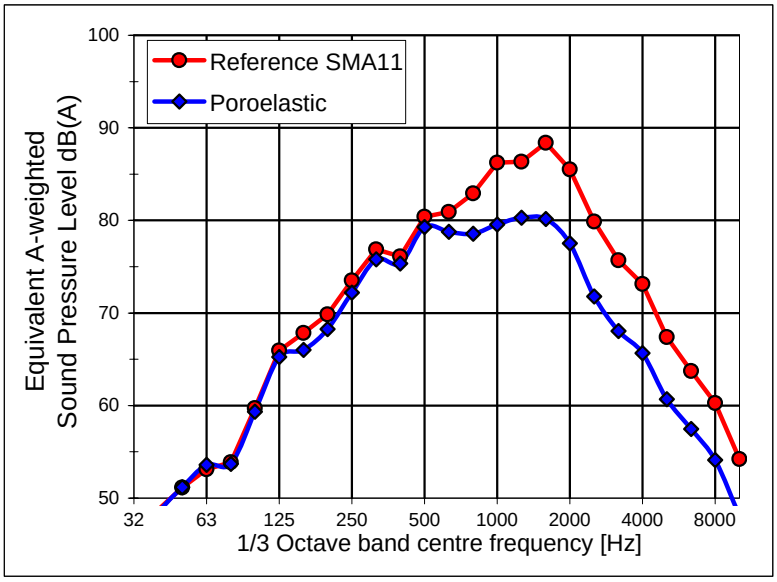
Reference road surface standard SMA11

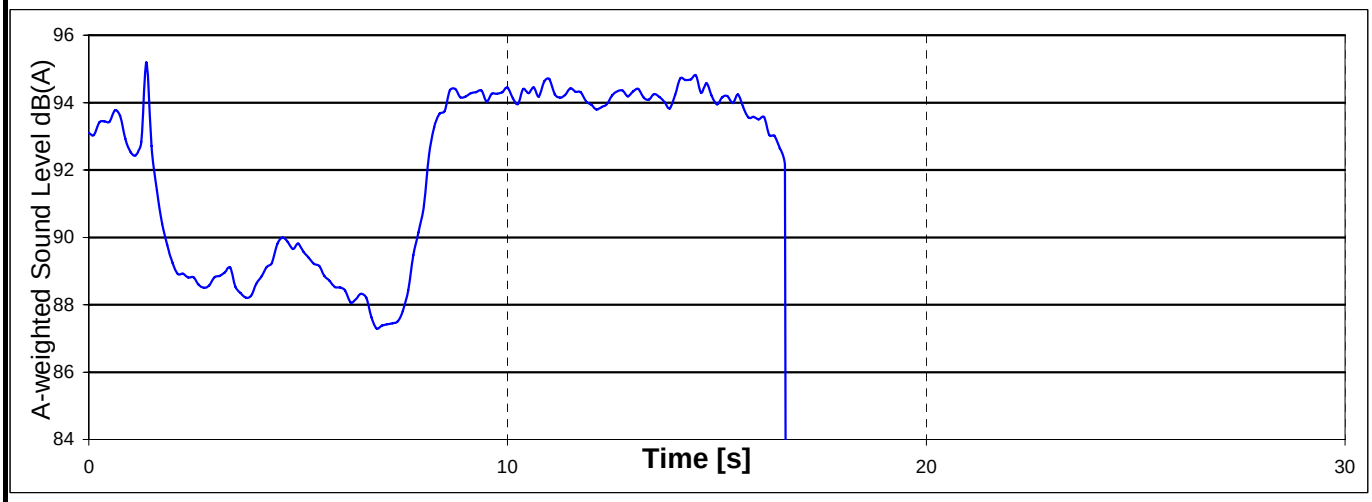
L_{Aeq} = **94 dB(A)**

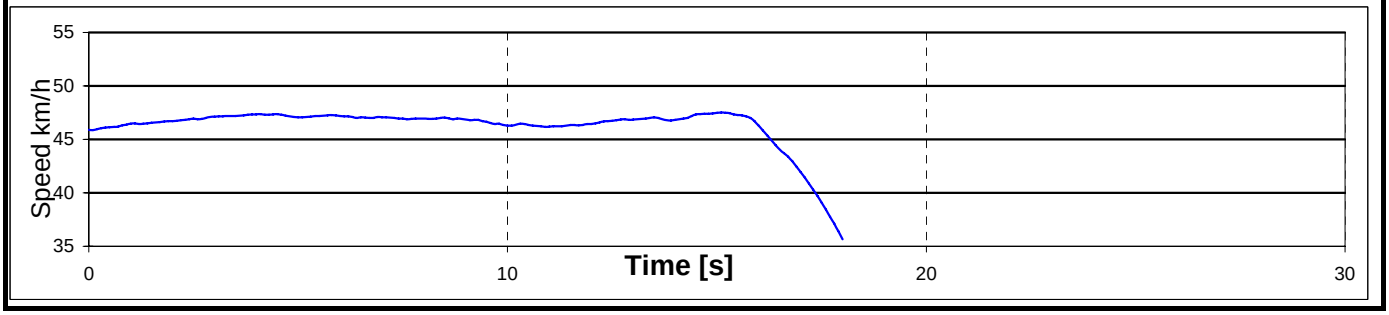
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420
PROJECT N°	FP6-516420
ACRONYM	QCITY
WORK PACKAGE	5.5

Car passage
20

Work task		Elaborator by	Date
	Measurement of road/tyre noise	Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

46-47 km/h

Poroelastic road surface

L_{Aeq} = **89 dB(A)**

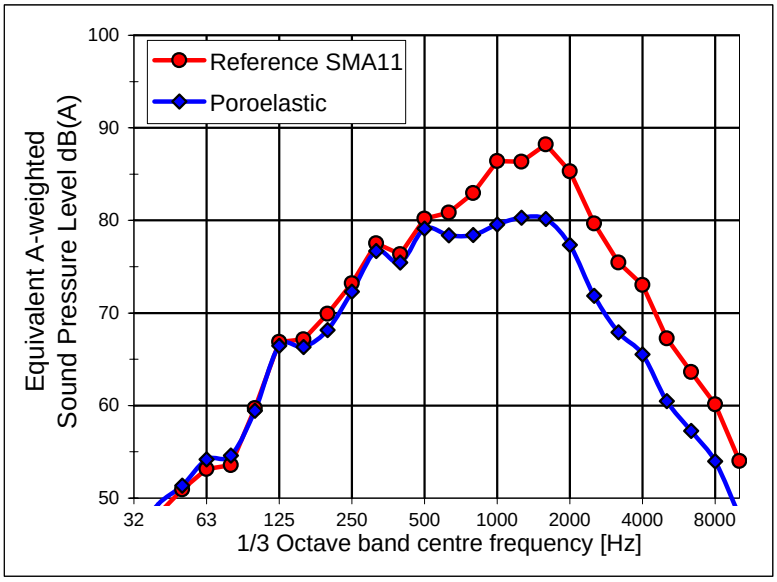
Reference road surface standard SMA11

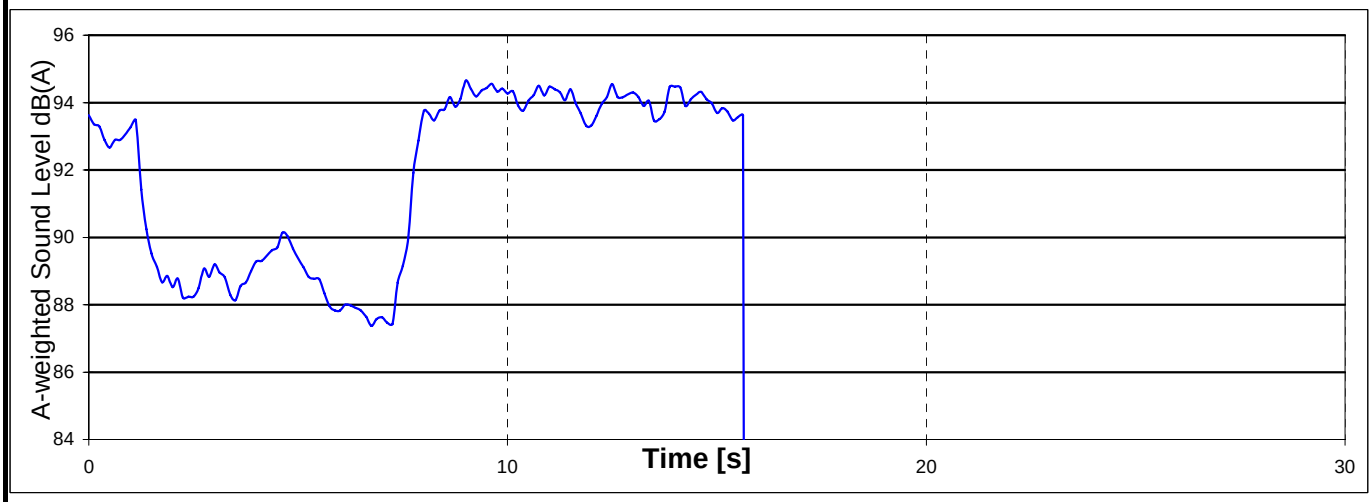
L_{Aeq} = **94 dB(A)**

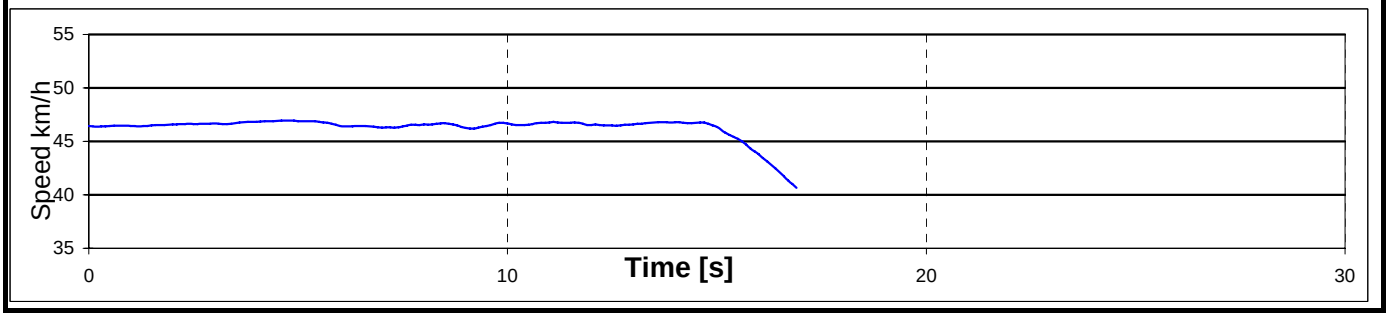
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420
PROJECT N°	FP6-516420
ACRONYM	QCITY
WORK PACKAGE	5.5

Car passage
7

Work task		Elaborator by	Date
	Measurement of road/tyre noise	Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

52 km/h

Poroelastic road surface

L_{Aeq} = **90 dB(A)**

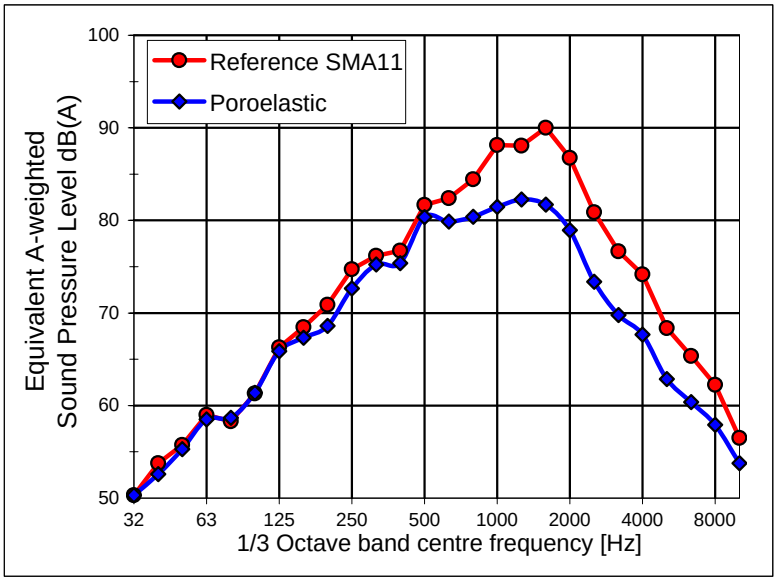
Reference road surface standard SMA11

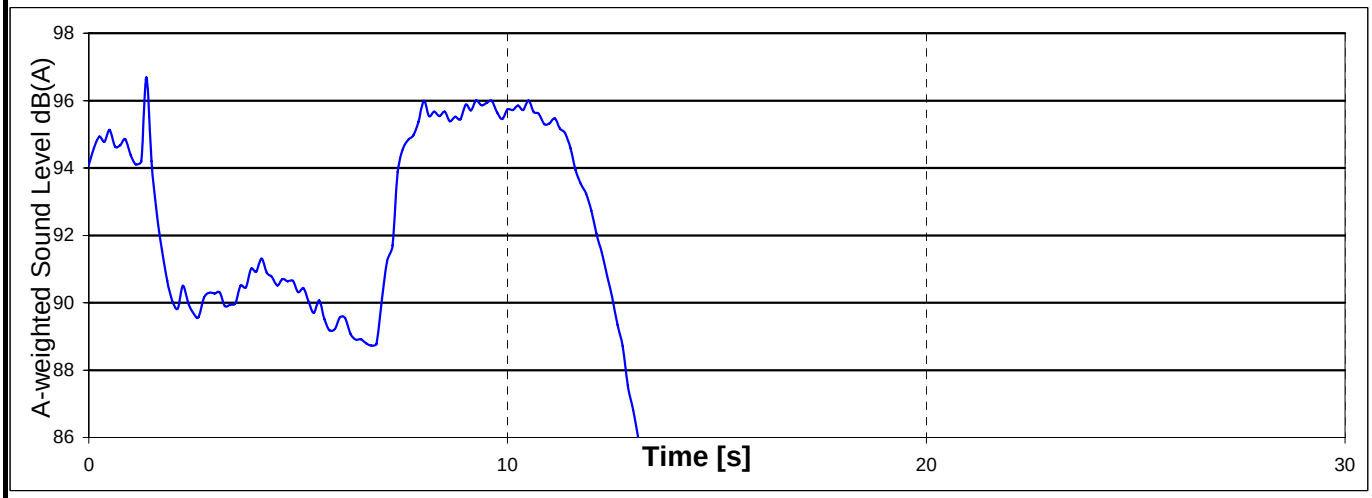
L_{Aeq} = **96 dB(A)**

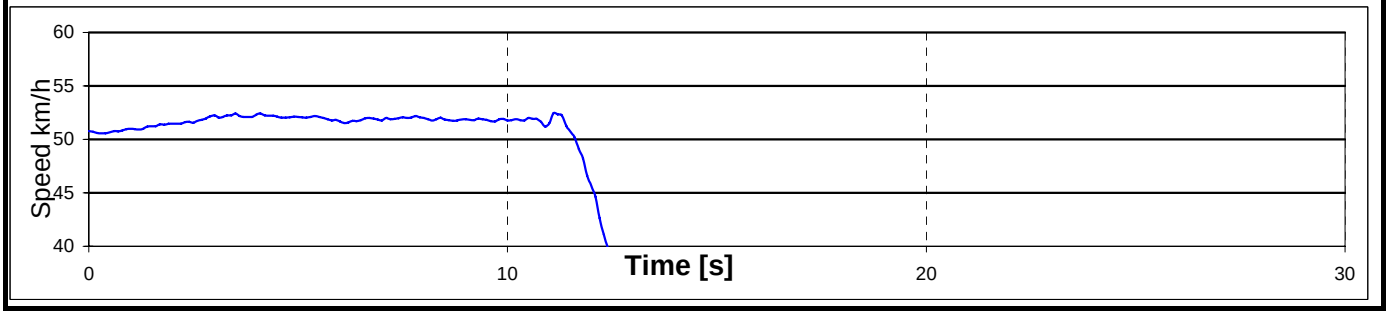
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**8**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

52 km/h

Poroelastic road surface

L_{Aeq} = **90 dB(A)**

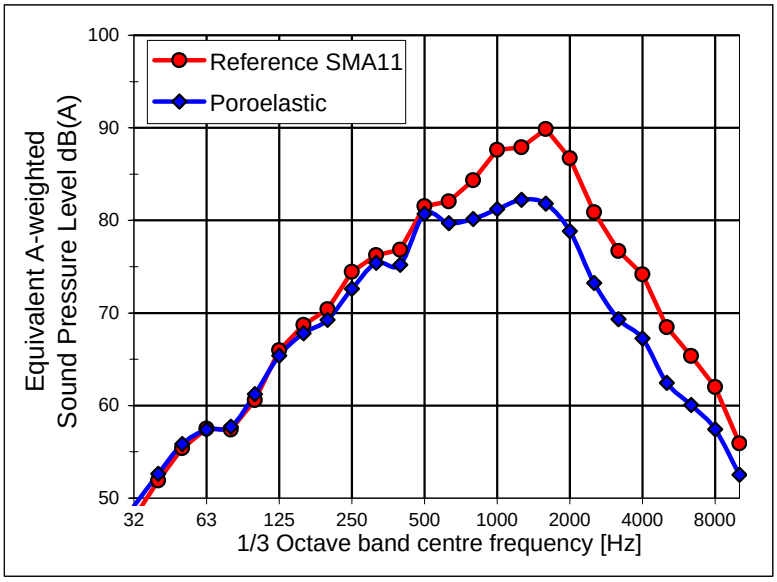
Reference road surface standard SMA11

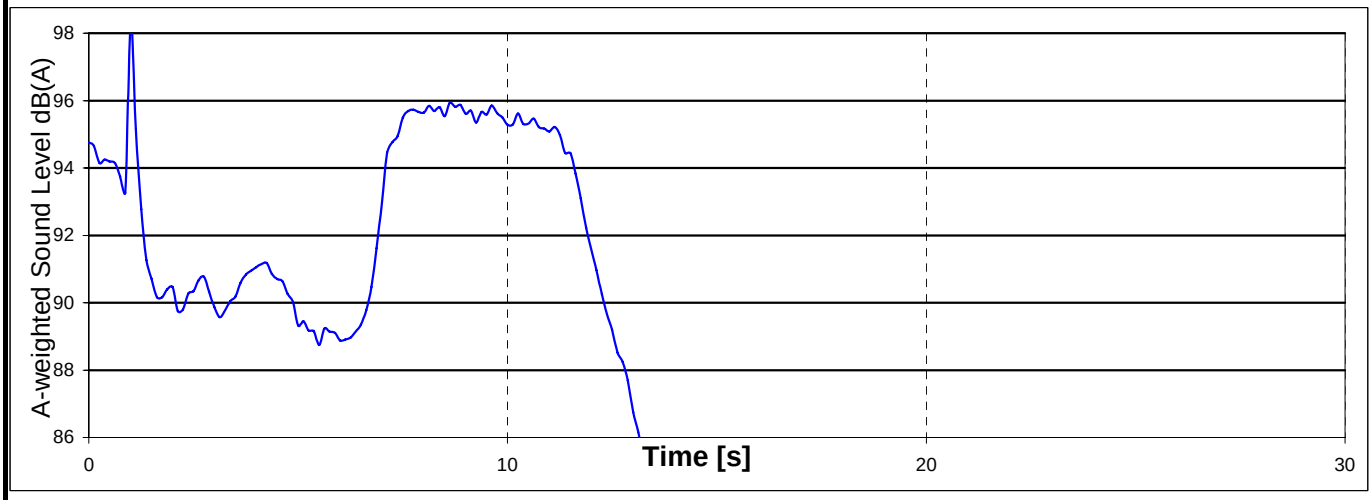
L_{Aeq} = **96 dB(A)**

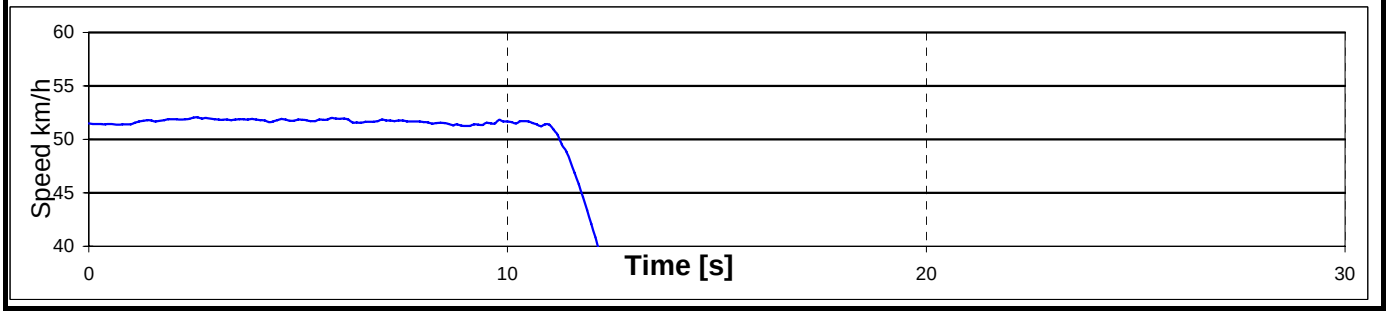
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420
PROJECT N°	FP6-516420
ACRONYM	QCITY
WORK PACKAGE	5.5

Car passage 9

Work task	Elaborator by	Date
Measurement of road/tyre noise	Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

52 km/h

Poroelastic road surface

L_{Aeq} = **90 dB(A)**

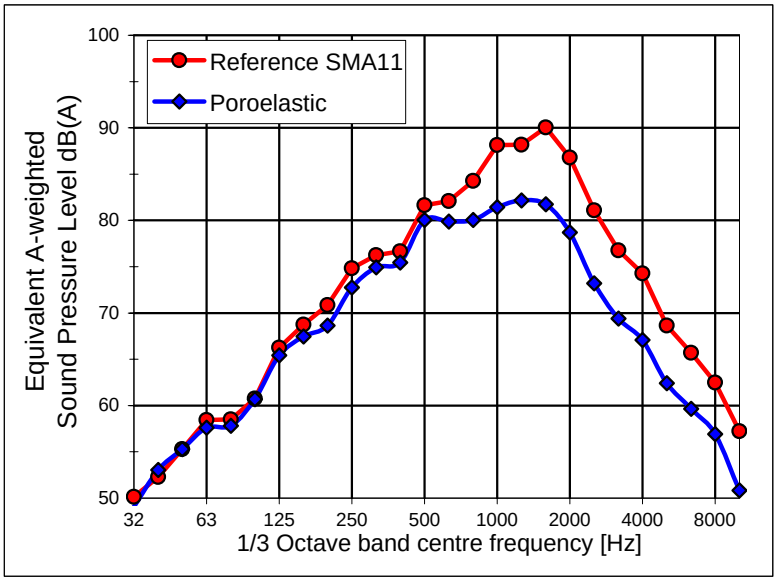
Reference road surface standard SMA11

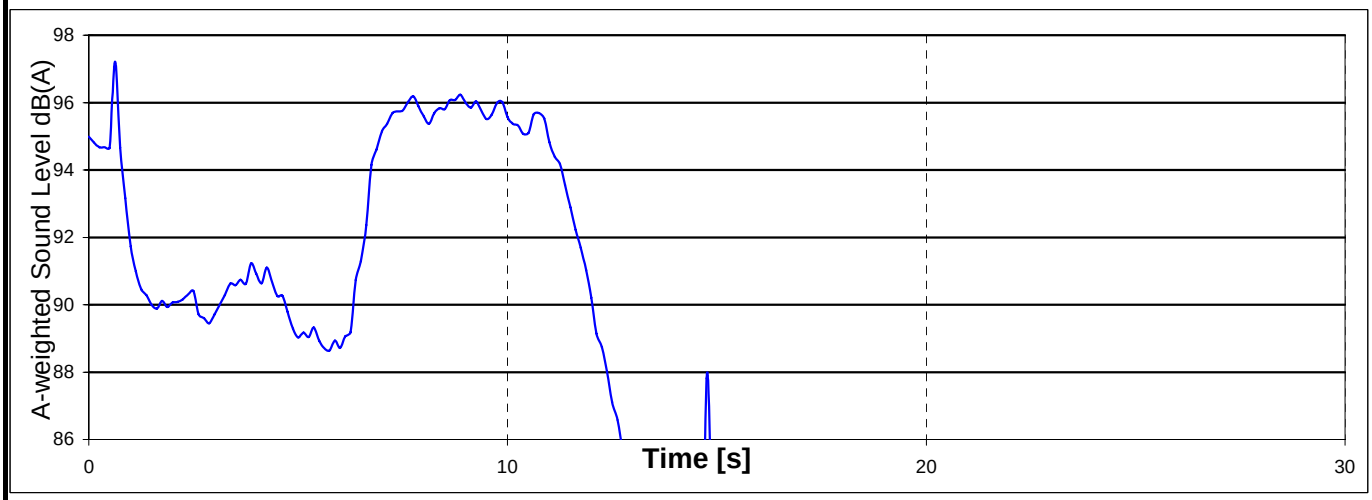
L_{Aeq} = **96 dB(A)**

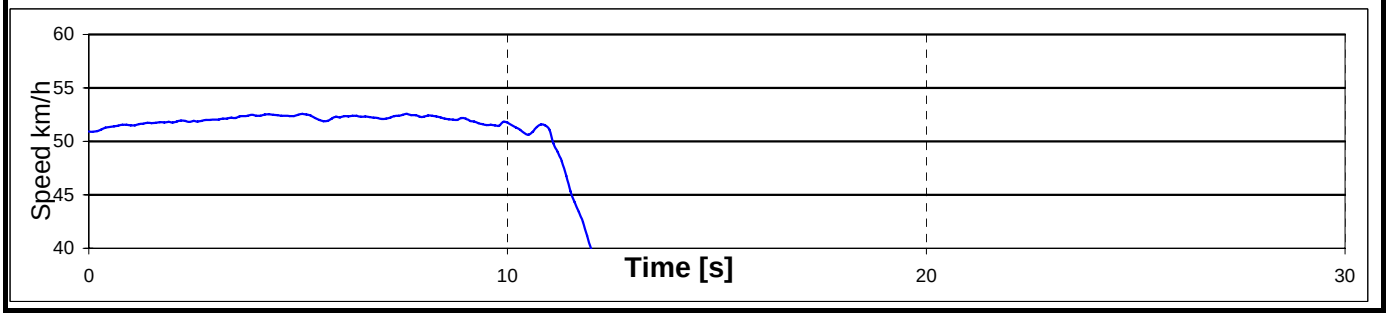
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420	**Car passage**	
PROJECT N°	FP6-516420	**21**	
ACRONYM	QCITY		
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

55 km/h

Poroelastic road surface

L_{Aeq} = **91 dB(A)**

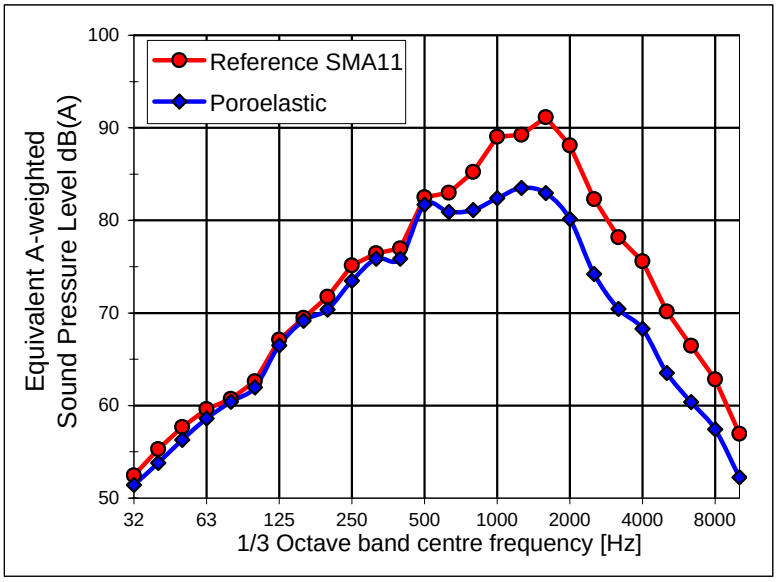
Reference road surface standard SMA11

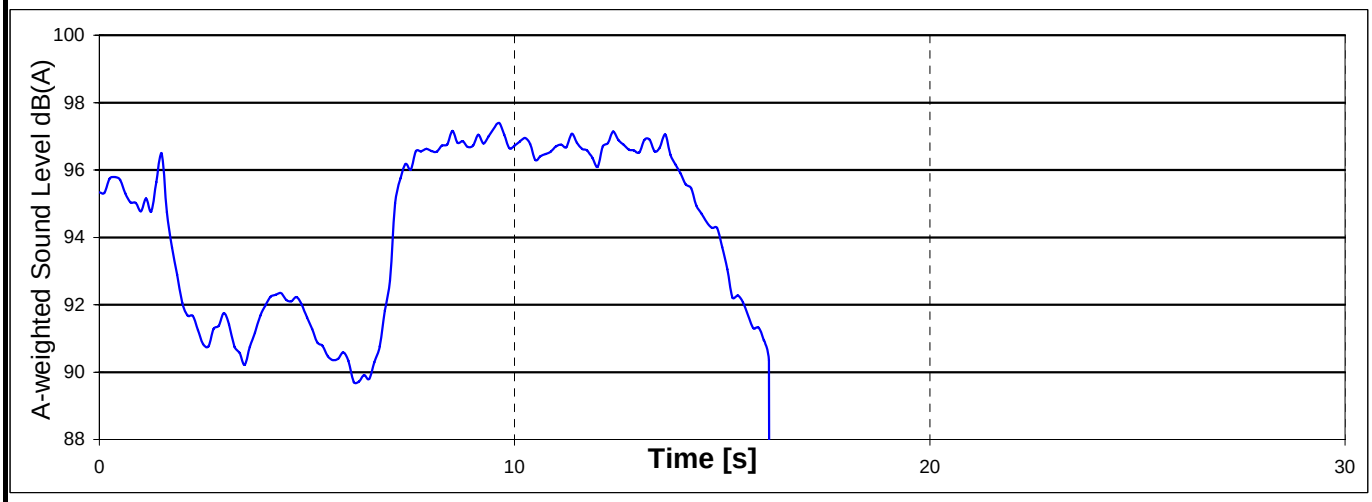
L_{Aeq} = **97 dB(A)**

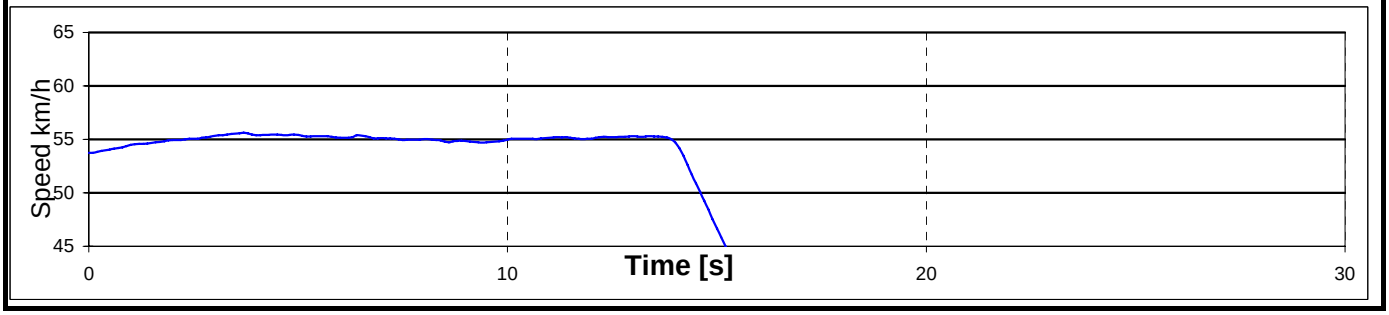
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420	**Car passage**	
PROJECT N°	FP6-516420	**22**	
ACRONYM	QCITY		
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

55 km/h

Poroelastic road surface

L_{Aeq} = **91 dB(A)**

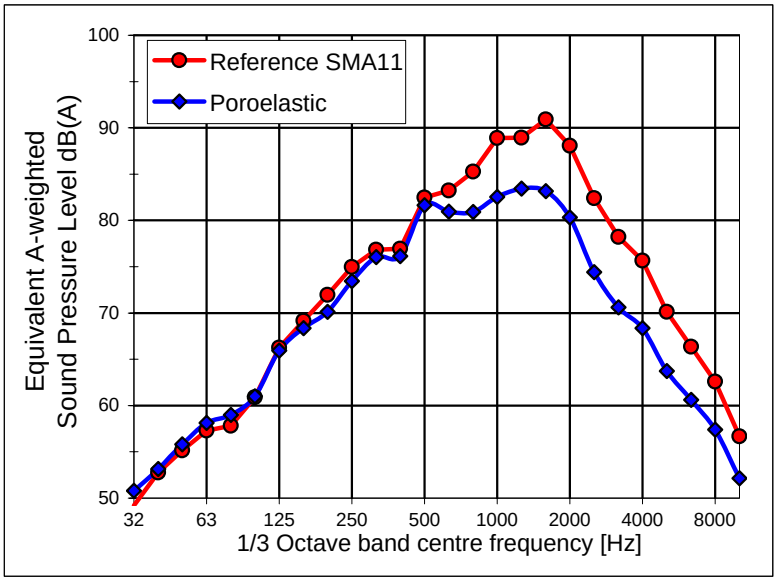
Reference road surface standard SMA11

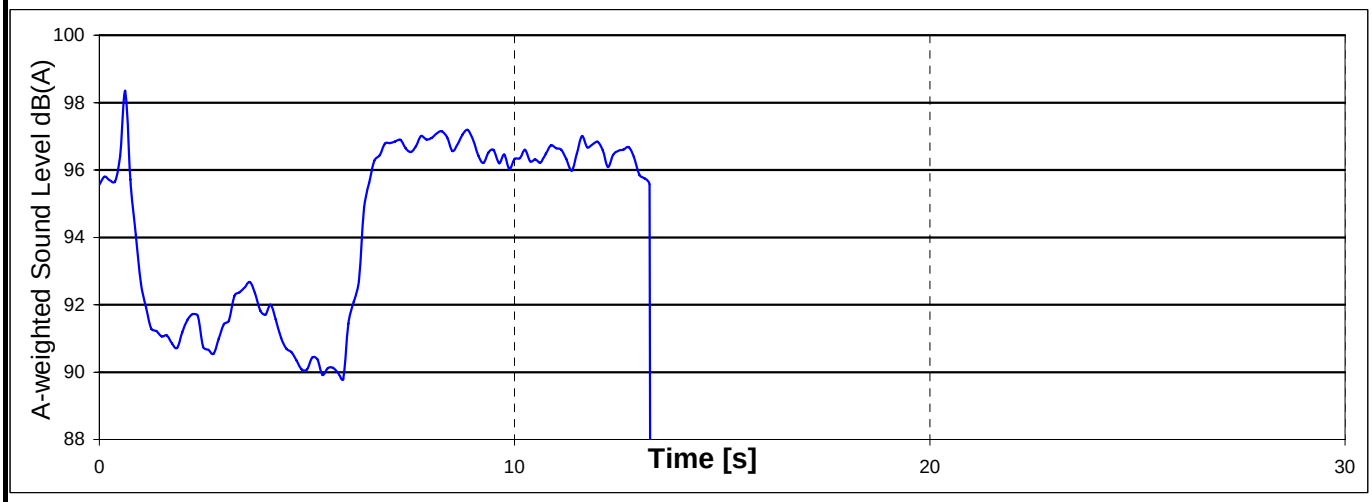
L_{Aeq} = **97 dB(A)**

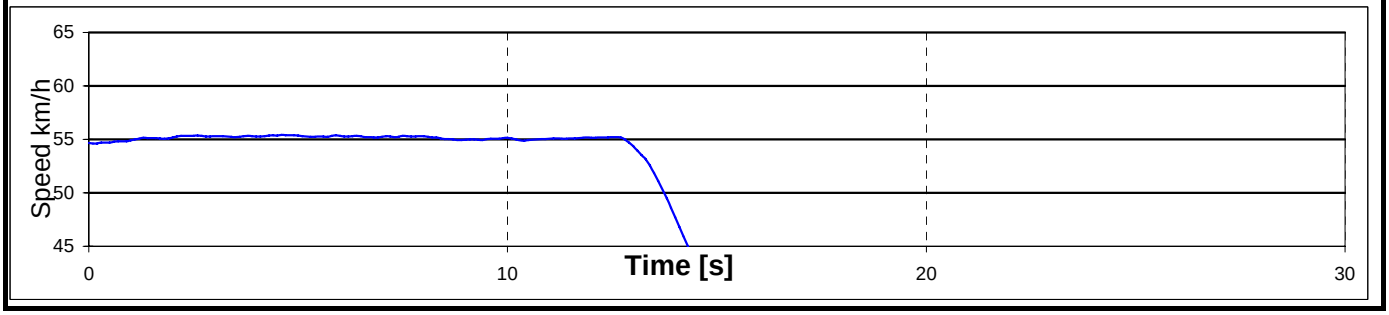
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**10**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

62 km/h

Poroelastic road surface

L_{Aeq} = **93 dB(A)**

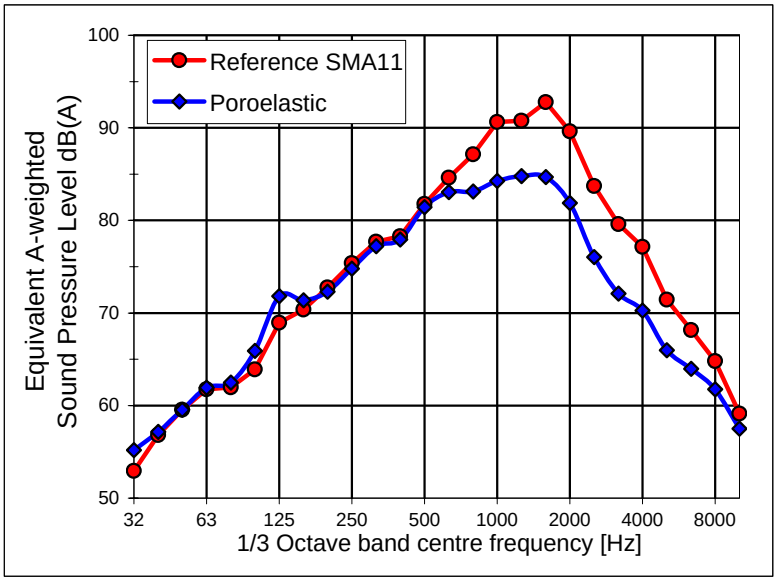
Reference road surface standard SMA11

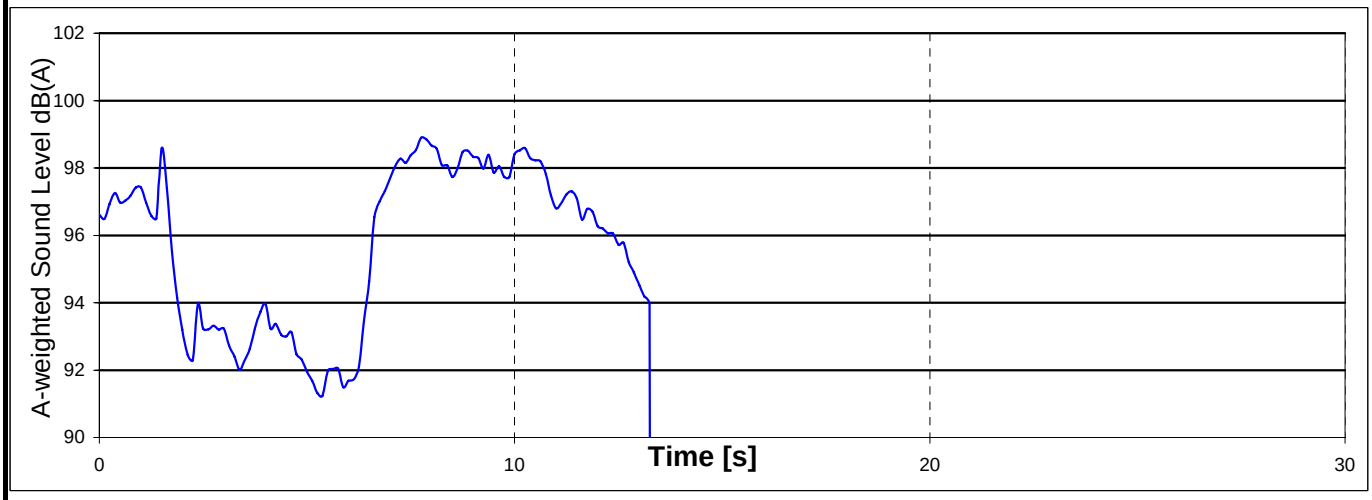
L_{Aeq} = **98 dB(A)**

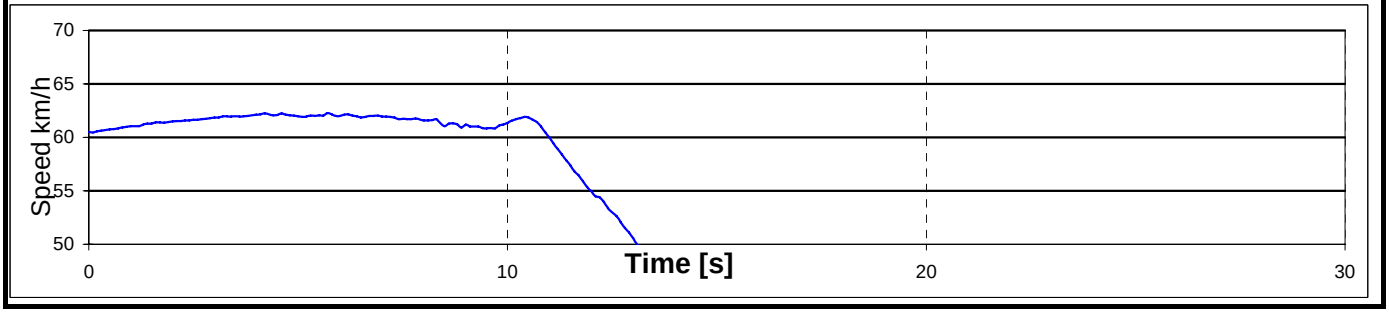
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420
PROJECT N°	FP6-516420
ACRONYM	QCITY
WORK PACKAGE	5.5

Car passage
11

Work task	Elaborator by	Date
Measurement of road/tyre noise	Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

62 km/h

Poroelastic road surface

L_{Aeq} = **93 dB(A)**

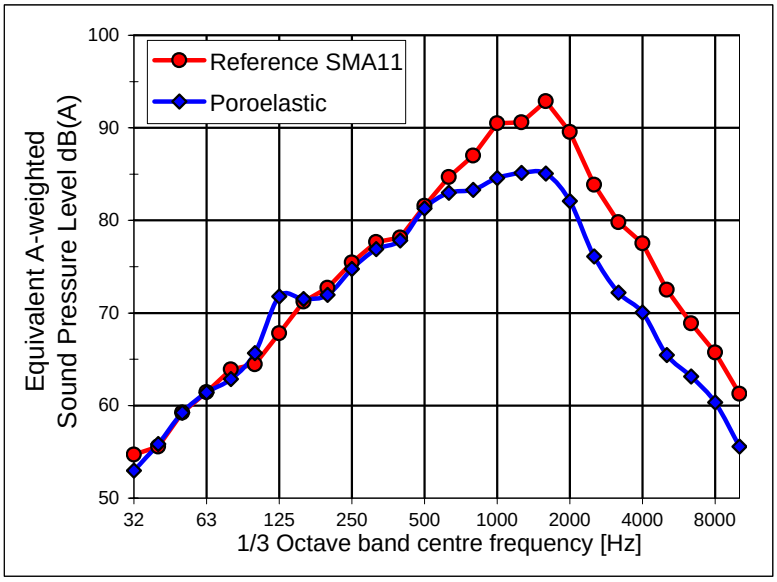
Reference road surface standard SMA11

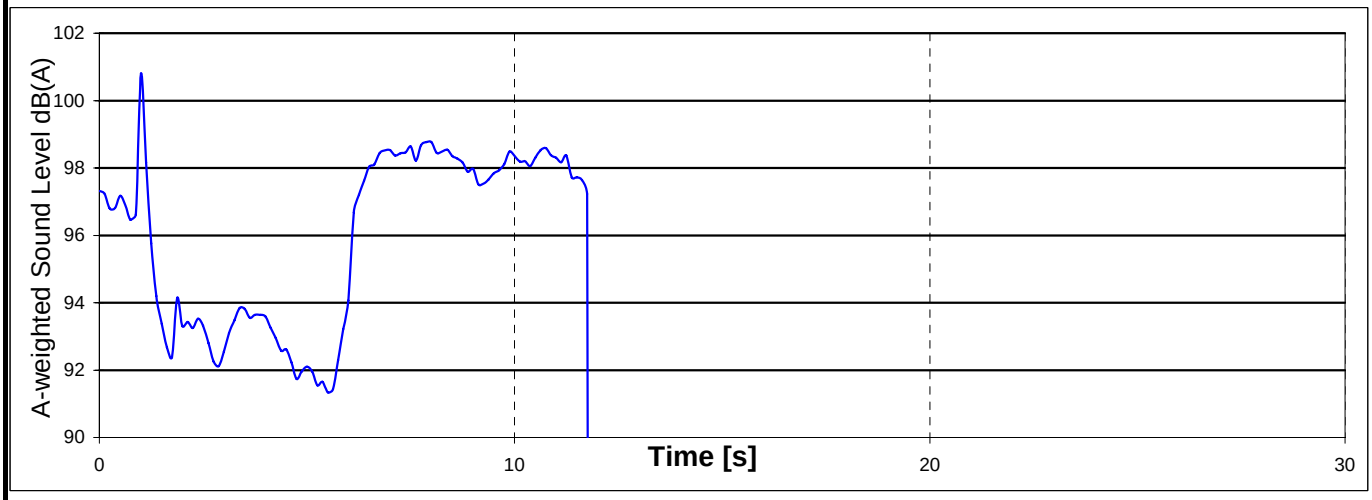
L_{Aeq} = **98 dB(A)**

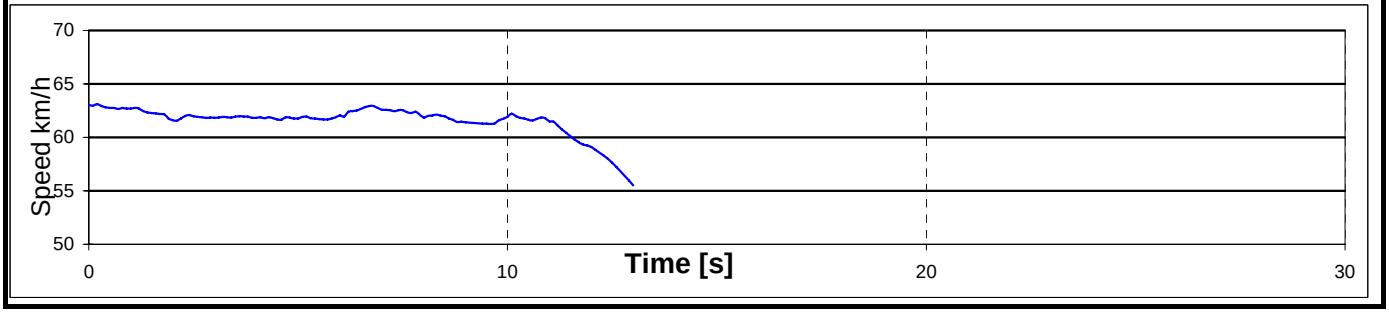
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**12**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

62-63 km/h

Poroelastic road surface

L_{Aeq} = **93 dB(A)**

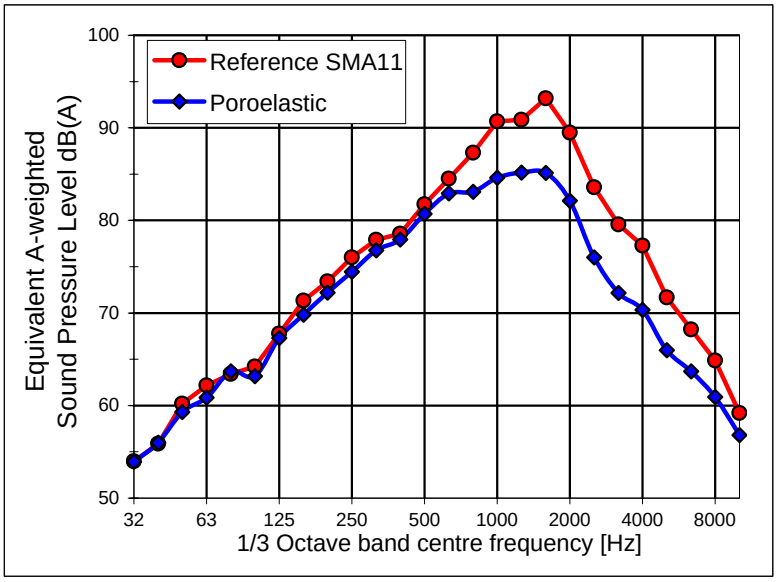
Reference road surface standard SMA11

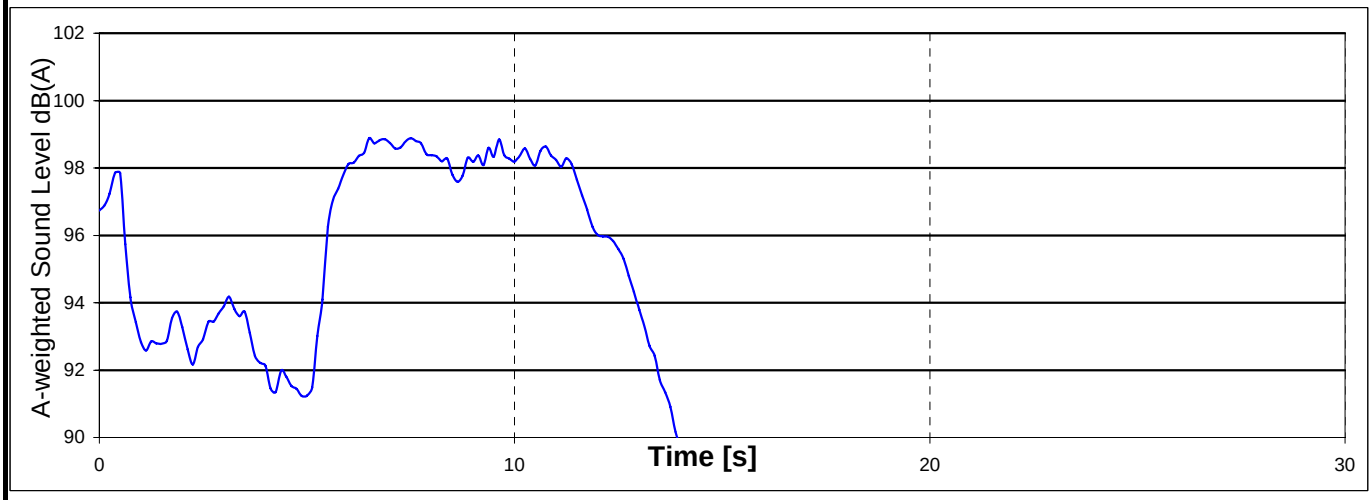
L_{Aeq} = **98 dB(A)**

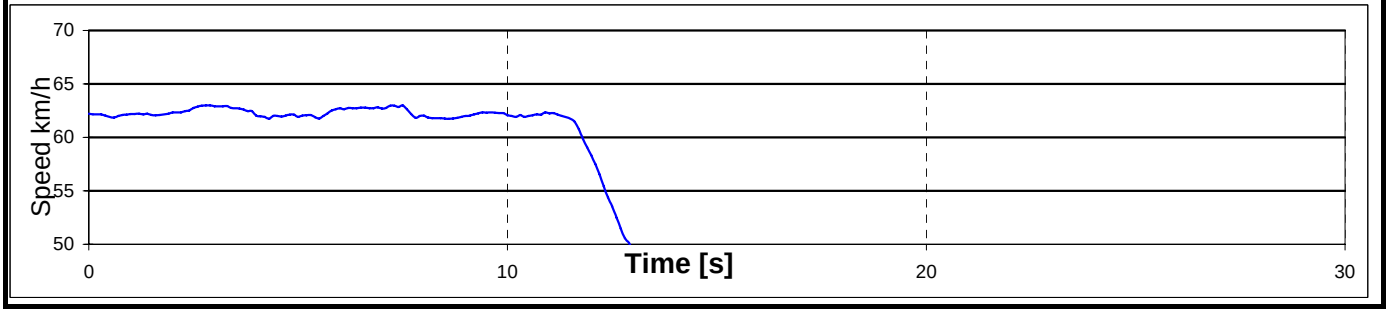
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**13**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

61-63 km/h

Poroelastic road surface

L_{Aeq} = **93 dB(A)**

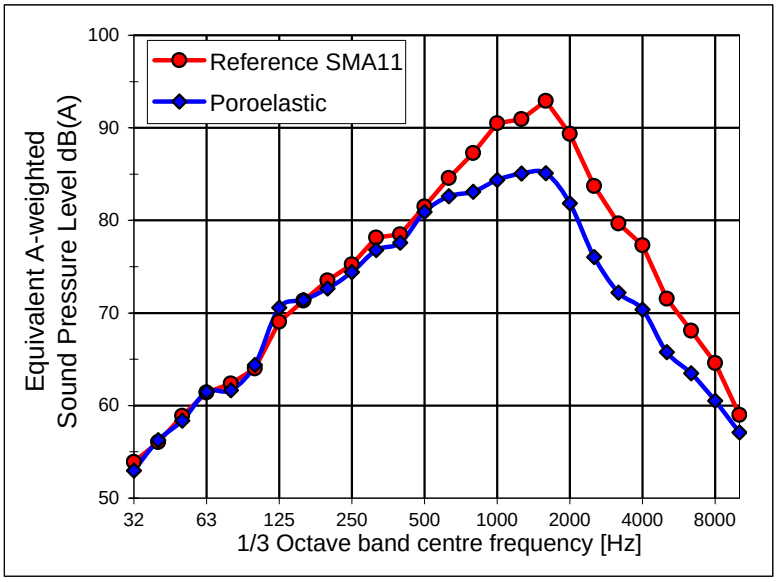
Reference road surface standard SMA11

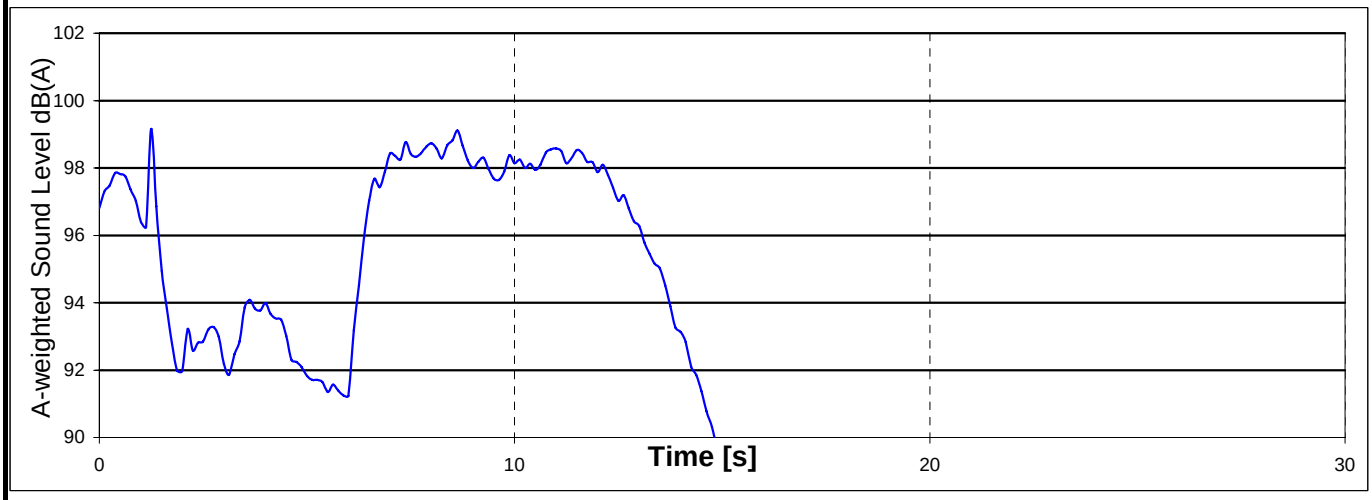
L_{Aeq} = **98 dB(A)**

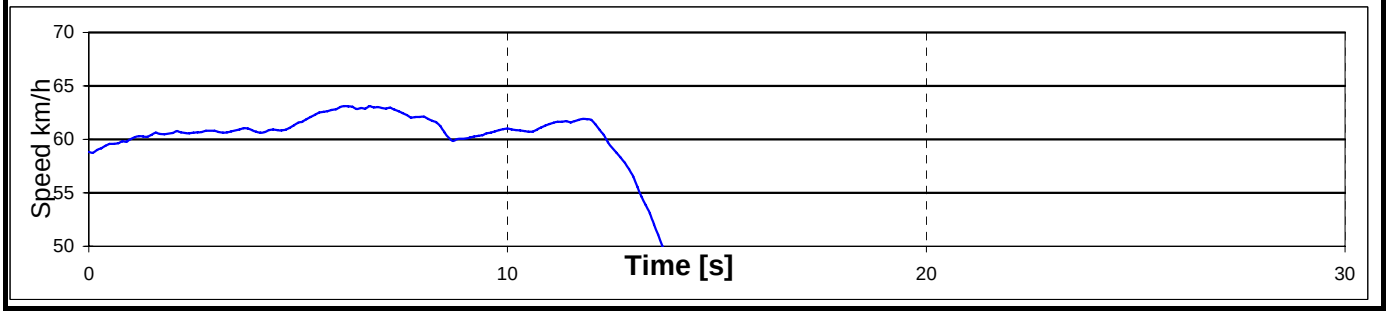
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**23**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

66 km/h

Poroelastic road surface

L_{Aeq} = **94 dB(A)**

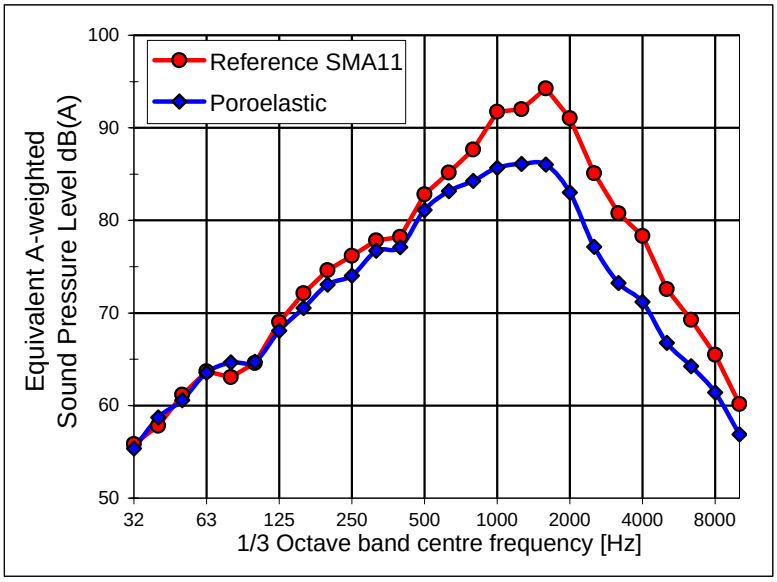
Reference road surface standard SMA11

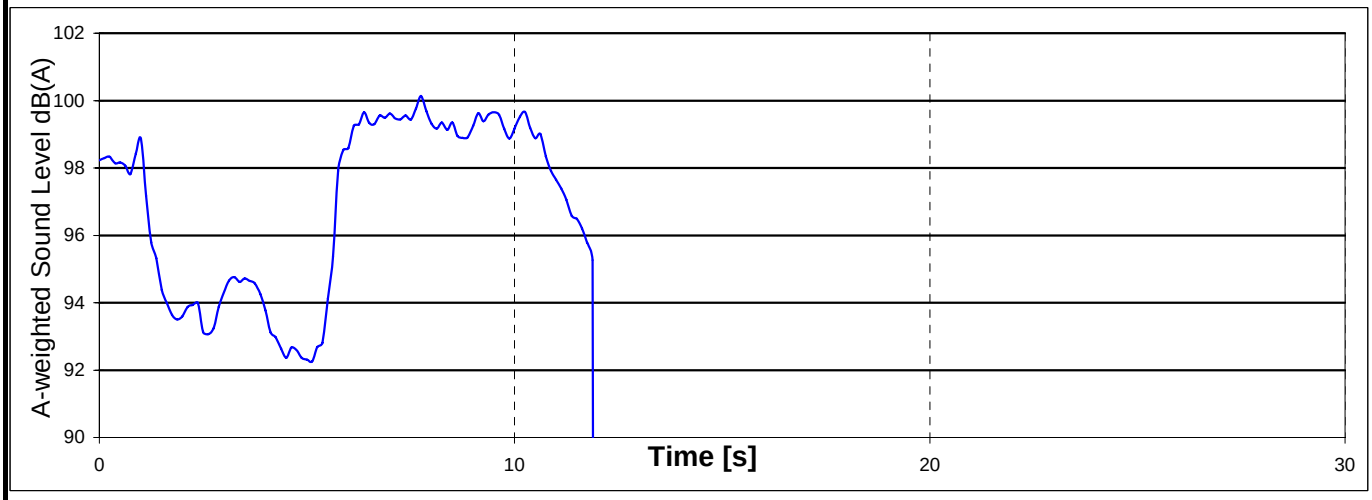
L_{Aeq} = **100 dB(A)**

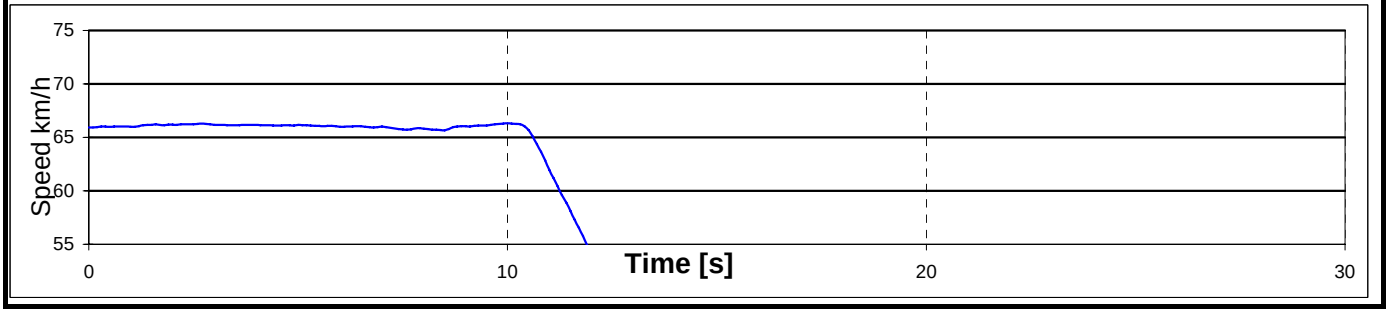
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**24**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

66 km/h

Poroelastic road surface

L_{Aeq} = **94 dB(A)**

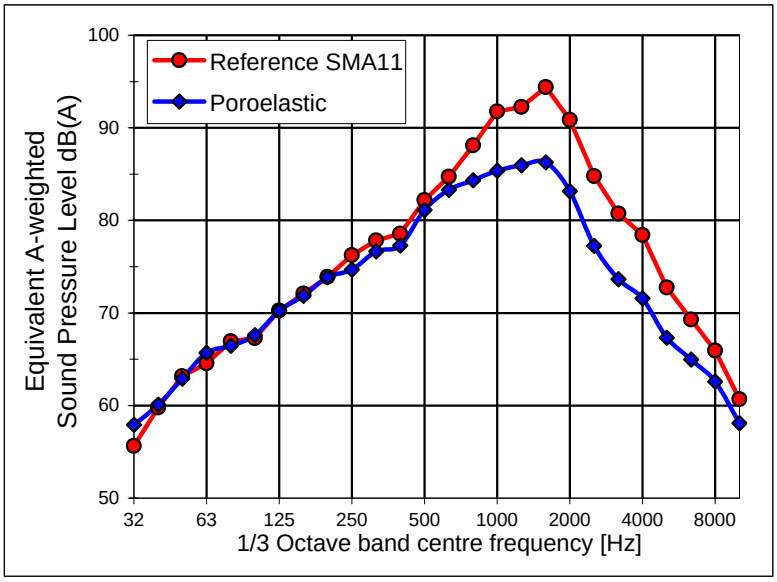
Reference road surface standard SMA11

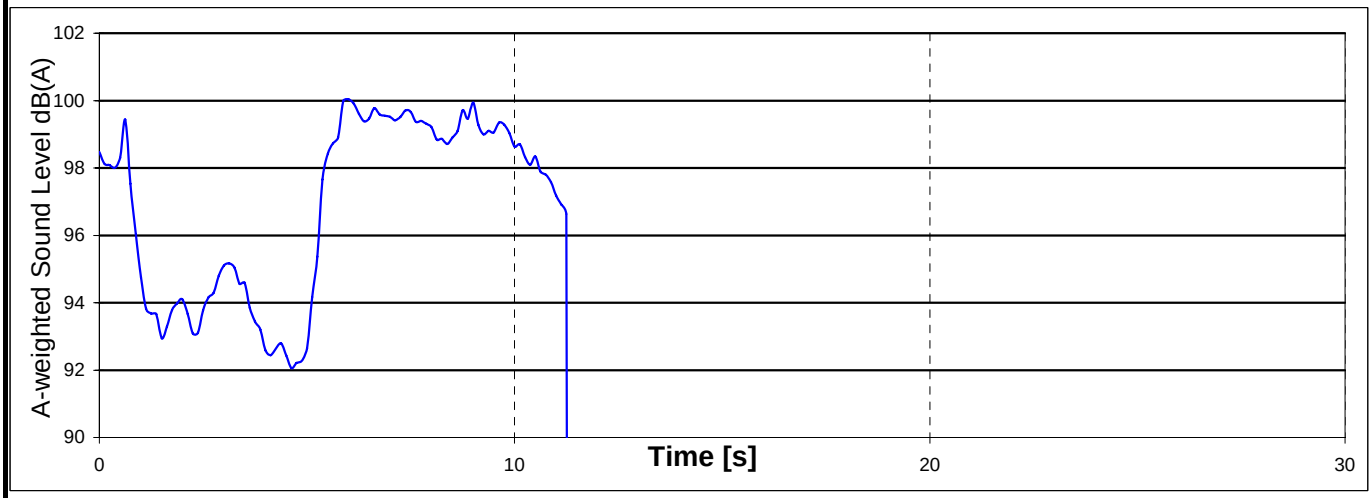
L_{Aeq} = **100 dB(A)**

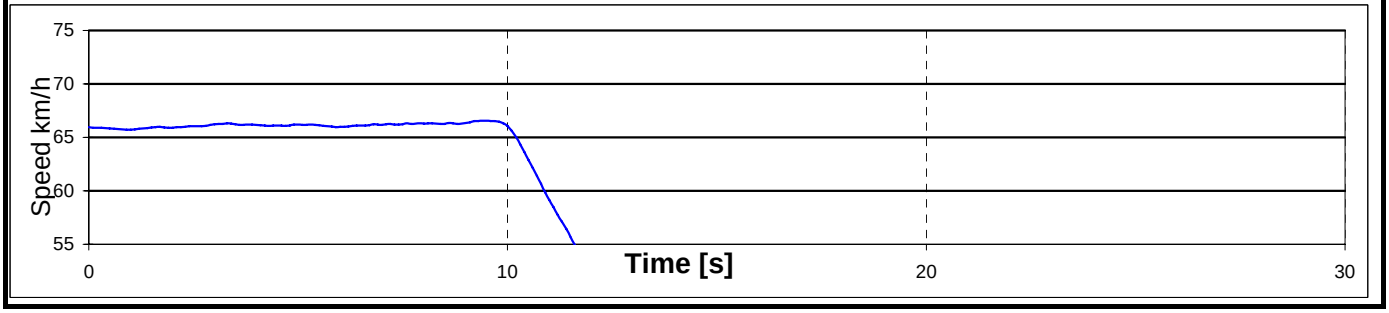
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**14**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

70-72 km/h

Poroelastic road surface

L_{Aeq} = **95 dB(A)**

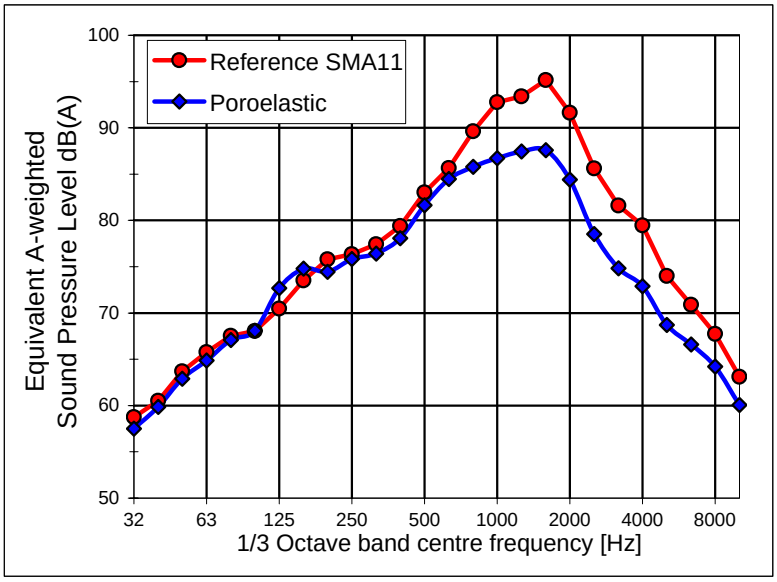
Reference road surface standard SMA11

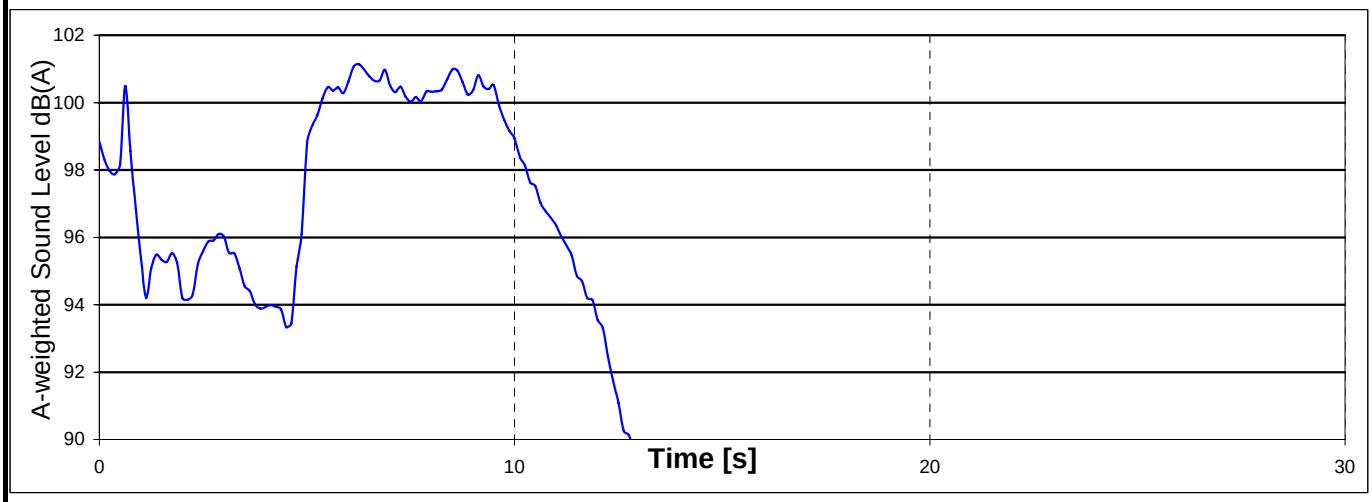
L_{Aeq} = **101 dB(A)**

MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.





Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**15**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

71-72 km/h

Poroelastic road surface

L_{Aeq} = **95 dB(A)**

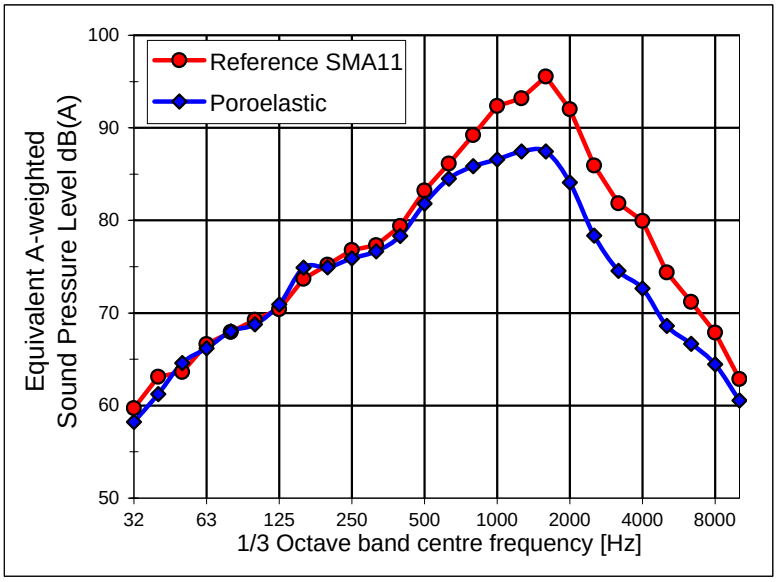
Reference road surface standard SMA11

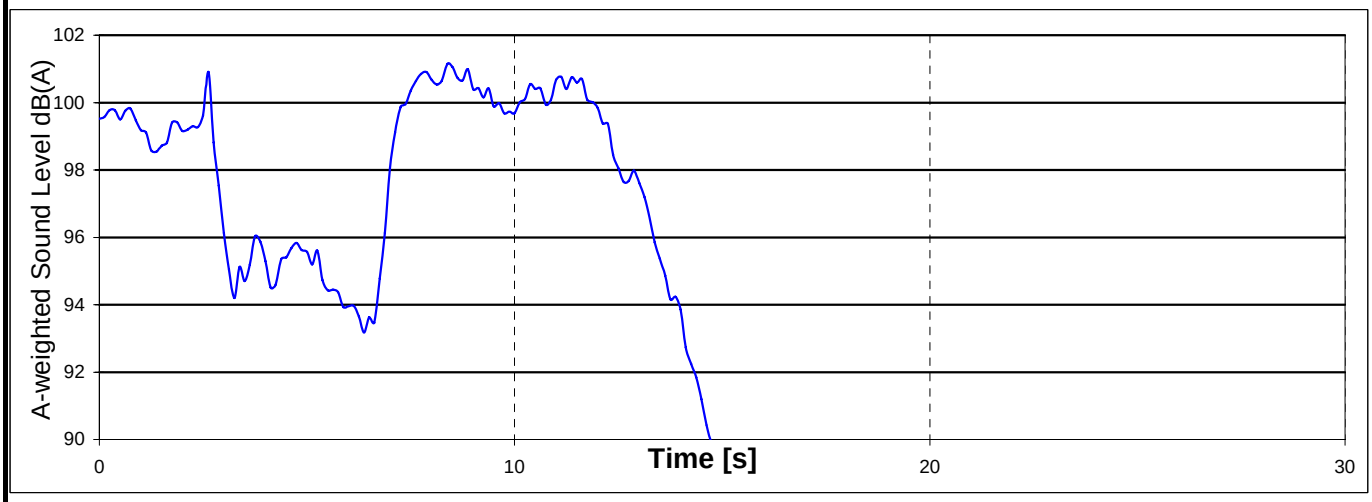
L_{Aeq} = **101 dB(A)**

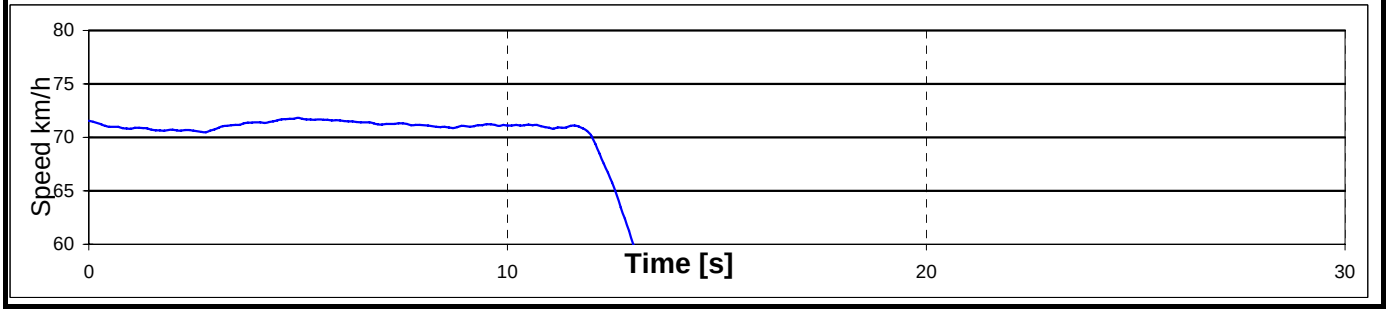
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.







Measurement of tyre/road noise with CPX

ACOUSTIC CONTROL LABORATORIES

CONTRACT N°	TIP4-CT-2005-516420		
PROJECT N°	FP6-516420	**Car passage**	
ACRONYM	QCITY	**16**	
WORK PACKAGE	5.5		
Work task	Measurement of road/tyre noise	Elaborator by	Date
		Henrik Malker	20061004

Applied measurement standard: ISO/CD 11819-2 to applicable extend.

Test object

Poroelastic road surface
Reference road surface standard SMA11

Speed

71 km/h

Poroelastic road surface

L_{Aeq} = **95 dB(A)**

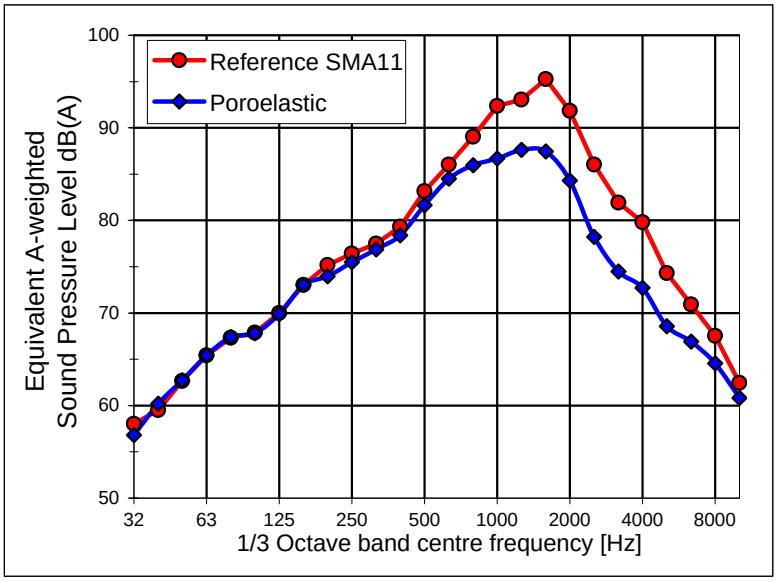
Reference road surface standard SMA11

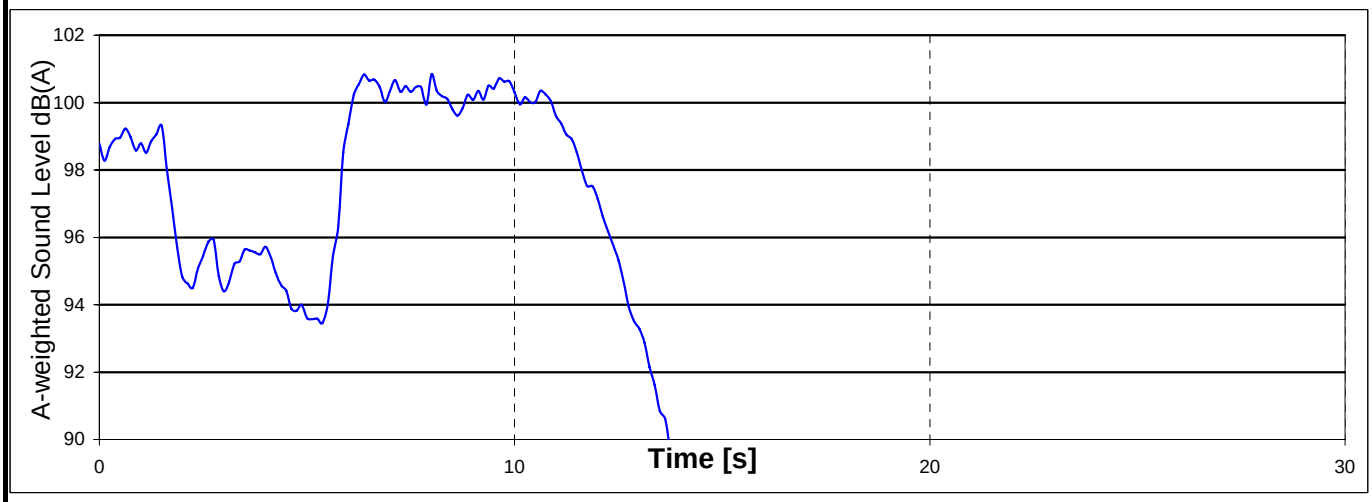
L_{Aeq} = **100 dB(A)**

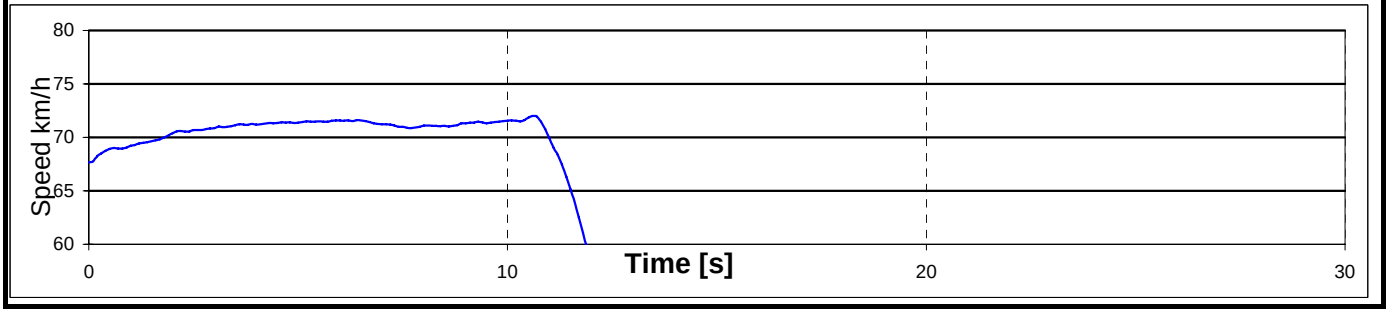
MEASUREMENT EQUIPMENT
Frequency analyser: Brüel & Kjaer Portable PULSE
Microphones: Brüel & Kjaer type 4189 A 021
Calibrator: Norsonic

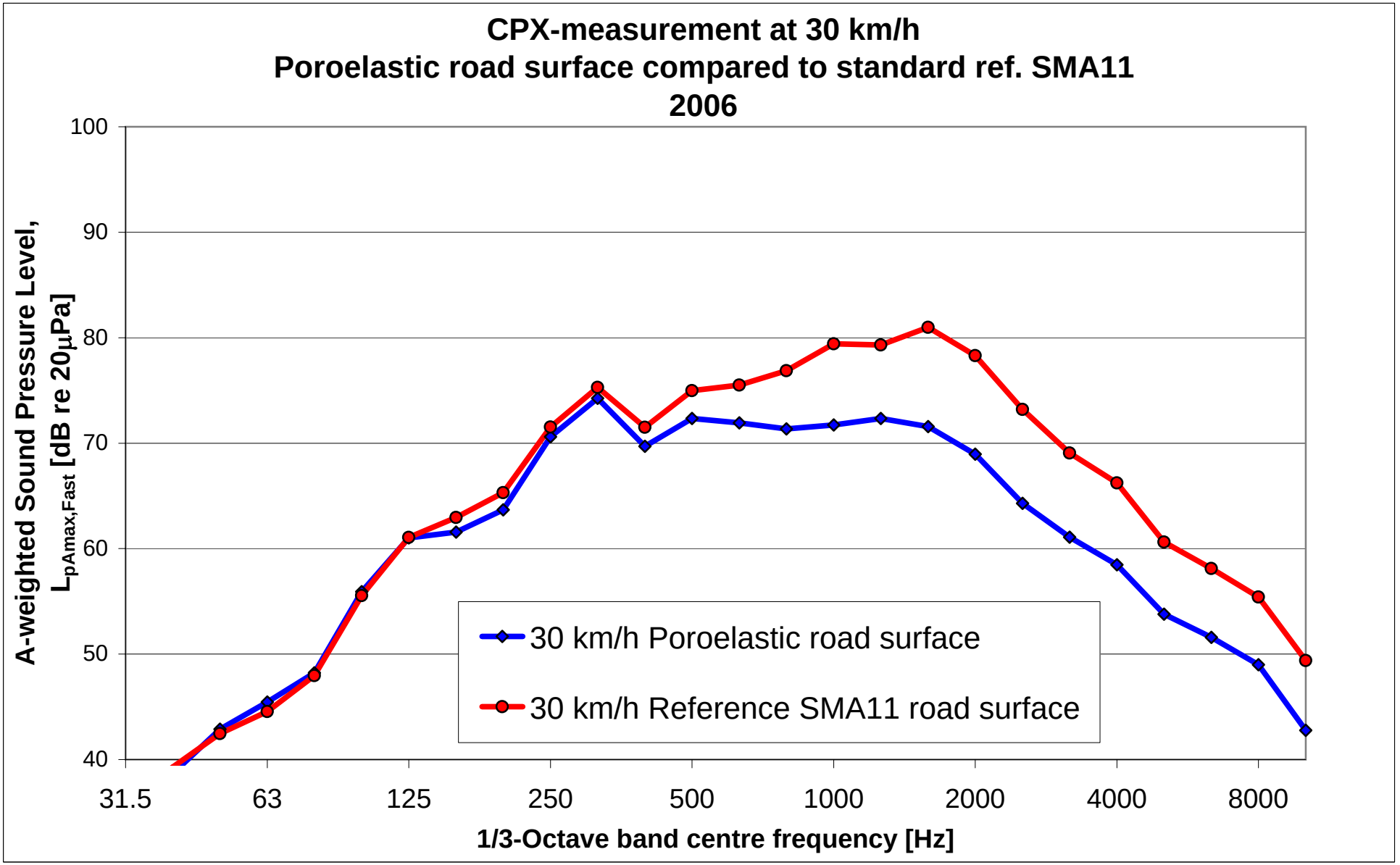
TEST TYRE
Goodyear Hydragrip
Dimension: 195/65R15

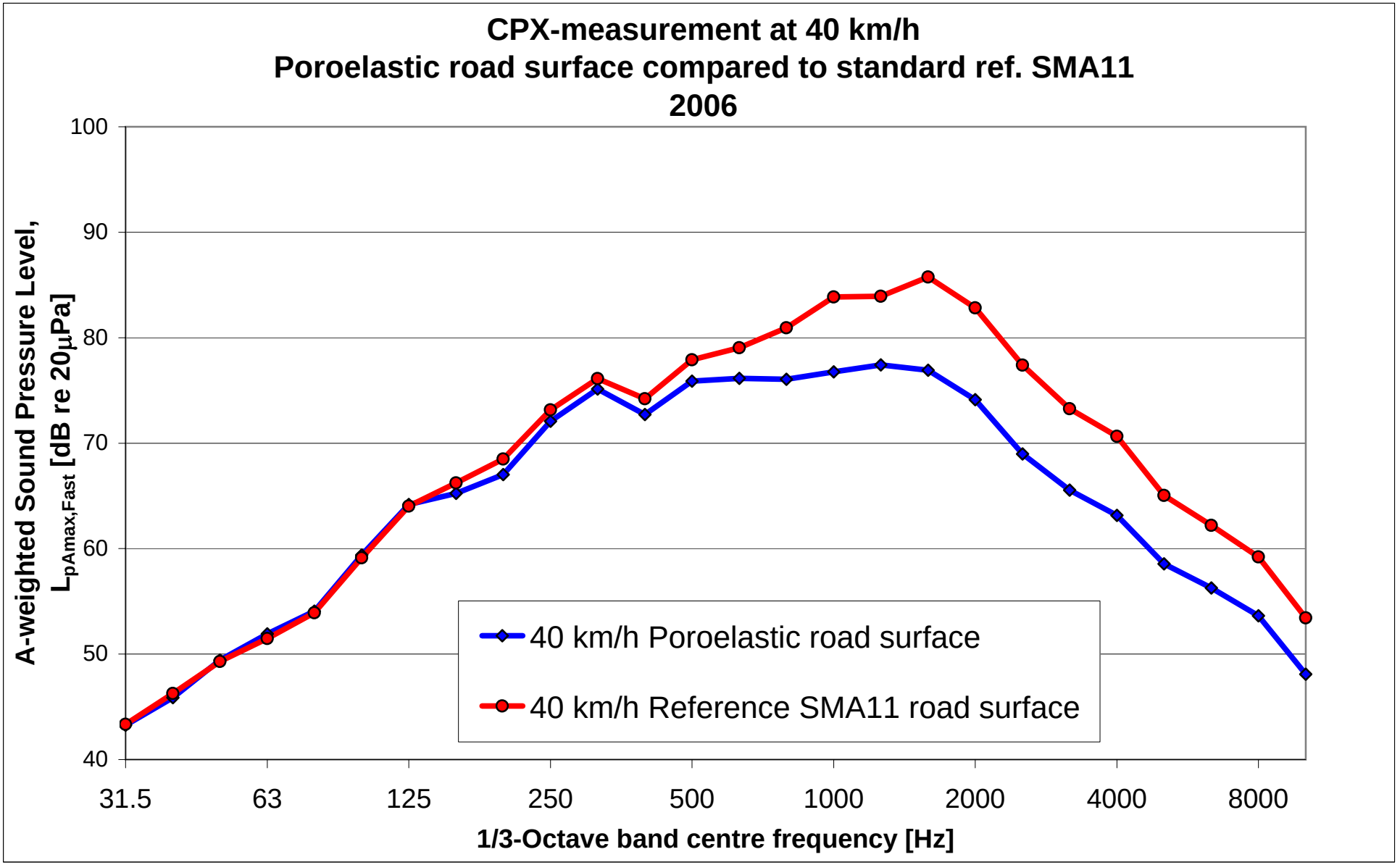
MEASUREMENT
Analysis: 1/3 Octave band
Averaging over to microphone positions one in front of the tyre and one behind.

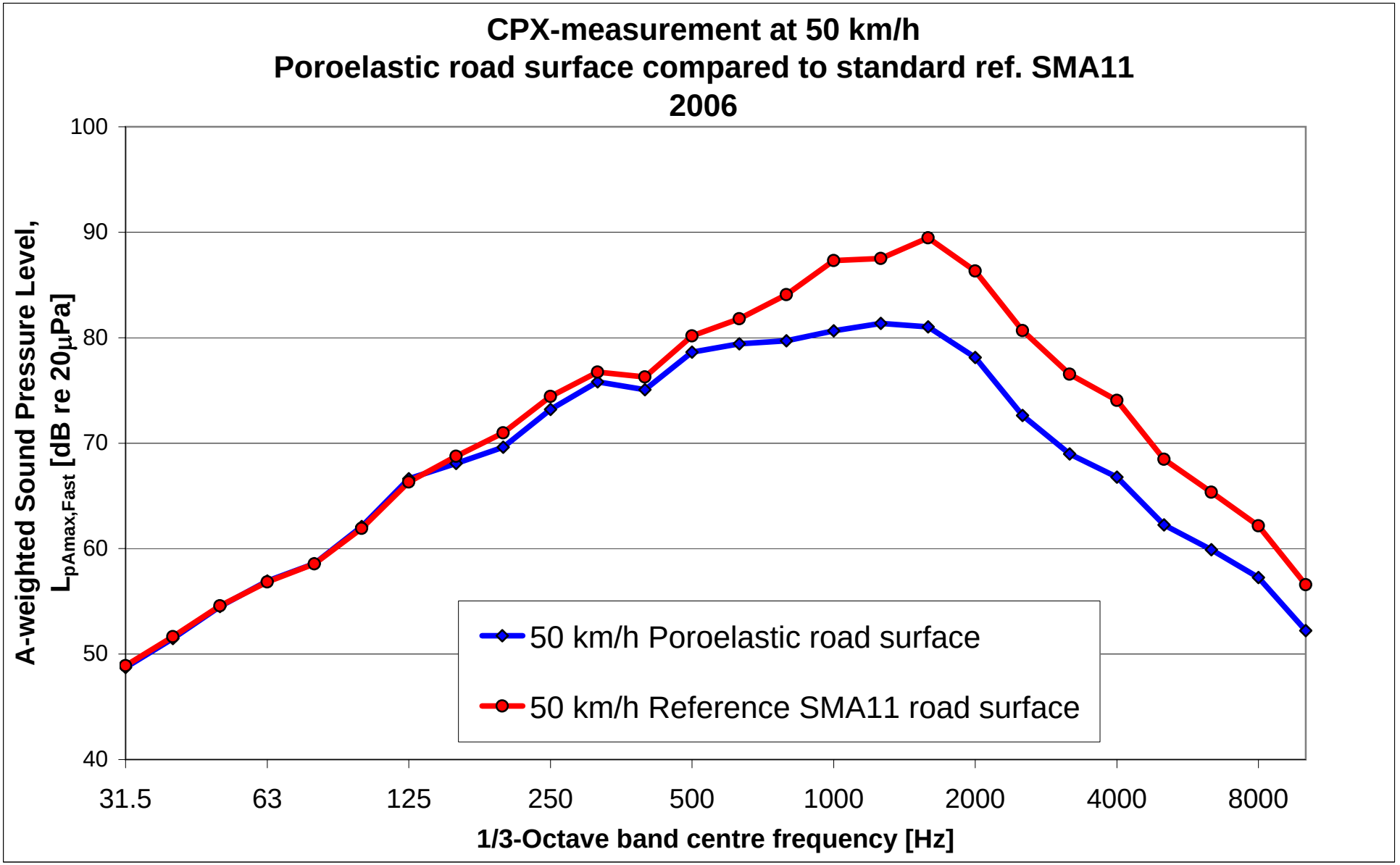


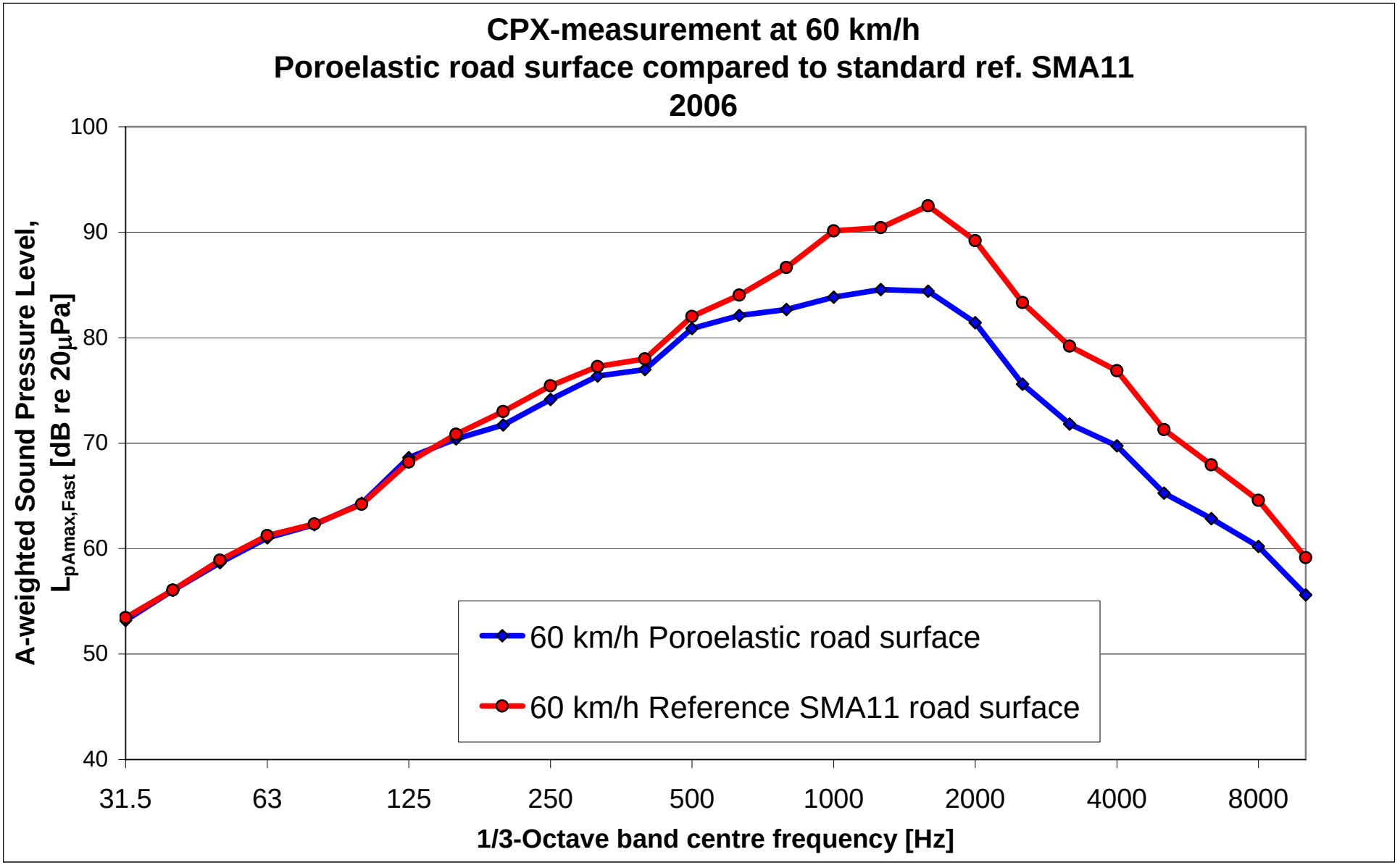


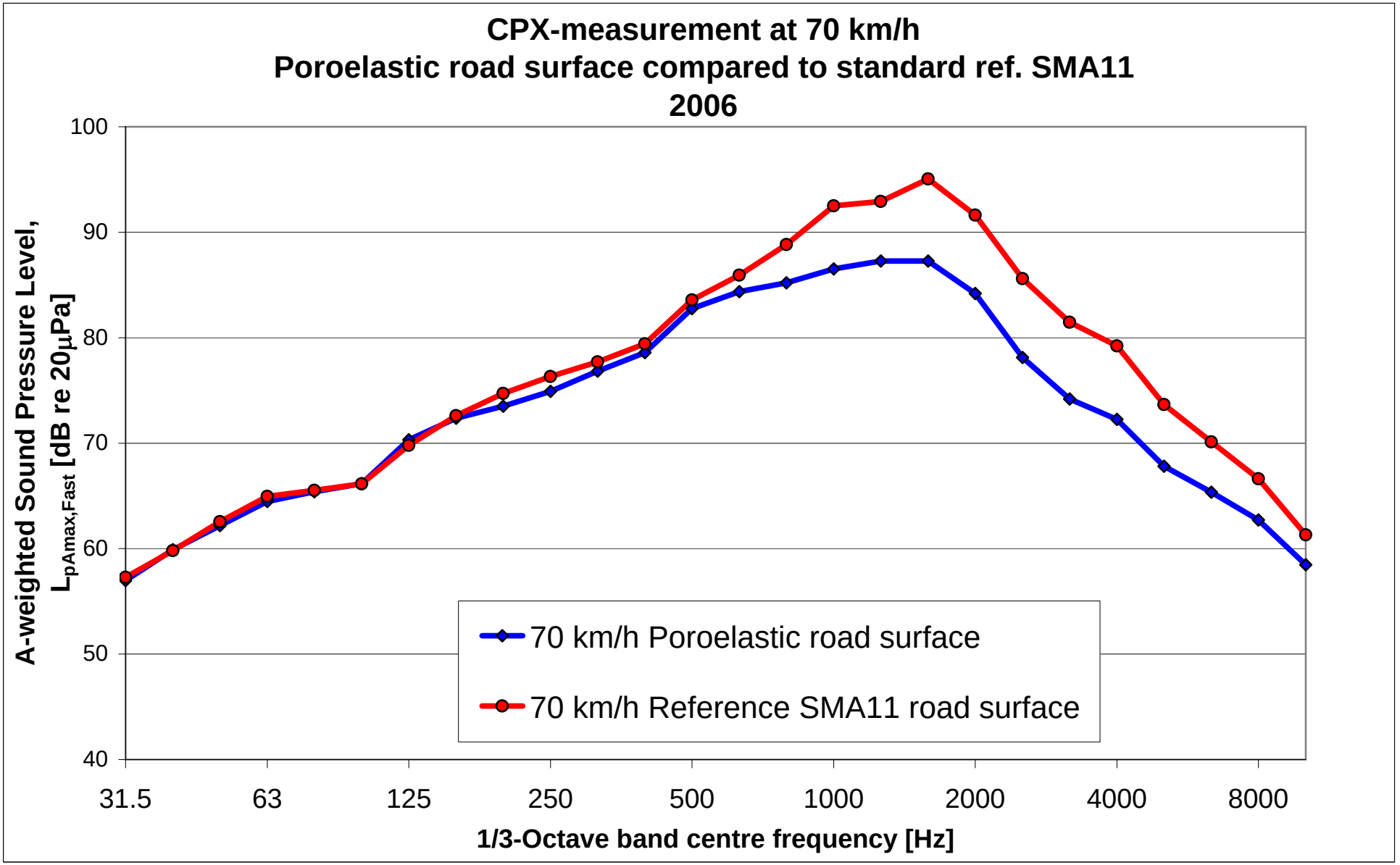


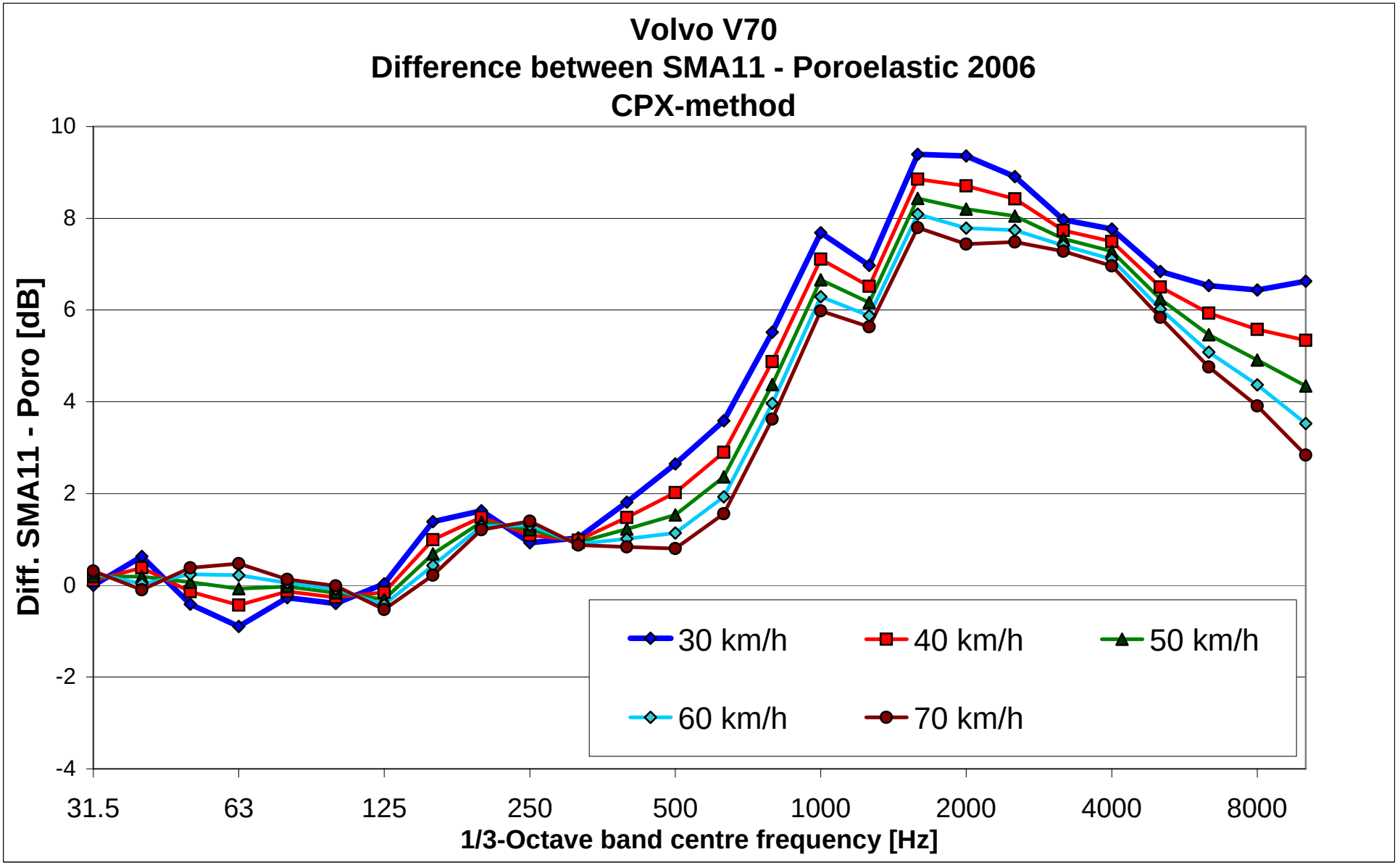

CPX-measurement at 30 km/h
Poroelastic road surface compared to standard ref. SMA11
2006
A-weighted Sound Pressure Level, $L_{pAmax,Fast}$ [dB re 20µPa]
100
90
80
70
60
50
40
31.5
63
125
250
500
1000
2000
4000
8000
1/3-Octave band centre frequency [Hz]
30 km/h Poroelastic road surface
30 km/h Reference SMA11 road surface


CPX-measurement at 40 km/h
Poroelastic road surface compared to standard ref. SMA11
2006
A-weighted Sound Pressure Level, LpAmax,Fast [dB re 20µPa]
100
90
80
70
60
50
40
31.5
63
125
250
500
1000
2000
4000
8000
1/3-Octave band centre frequency [Hz]
40 km/h Poroelastic road surface
40 km/h Reference SMA11 road surface


CPX-measurement at 50 km/h
Poroelastic road surface compared to standard ref. SMA11
2006
A-weighted Sound Pressure Level, $L_{pAmax,Fast}$ [dB re 20µPa]
100
90
80
70
60
50
40
31.5
63
125
250
500
1000
2000
4000
8000
1/3-Octave band centre frequency [Hz]
50 km/h Poroelastic road surface
50 km/h Reference SMA11 road surface


CPX-measurement at 60 km/h
Poroelastic road surface compared to standard ref. SMA11
2006
A-weighted Sound Pressure Level, $L_{pAmax,Fast}$ [dB re 20µPa]
100
90
80
70
60
50
40
31.5
63
125
250
500
1000
2000
4000
8000
1/3-Octave band centre frequency [Hz]
60 km/h Poroelastic road surface
60 km/h Reference SMA11 road surface

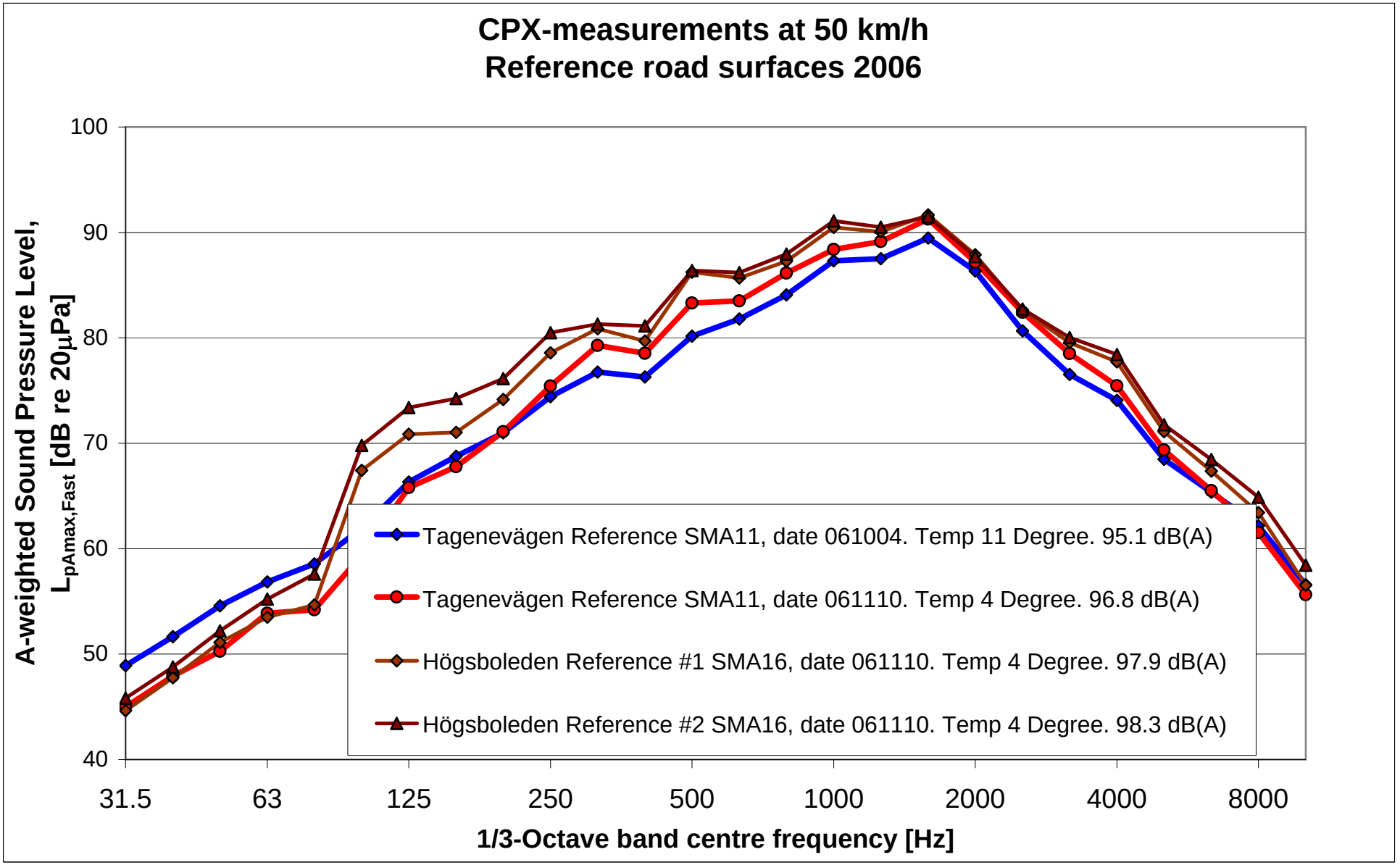

CPX-measurement at 70 km/h
Poroelastic road surface compared to standard ref. SMA11
2006
A-weighted Sound Pressure Level, $L_{pAmax,Fast}$ [dB re 20µPa]
100
90
80
70
60
50
40
31.5
63
125
250
500
1000
2000
4000
8000
1/3-Octave band centre frequency [Hz]
70 km/h Poroelastic road surface
70 km/h Reference SMA11 road surface

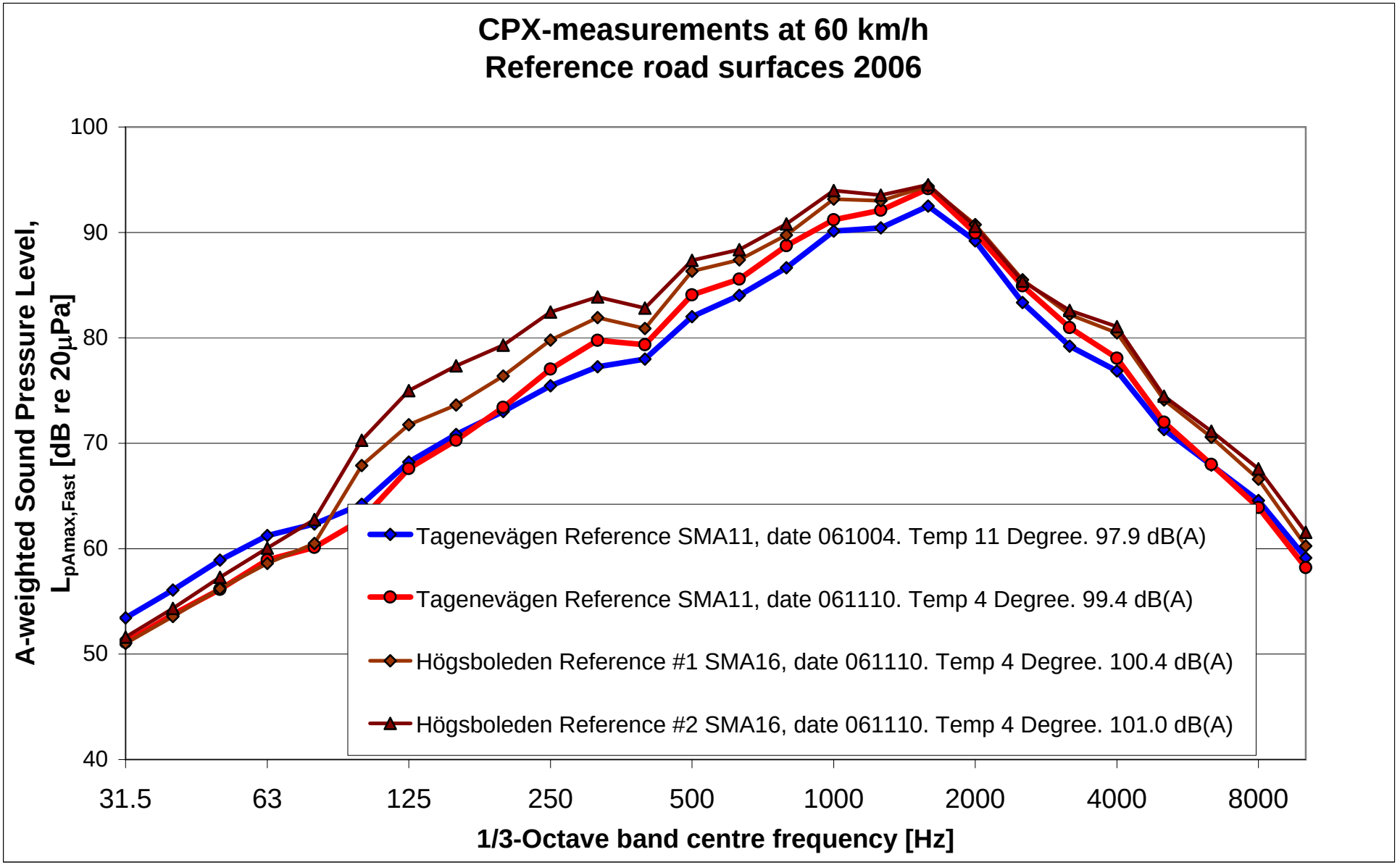

Volvo V70
Difference between SMA11 - Poroelastic 2006
CPX-method
Diff. SMA11 - Poro [dB]
10
8
6
4
2
0
-2
-4
31.5
63
125
250
500
1000
2000
4000
8000
1/3-Octave band centre frequency [Hz]
30 km/h
40 km/h
50 km/h
60 km/h
70 km/h

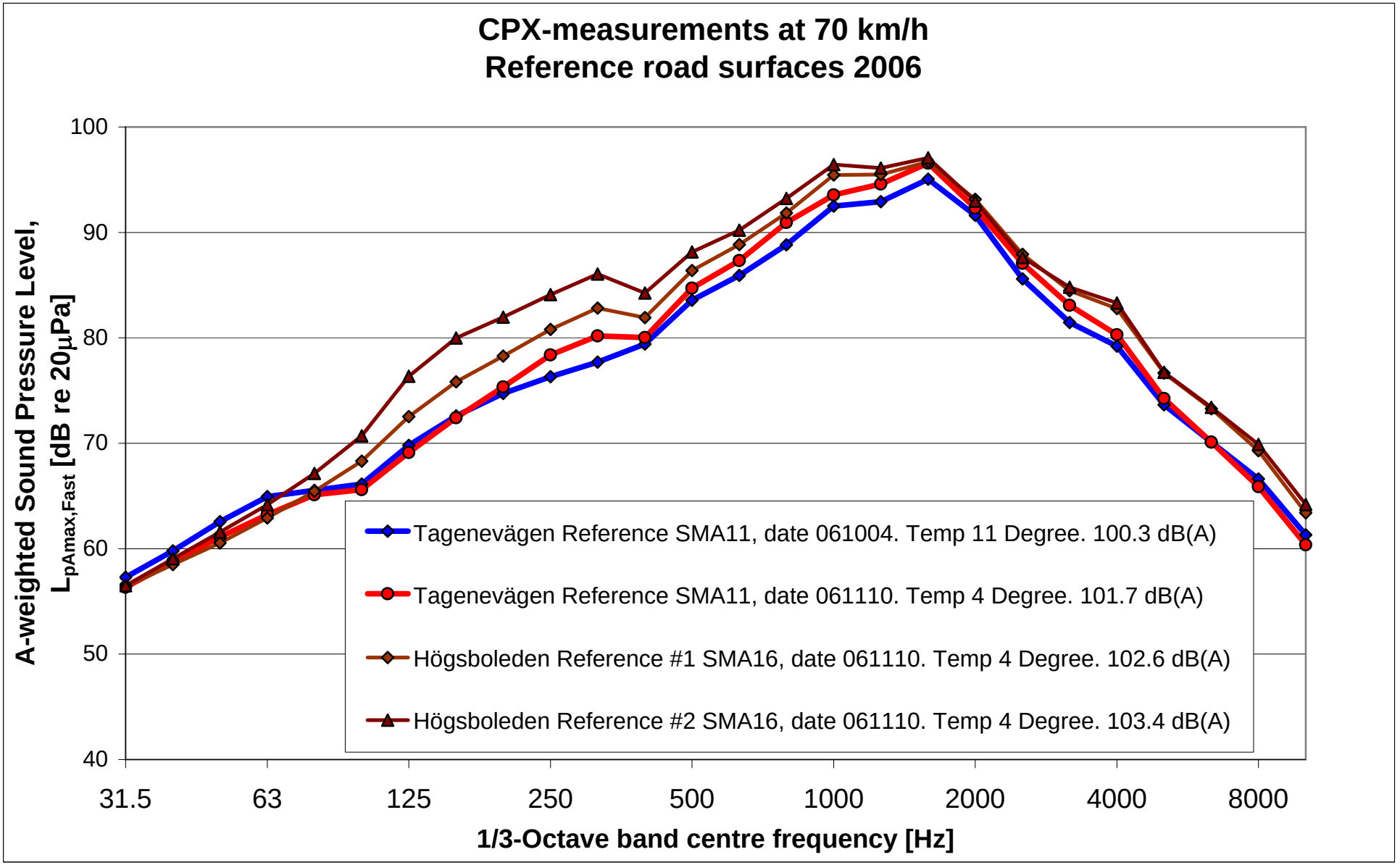
Appendix 3

Measurement of tyre/road noise using the CPX-method on standard road surfaces

A-weighted Sound Pressure Level evaluated at speed 50, 60 and 70 km/h.


CPX-measurements at 50 km/h
Reference road surfaces 2006
A-weighted Sound Pressure Level, $L_{pAmax,Fast}$ [dB re 20µPa]
100
90
80
70
60
50
40
31.5
63
125
250
500
1000
2000
4000
8000
1/3-Octave band centre frequency [Hz]
Tagenevägen Reference SMA11, date 061004. Temp 11 Degree. 95.1 dB(A)
Tagenevägen Reference SMA11, date 061110. Temp 4 Degree. 96.8 dB(A)
Högsboleden Reference #1 SMA16, date 061110. Temp 4 Degree. 97.9 dB(A)
Högsboleden Reference #2 SMA16, date 061110. Temp 4 Degree. 98.3 dB(A)


CPX-measurements at 60 km/h
Reference road surfaces 2006
A-weighted Sound Pressure Level, $L_{pAmax,Fast}$ [dB re 20µPa]
100
90
80
70
60
50
40
31.5
63
125
250
500
1000
2000
4000
8000
1/3-Octave band centre frequency [Hz]
Tagenevägen Reference SMA11, date 061004. Temp 11 Degree. 97.9 dB(A)
Tagenevägen Reference SMA11, date 061110. Temp 4 Degree. 99.4 dB(A)
Högsboleden Reference #1 SMA16, date 061110. Temp 4 Degree. 100.4 dB(A)
Högsboleden Reference #2 SMA16, date 061110. Temp 4 Degree. 101.0 dB(A)


CPX-measurements at 70 km/h
Reference road surfaces 2006
A-weighted Sound Pressure Level, $L_{pAmax,Fast}$ [dB re 20µPa]
100
90
80
70
60
50
40
31.5
63
125
250
500
1000
2000
4000
8000
1/3-Octave band centre frequency [Hz]
Tagenevägen Reference SMA11, date 061004. Temp 11 Degree. 100.3 dB(A)
Tagenevägen Reference SMA11, date 061110. Temp 4 Degree. 101.7 dB(A)
Högsboleden Reference #1 SMA16, date 061110. Temp 4 Degree. 102.6 dB(A)
Högsboleden Reference #2 SMA16, date 061110. Temp 4 Degree. 103.4 dB(A)