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PP	Restricted to other programme participants (including the Commission Services)		
RE	Restrictec to a group specified by the consortium (including the Commission Services)		
CO	Confidential, only for the members of the consortium (including the Commission Services)		
Nature of Deliverable			
R	Report		
P	Prototype		
D	Demonstrator		
O	Other		



SEVENTH FRAMEWORK PROGRAMME

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<sup>1</sup> see List of Deliverables, DoW – Annex I to the contract, p.32  
(document 233655\_CITYHUSH\_AnnexI\_DoW\_2010-01-31\_Corrections.pdf - available on the ftp-server)

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## **0 EXECUTIVE SUMMARY**

### **0.1 OBJECTIVE OF THE DELIVERABLE**

An important element in fully utilizing the low-noise potential inherited in the hybrid concept (or fully electric vehicles) is reduced tyre/road noise. At higher speed, the tyre/road noise will dominate the total noise emission from both hybrid and conventional vehicles. One way of reducing the tyre/road noise is to design the road surface properties so that lower sound levels will be emitted. Normally the parameters of interest to alter are the:

- porosity or void content
- surface roughness, (mainly controlled by the maximum stone size in the asphalt mix)
- elasticity or flexibility of the surface.

A problem with the open graded road surfaces, with porosity or voids, is clogging and wear. Clogging is a particular severe problem at the lower vehicle speeds, which are typical for inner city driving. This is because the low vehicle speeds will obstruct the "self-cleaning" capability of the surface that will be obtained at higher speeds. A quiet road surface that can preserve its low-noise characteristics even at lower speeds is thus needed. In this deliverable the "Smooth and dense" road surface for the inner city application has been studied. By carefully selecting the size distribution of the stone ballast in the asphalt mix it is anticipated that an optimally smooth surface with good friction characteristics and wear rate can be obtained.

### **0.2 DESCRIPTION OF THE WORK PERFORMED SINCE THE BEGINNING OF THE PROJECT**

In the beginning of the project a laser texture scanner was developed. It was used to measure the road texture profile and the road texture spectrum for different road surfaces in the NCC laboratory. From these measurements a couple of prescriptions has been tested in field using the laser scanner but also by measuring the noise emission according to the CPX-method. The field tests were performed in Gothenburg, Sweden. After evaluation of the results new laboratory measurements were performed as well as an additional field test in Gothenburg.

### **0.3 MAIN RESULTS ACHIEVED SO FAR**

So far, the studies have showed that it is possible to vary the road texture for a pavement by using the same maximum stone size. The studies also reveal that the produced NCC laboratory samples give similar road texture profile/spectrum also when produced in field. The resulting noise emission is still not completely verified. The reason for this is that the CPX-measurement needed to be performed before the winter meaning that all pavement were only one week old when performing the

measurements. All pavement were therefore soft giving a general low noise emission. The road surfaces will be tested again in the spring under work package 5.

#### **0.4 PARTNERS INVOLVED AND THEIR CONTRIBUTION**

NCC has developed several new prescriptions for different road surfaces. NCC has also measured normally used road parameters such as MPD and sand patch values for all surfaces. Acoustic Control has performed road texture measurements and noise measurements on tested road surfaces.

#### **0.5 CONCLUSIONS**

The performed studies shows that it is possible to create a low noise road surface for inner city use by optimizing the road texture. The noise reduction might not be as high as for porous road surfaces but the effect hopefully last for a longer time period. For standard vehicles at lower speeds, the effect from reducing the tyre/road noise is small due to the higher driveline noise. For hybrid and electrical vehicles, the tyre/road noise is dominating which means that the reduced tyre/road noise results in a reduced total noise level for the whole vehicle.

By combining the noise reduction from road surface texture optimizations with the noise reduction from selecting only the 25 % of the quietest tyre tread patterns a total noise reduction from both measures of 4-5 dB(A)-units of noise reduction can be achieved.

For smooth road surfaces the tire tread pattern becomes gradually of increased importance, which is one of the foundations to claim the effect of 4-5 dB(A) units in total noise reduction from the two measures.

## 1 DESCRIPTION OF USED METHODS FOR EVALUATING DIFFERENT ROAD SURFACES

### 1.1 EVALUATION OF ROAD TEXTURE

A laser texture scanner was developed in early stage of the project. It has been used to measure the road texture profile and the road texture spectrum for different road surfaces in the NCC laboratory and in field measurements. The 0.8 mm wide laser moves with a step size of 0.1 mm. This gives a resolution high enough to analyse the frequency range representing tyre/road noise.



Figure 1. Laser scanner developed for road texture measurements.

The data from the measurements have been analysed by calculation the area of support versus the depth of the pockets between the stones. By looking on the resulting curve (see Figure 2) it is possible to characterize the road texture profile. Also the frequency spectrum of the profile is used in the evaluation.

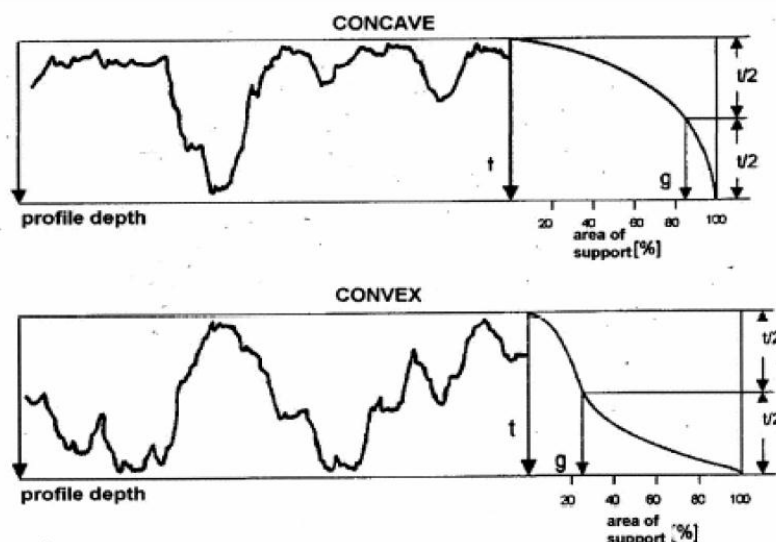


Figure 2. Concept for evaluating road texture profile. The Concave road surface with a lot of dips in the surface give rise to a convex support area curve. Similarly the Convex surface with a lot of projected surface elements (stones) will give rise to a concave support area curve as the Figure shows.

## 1.2 EVALUATION NOSIE EMISSION USING THE CPX-METHOD

CPX-measurements were performed with the single wheel trailer. The single wheel trailer for measurement of tyre/road noise has the advantage of measuring the sound at very well defined locations relative to the test wheel, with careful control of load, microphone positions, test surface, test tyre, test tyre pressure, temperature etc.

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 3 shows the single wheel trailer mounted with the reference tyre of type "Uniroyal Tiger Paw AWP P225/60R16 97S". The selected reference tyre is representing an average tyre with respect to noise emission out of a typical modern tyre population.



Figure 3. Single wheel trailer for CPX-measurements



## 2 STUDIES IN LABORATORY

The project started with several measurements carried out in the NCC laboratory. Mainly road surfaces with a maximum stone size of 8 mm have been tested. Some samples of ABS 16 with 16 mm maximum stone size have also been tested.

### 2.1 STUDIES ON ASPHALT WITH 16 MM STONE SIZE

#### 2.1.1 Measurements of road profile

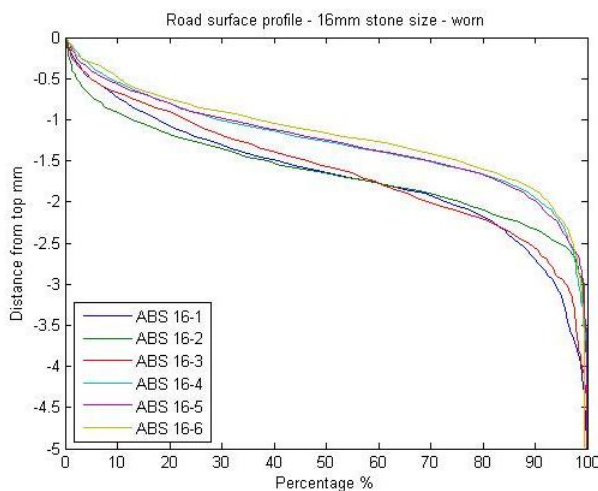


Figure 4. Measured road texture profile for worn ABS16 with 16mm maximum stone size.

#### 2.1.2 Measurements of road profile spektrum

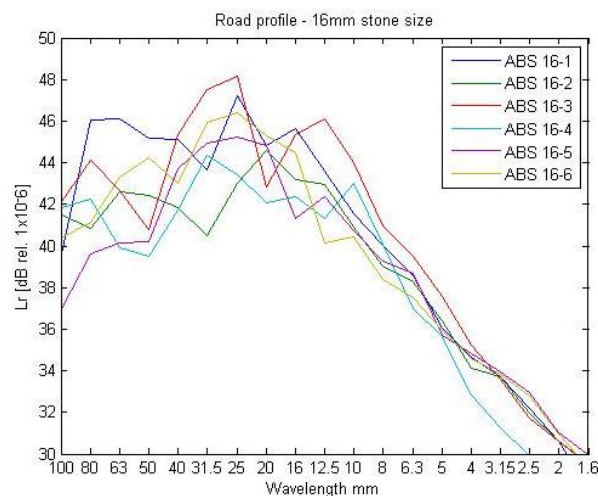


Figure 5. Measured road texture spectrum for worn samples of ABS16 with 16mm maximum stone size.



## 2.2 STUDIES ON ASPHALT WITH 8 MM STONE SIZE

The results for road surfaces with 8 mm stone size can be seen in the figures below. Two surfaces were picked out for further field studies at "Arvid Lindmans Gata" in Gothenburg. Sample #2 (representing a smooth surface) and sample #12 (representing a rough surface). The choices were made in order to get a clear result for the following measurements.

### 2.2.1 Measurements of road profile

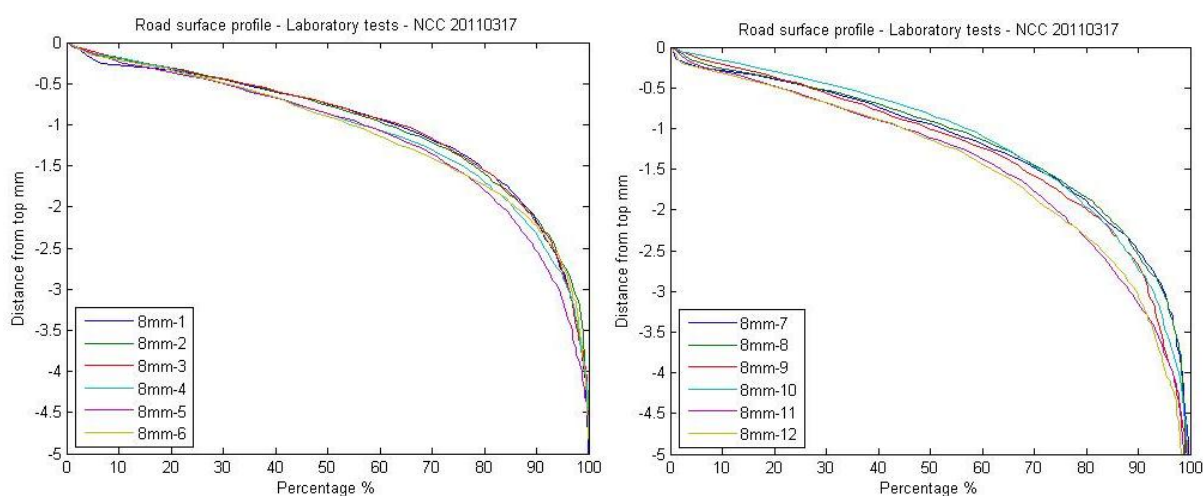


Figure 6. Measured road texture profile for laboratory samples with 8 mm maximum stone size.

### 2.2.2 Measurements of road profile spektrum

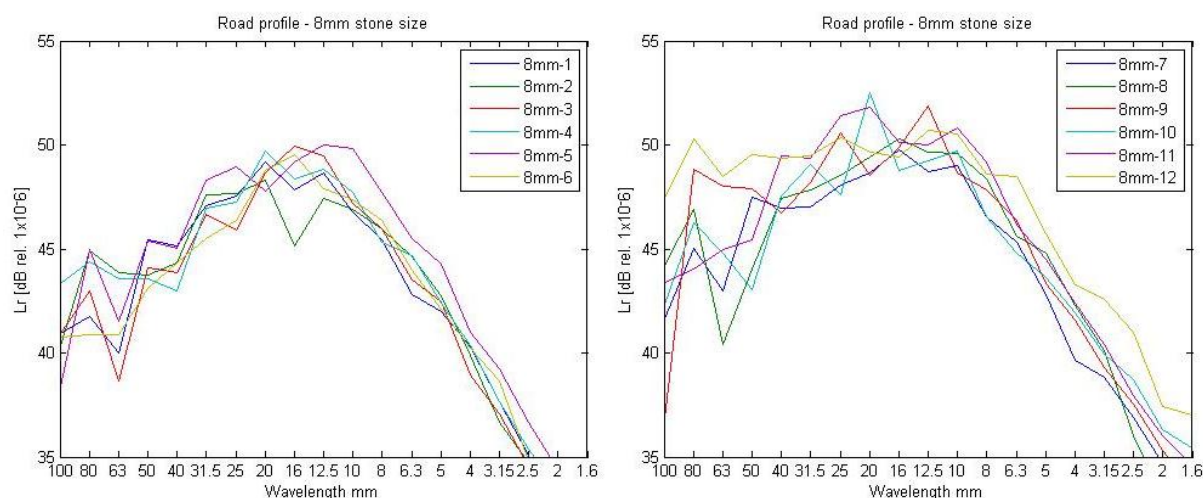


Figure 7. Measured road texture spectrum for laboratory samples with 8 mm maximum stone size.

### 3 FIELD STUDIES

#### 3.1 GOTHENBURG – BRAHEGATAN

Two new road surfaces with different prescriptions have been tested at Brahegatan, Gothenburg. As reference a new standard road surface (8mm maximum stone size) was used. The results presented below shows that the surface profile is almost the same. This means that the test failed in terms of creating two different textures.

##### 3.1.1 Brahegatan - Measurements of road profile

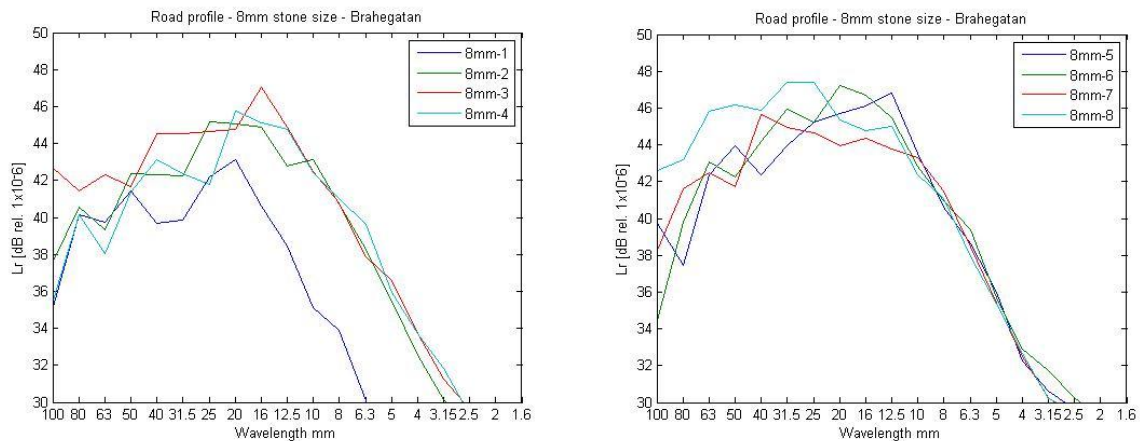


Figure 8. Measured road profile spectrum for road surfaces at Brahegatan, Gothenburg.

##### 3.1.2 Brahegatan - Measurements of road profile spektrum

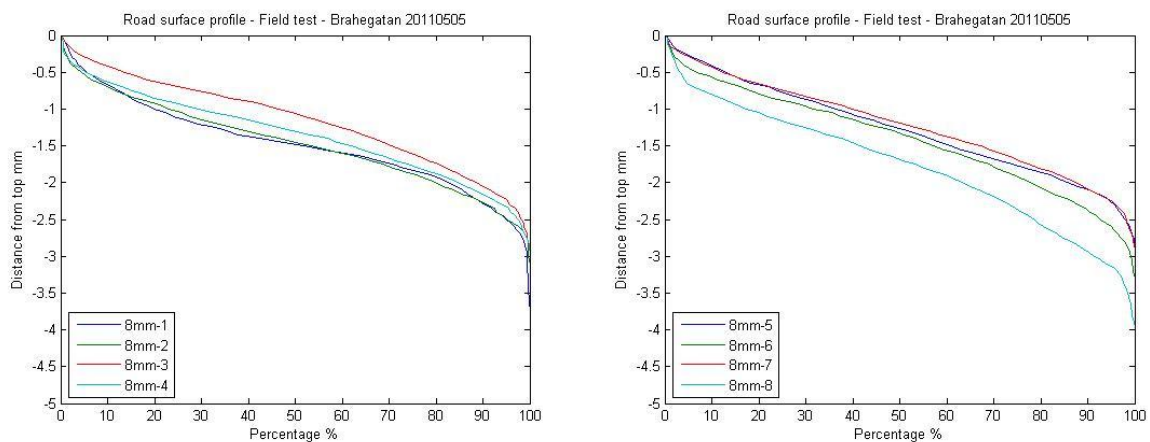


Figure 9. Measured road texture profile for road surfaces at Brahegatan, Gothenburg.

## 3.2 GOTHENBURG – ARVID LINDMANS GATA

Three new road surfaces with different prescriptions were tested. As reference one new standard road surface (8mm stone size) and one worn road surface with 11 mm maximum stone size (only for the CPX-measurement) were used. Except for the laboratory sample #2 and #12 a surface with 4mm maximum stone size was tested. The new road surfaces were only 1 week old when measuring the noise emission. The reason for this was the upcoming winter weather. (The same measurement will be performed later in the spring 2012)

### 3.2.1 Arvid Lindmans gata - Measurements of road profile

The road texture profiles for the different surfaces at Arvid Lindmans Gata are presented below. The result show clear differences for the tested surfaces.

#### 3.2.1.1 Arvid Lindmans Gata – 8 mm stone size

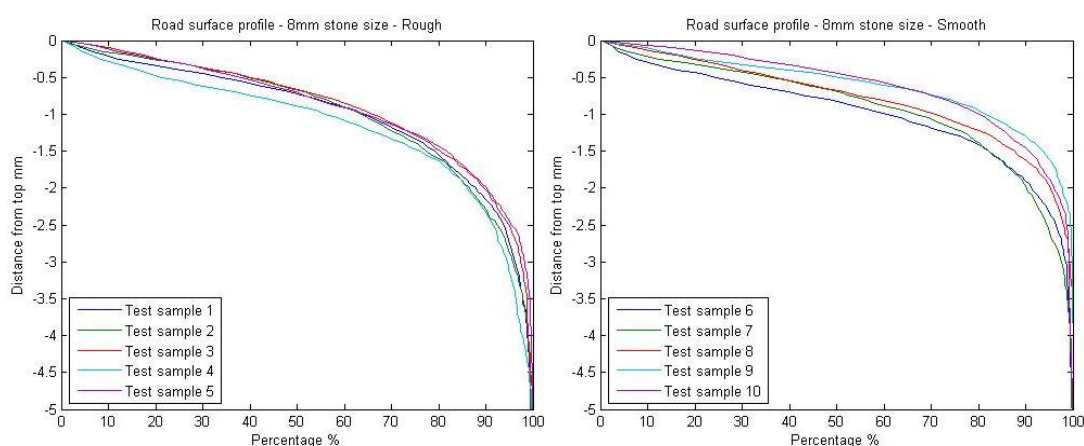


Figure 10. Measured road profile for the road surfaces with maximum stone size 8mm at Arvid Lindmans Gata, Gothenburg. The left picture represent the rough surface and the right picture represent the smooth surface.

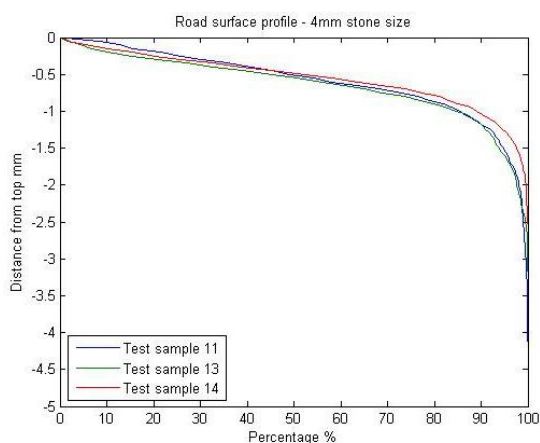


Figure 11. Measured road profile for the road surface with maximum stone size 4mm at Arvid Lindmans Gata, Gothenburg.

### 3.2.2 Arvid Lindmans gata - Measurements of road profile spektrum

The road texture spectrum measured at Arvid Lindmans Gata have been separated for the different road surface types. The results are presented below

#### 3.2.2.1 Arvid Lindmans Gata – 8 mm stone size

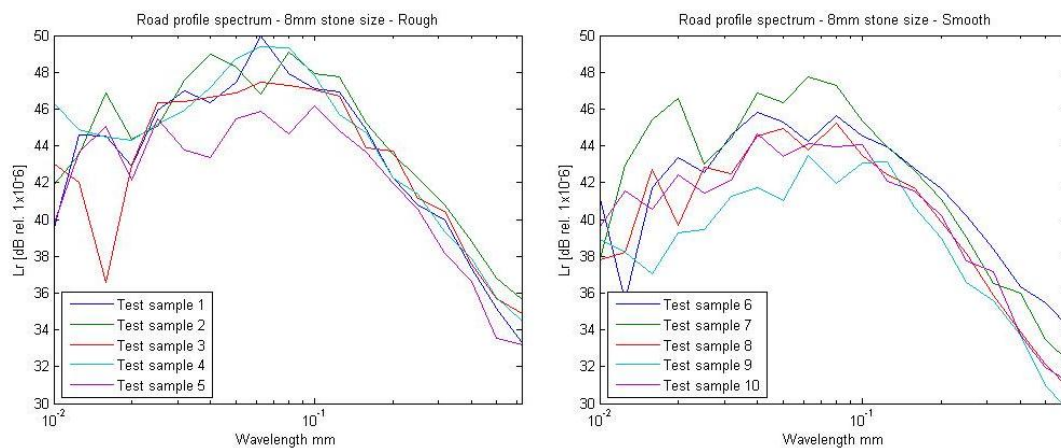


Figure 12. Measured road profile spectrum for the road surfaces with maximum stone size 8mm. The left picture represent the rough surface and the right picture represent the smooth surface.

### 3.2.2.2 Arvid Lindmans Gata – 4 mm stone size

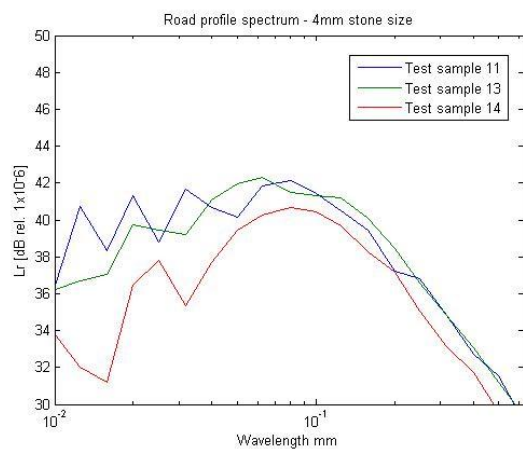


Figure 13. Measured road profile spectrum for the road surface with maximum stone size 4mm.

## 4 VALIDATION USING CPX-MEASUREMENTS

### 4.1 GÖTHEMBURG – BRAHEGATAN

The road surfaces at Brahegatan, Gothenburg, have been evaluated using the CPX-method. This measurement was carried out using another tire (an earlier version of ACL:s reference tyre for CPX measurements). The results from the texture measurements indicated that there were no difference for the two pavements. That is confirmed also by the results from CPX-measurements. Due to traffic situation on the site it was only possible to evaluate at the speed of 30 km/h.

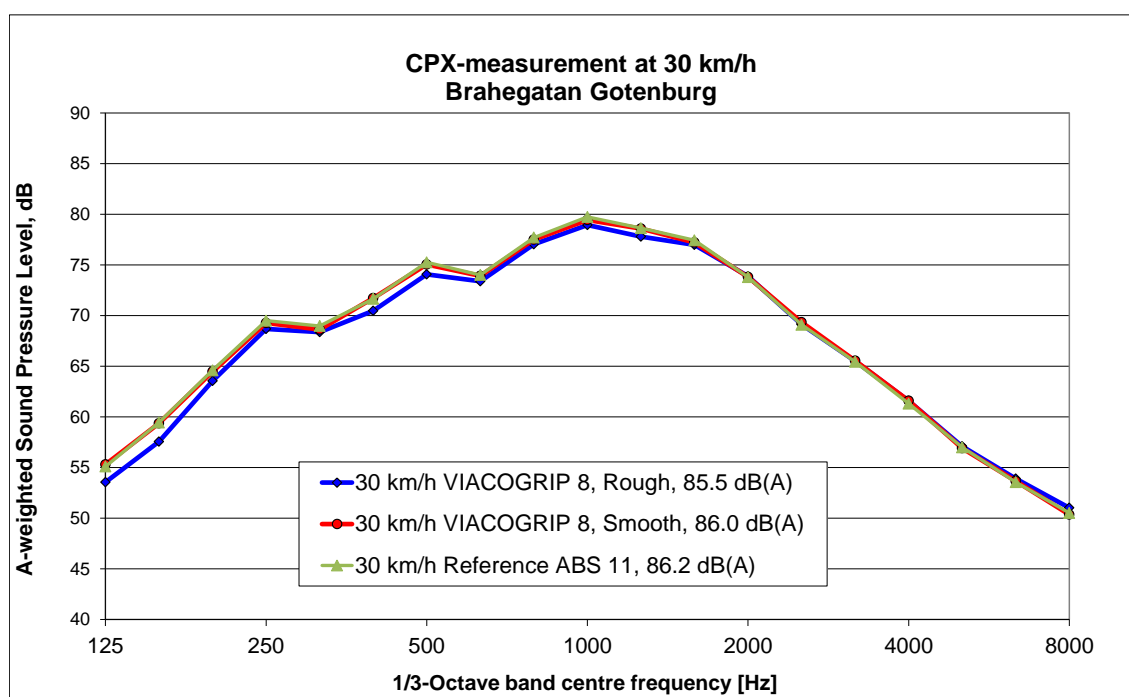


Figure 14. Tire/road noise measured for the new road surfaces on Brahegatan, Gothenburg.

### 4.2 GÖTHEMBURG – ARVID LINDMANS GATA

The road surfaces at "Arvid Lindmans gata" have been evaluated using the CPX-method. The measurements were performed only 1 week after the exposition of the pavement because of the winter. This means that the all pavements were soft and therefore also less noisy. Compared to an old standard pavement with 11 mm stone size all pavements measured a noise reduction of about 5-6 dB(A) units.

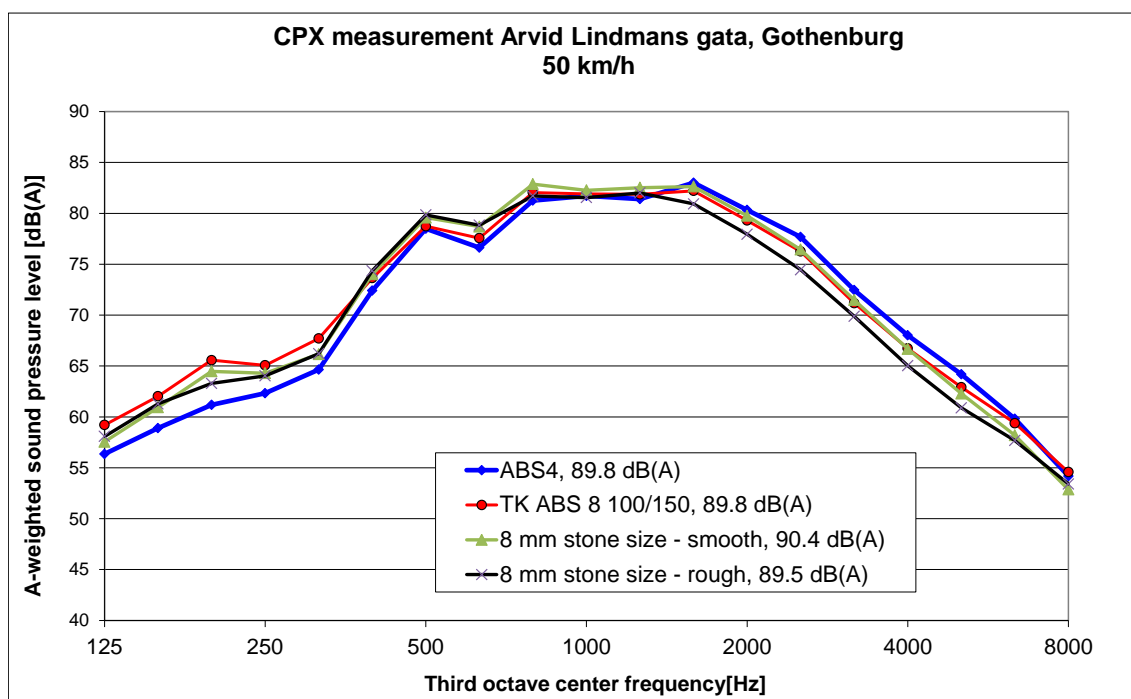


Figure 15. Tire/road noise measured for the new road surfaces on Arvid Lindmans gata.

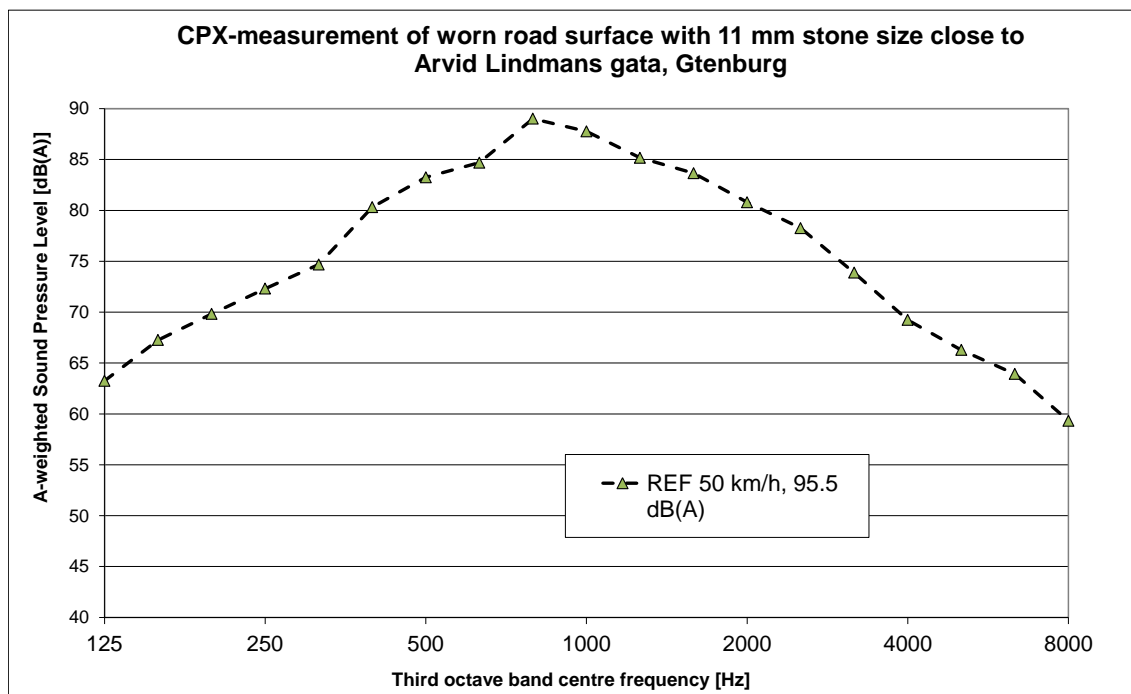


Figure 16. Tire/road noise measured for a worn road surface with 11 mm stone size.



### 4.3 GOTHENBURG – ARVID LINDMANS GATA, 6 MONTH OLD

In the spring 2012 the CPX measurements were performed again at Arvid lindmansgatan. This time the texture in the wheel tracks was more like the texture in the laboratory. The difference in noise emission for the two test surfaces was almost 2 dB(A)-units and it was the rough texture that gave the lowest noise levels. The major reason for this are the leakage effects in the gaps between the stones. Compared to the reference (TK ABS 8 100/150) the rough surface gave 2.1 dB(A)-units lower noise level.

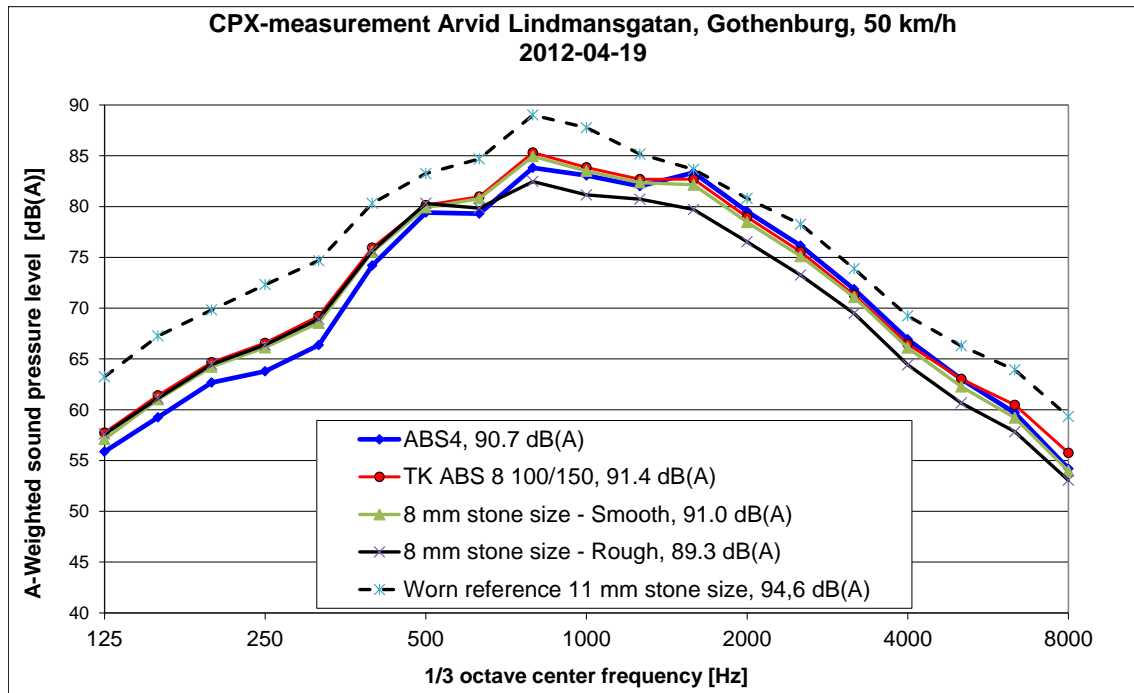


Figure 17. Tire/road noise measured for the new road surfaces on Arvid Lindmans gata 6 month after paving.

## 5 CONCLUSIONS

Despite the fact that the results didn't differ very much on the total noise level for the first CPX measurements, some interesting results were found. In figure 10-11 it can be seen that for frequencies above 1000 Hz the smooth dense ABS 4 pavement give about 3 dB-units higher noise levels. For frequencies below 1000 Hz the same pavement give about 3 dB-units reduced noise levels. This means that a rough texture leads to a lower noise at high frequencies. The reason for this is judged to be due to the leakage through the air gaps between the stones. At lower frequencies, the road surface excitation of the noise is less due to the smooth surface. The measurements shows that the potential reduction of noise only due to road texture is about 3 dB(A) for pavements using the same maximum stone size.

In the spring 2012 the road surfaces were tested again after the winter. The results (se figure 17) shows that the rough texture with 8 mm maximum stone size give about 2 dB(A)-units less noise than the smooth texture with the same maximum stone size. From these results, it looks like the optimal texture should be rough but with a maximum stone size not more than 8 mm.

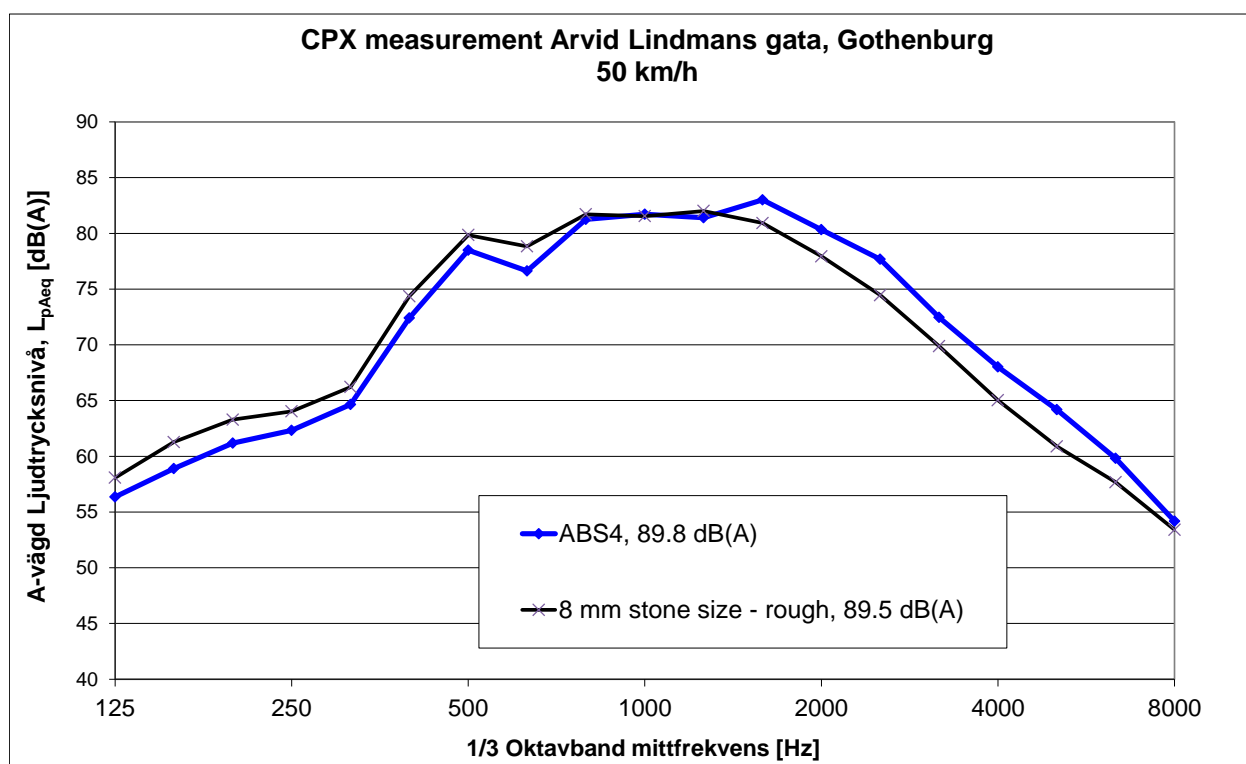


Figure 18. Measured tyre/road noise for a smooth ABS 4 road surface and a rough 8 mm road surface.

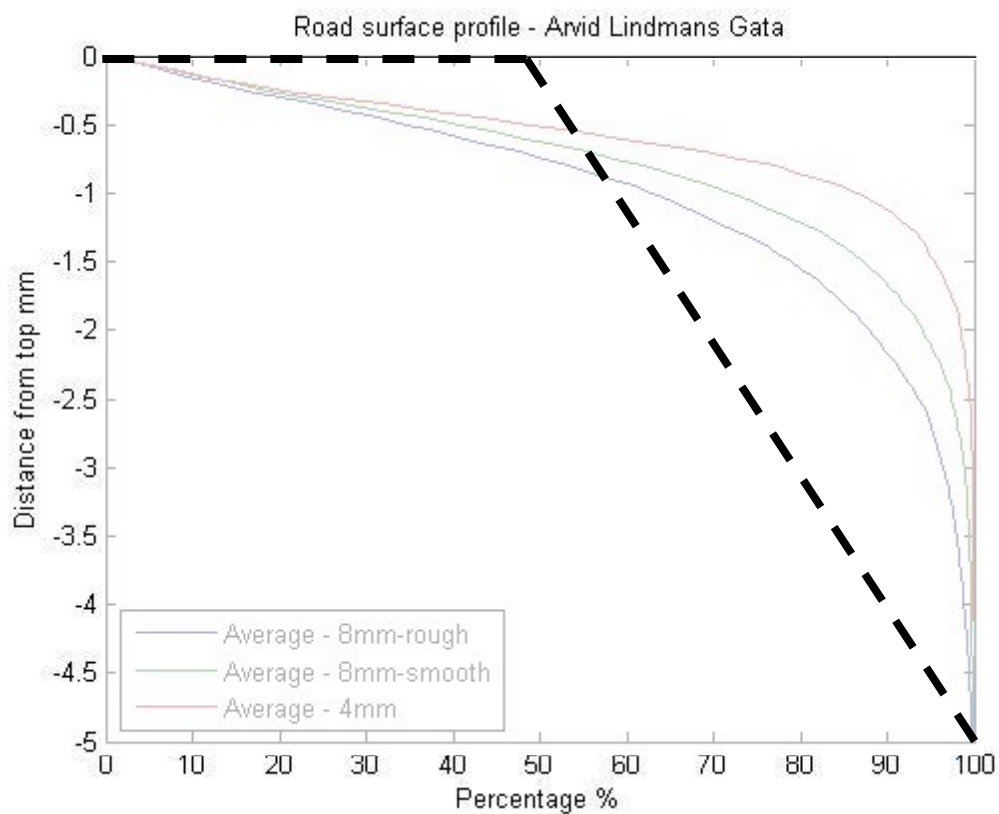


Figure 19. Possible optimal road texture profile for reducing tyre/road noise. In the background the ABS 4 and the two 8mm pavements are shown.



## 6 APPENDIX - ASPHALT MIXES STUDIED IN CITYHUSH WP3.3

Asphalt mixes have been produced in lab as well produced in an asphalt plant and installed on streets in Gothenburg. This has been done in order to be able measure the influence of texture depth and surface profile on noise reduction. The mixes have all had a nominal maximum size of 4 or 8 mm. Variations have besides nominal aggregate size also been done in grading as well as binder content. This has been done in several steps going in between lab and field (table 1). Descriptions for the work in lab can be found in table 2. All formulas are presented in tables 3-5 as well as data for void content and sand patch values for Marshall compacted, gyratory compacted and field cores.

Table 1 Steps for lab and field work

Formula	Step
L1-3	Laboratory blended - Variation of grading
L4-9	Laboratory blended - Variation of binder content (4-6 same grading as 1, 7-9 same grading as 2)
F10-11	Field-test Gothenburg 2010 Brahegatan (Sample values). Recipes as grading 1 and 2 and binder content 6,0 %.
L12-13	Laboratory blended
F14-16	Field-test Gothenburg 2011 Arvid Lindmansgatan

Table 2 Description of lab work

Aggregate local granite/gneiss
Bitumen 70/100. Bitumen content SS-EN 12697-1:2005
Marshall impaction (SS-EN 12697-30+A1:2007) 2x50 blows
Gyratory (angle 2°) 98 % (density) compaction of Marshall, 50-100 rotations
Void content in weight-%. Bulk density in water (SS-EN 12697-6+A1:2007 part b) and by measurement (SS-EN 12697-6+A1:2007 part d)
Sand-patch method (SS-EN 13036-1), texture depth in mm
Void contents and Sand-patch, all values in tables 3-5 the average of 2 samples

Table 3 Lab mixes

	Mixes						
	L1	<b>L2 (rough)</b>	L3	L4	L5	L6	L7
Bitumen content (%)	5,8	<b>5,8</b>	5,8	6,0	6,4	6,8	6,0
<i>Aggregate grading Passing sieve mm</i>							
0,063	9,7	<b>9,7</b>	10,0	9,7	9,7	9,7	9,7
1	21	<b>18</b>	26	21	21	21	18
2	27	<b>21</b>	34	27	27	27	21
4	34	<b>25</b>	44	34	34	34	25
5,6	58	<b>52</b>	65	58	58	58	52
8	95	<b>95</b>	96	95	95	95	95
<i>Void content (%)</i>							
Marshall Water	2,1	<b>7,0</b>	0,8	2,6	2,2	1,4	6,6
Marshall Measure	6,3	<b>12,7</b>	3,6	7,0	6,2	4,5	13,2
Gyratory Measure	7,8	<b>16,2</b>	5,0	8,4	7,6	5,8	14,4
<i>Sand-patch (mm)</i>							
Gyratory	1,15/	<b>2,51/</b>	0,97/	1,03/	0,93/	0,93/	1,52/
	1,31	<b>2,78</b>	1,00	1,03	1,00	0,94	1,93

Table 4 Lab mixes

	Mixes						
	L8	L9	<b>L12 (Smooth)</b>	L13			
Bitumen content (%)	6,4	6,8	<b>8,1</b>	8,6			
<i>Aggregate grading Passing sieve mm</i>							
0,063	9,7	9,7	<b>10,8</b>	10,8			
1	18	18	<b>25</b>	25			
2	21	21	<b>33</b>	33			
4	25	25	<b>88</b>	88			
5,6	52	52					
8	95	95					
Void content (%)							
Marshall Water 1)	5,8	3,8	<b>3,8</b>	3,0			
Marshall Measure	11,4	9,4	<b>6,0</b>	5,1			
Gyratory Measure	12,6	10,6	<b>7,6</b>	6,6			
Sand-patch (mm) 2)							
Gyratory	1,50/ 1,47	1,42/ 1,37	<b>0,54/ 0,47</b>	0,51/ 0,49			



Table 5 Field mixes

	Mixes						
	F10	F11	F14 (smooth)	F15 (Ref.)	F16 (Rough)		
Bitumen content (%)	5,0	5,3	8,6	6,7	6,0		
Aggregate grading Passing sieve mm							
0,063	7,5	8,1	10,8	9,7	9,7		
1	15	15	25	21	18		
2	21	19	33	27	21		
4	29	25	88	34	25		
5,6	50	45		58	52		
8	97	95		95	95		
Void content (%)							
Marshall Water 1)	9,4/9,4	8,9/9,3	1,3	1,5	5,7		
Marshall Measure	13,9	15,4	2,8	3,8	9,8		
Gyratory Measure	14,3	14,2	4,5	5,9	10,8		
Sand-patch (mm) 2)							
Gyratory	1,50/ 1,47	1,42/ 1,37	0,53/ 0,48	0,74/ 0,69	1,02/ 0,82		
Cores from road 3)			0,27 ±0,04	0,49 ±0,07	0,81 ±0,16		
Field Wheel-path 3)	1,19 ±0,08	1,22 ±0,14	0,54 ±0,05	0,83 ±0,13	1,34 ±0,40		
Field Between wheel-paths	1,12 ±0,04	1,18 ±0,10	No traffic	No traffic	No traffic		

1. Marshall Water: Results lab in Gothenburg and Stockholm respectively
2. Sand-patch: Cores and field, average of 5 samples with standard deviation
3. For mixes, F14-16 results from Sand-patch analyses show a great difference between field measurements and measurement on cores. The reason for this is still not understood, but is under investigation