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VEHICLE NOISE EMISSION ON WET ROAD SURFACES

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ABSTRACT
A measurement campaign has been carried out with a view to determining the influence on vehicle noise emission of the presence of water on the road surface. The noise measurements were made according to the so-called CPB " Controlled Pass-By " method using a car and a 16t, two-axle lorry. These measurements were performed both in dry and wet condition of the surface on fourteen road sections including a wide range of pavement materials and textures among which porous surfaces. The analysis of the recorded noise signals, also involving the examination of their spectra, has revealed the influence of a so far overlooked phenomenon by which the noise level on the wet surface is sometimes lower than on the dry surface. This effect is competing with the well-known noise level increase due to water droplet projections. The former attenuates the low and medium frequency components of the noise on the wet surface while the latter produces a typical noise level increase in the medium and high frequencies. Although the newly observed phenomenon occurs with the car as well as with the lorry, it is more frequent and important with the latter. As texture measurements were carried out by means of a laser profilometer, the overall influence of the wet surface on vehicle noise has been related in this study to surface texture.

1 - INTRODUCTION
The presence of water, depending on its quantity, the surface type, the vehicle, the tyres, the driving conditions, etc. has been reported by several authors to increase the vehicle noise emission level, with respect to the dry condition, by amounts ranging from 0 to 15 dB(A) [1]. Then, in regions where rain days are frequent, it is no academic issue how to take these circumstances into account in the evaluation of road surfaces with respect to their potential influence on traffic noise. All the more as noise reductions of the order of 3 to 5 dB(A) suffice to qualify a surface as "low-noise". The measurement data published so far on the effect of rain on vehicle noise were never related to actual surface characteristics. In view of the wide variability within any given type of surfacing material or technology, one cannot be content with data referring to " types " of surfaces. The investigation presented here is an attempt to relate the influence of wetness of the surface to its macrotexture.

2 - MEASUREMENT CAMPAIGN
Essentially two methods are available in this case to measure in a way as representative as possible of the noise emission level of the vehicles, i.e. the Controlled Pass-By method (CPB) or the Statistical Pass-By method (SPB). In order to overcome the difficulty of controlling the water film thickness on the tested surface when it is repeatedly travelled by vehicles, we have chosen the CPB method and the following measurement design. It consists of spreading a known, reproducible quantity of water on the tested road section before starting with the tested vehicle a series of runs all in the same driving conditions, namely: same speed, same gear ratio and cruising at stabilised speed, while the surface is slowly drying. By recording the time delay between the wetting (time t_0) and each measurement, it is then possible, by regression analysis of noise level versus time (as the surface is drying off) to retrospectively predict the noise level corresponding to t_0. This allows relating the extrapolated noise level to a constant water film thickness as if the tested vehicle had closely followed the tank lorry which, of course, is to be excluded because of the interference between the two vehicle noise emissions.
All pass-by noise measurements were carried out both on the dry surface and on the wet surface. In the latter case, at least 3 repeated runs were made. The test section is 40 m long, the microphone being

located in front of the middle point. The measurement was triggered manually at the entrance of the vehicle on the section. Its programmable duration was set at 3 second. The peak A-level is automatically determined and stored by the software in the SLM. The noise spectrum however does not correspond exactly to that peak; it is instead an average over the 3-second measurement duration. No measurement was carried out by a wind stronger than 5 m/s or by rain.
To determine what amount of water should be present on the surface to be representative of typical conditions by rain, we have referred to a value of 0.5 mm water film thickness which is typical for skidding resistance testing [3]. We subsequently found that it was not quite different from an already standardised rainfall intensity of 20 mm/h recommended in EN1436 [4] for testing the visibility of road markings by night. The tank lorry is equipped at the rear with a water distributor spraying 72 l/min over the full width of the lane (2.75 m), the end nozzles being inclined. To wet the surface before each series of repeated noise vehicle measurements, it runs over the 40 m long section at a steady speed of 9.5 km/h and repeats that twice so as to make three wetting passes in total. This amounts to a rain intensity of 39 mm/h which is twice as much as in EN 1436 and a total initial rainfall of 0.5 mm.
Nine road sections were chosen so as to cover as wide a range as possible of texture characteristics while complying with the requirements for good free-field sound measurements. The sampled surfaces are the following: Cement concrete 0/7 "Exposed aggregates", Porous cement concrete 0/7, Porous asphalt 0/14, SMA 0/14, Asphalt concrete, Ultra thin layer, Porous asphalt, Asphalt concrete and Surface dressing.
The road surface texture was measured by means of the BRRC stationary laser profilometer. It records the texture longitudinal profile over a length of 555 mm, with a vertical resolution of about 50 μm and a horizontal resolution of 1 mm. It delivers the mean profile depth (MPD) in mm as defined by ISO [5].
On each tested road section, 6 successive texture profile samples were taken in the right wheel track in front of the microphone location. The reported data are the mean of these 6 measurements.
Two vehicles were used on each site: a petrol car and a diesel lorry. The car is a CHRYSLER " Stratus " 2000 cc fitted with four identical tyres type CONTI Eco Contact CP 195/65R15. The lorry is a 10 t unladen, two-axle IVECO type 160-23 AHW fitted with four different tyres. During the tests it was laden with 6.3 t of concrete blocks. The loads were then 5.8 t on the front axle and 10.5 t on the rear axle, hence a total of 16.3 t. The car was operated at five different combinations of speed and gear ratio deemed to cover typical urban and extra-urban driving conditions, namely:

Speed (km/h)	45	60	60	75	90
Gear ratio	3	3	4	4	4

Table 1.

The lorry was also operated at different low to medium speed driving conditions, namely:

Speed (km/h)	45	45	60	60	75	90
Gear ratio[1]	5S	5L	5L	6S	6L	6L

Table 2: [1]: L and S stand for large and small ratio, respectively.

3 - MEASUREMENT RESULTS

The texture range covered happened to be 0.8 to 2.6 mm for MPD. The texture of 3 porous surfaces (sites 2, 3 and 7) can be considered as adequately characterised here since the drop-outs in the profile signal were extremely few, namely: from 0.0 to 0.3 %. This probably means that they were already clogged to some extent after 3 years (site 2 and 3) and 10 years (site 7) of service.
When plotting on the same graph the vehicle pass-by noise levels on the dry and wet surface, versus time in the latter case, one would expect in all cases to get a picture similar to the example of Figure 1 i.e. a decreasing " wet " noise level eventually catching up the lower " dry " level. In our set of measurement results, this is not generally so however. In many cases, as in the example of Figure 2, the wet level starts below the dry level and increases with time to eventually reach the dry level again.
Further insight on the effects described above can be gained by examining some typical pass-by noise spectra.
Figure 3 presents the spectra corresponding to measurements with the car at 45 km/h – 3rd gear on smooth asphalt. It illustrates the cases where the difference (ΔL) between the wet and the dry noise

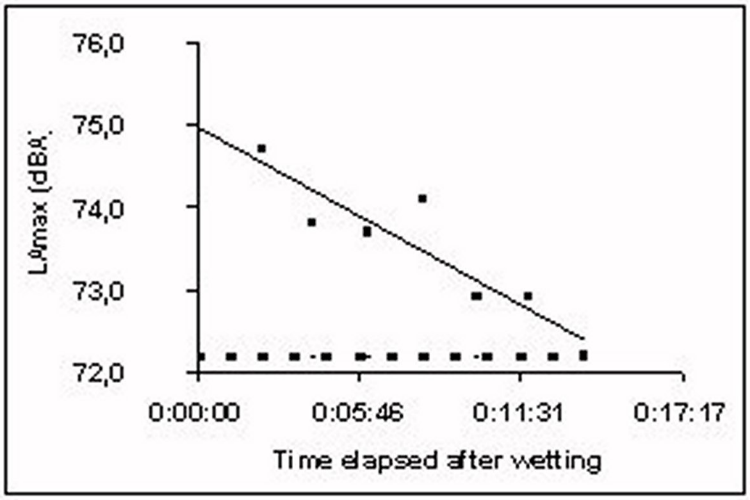

Figure 1: Normal behaviour of the pass-by noise level over time on the wet surface: starting higher than the dry level, it decreases as the surface dries off and eventually catches up the dry level (car at 75 km/h – 4th gear on asphalt concrete).

level is positive. The decreasing noise level when the surface dries off is essentially explained by the high-frequency spectral components associated with water droplet projections as reported in the literature [1].

Figure 4 presents the spectra corresponding to measurements with the lorry at 75 km/h – 6th large gear on porous asphalt. It illustrates the cases where ΔL is negative. The increasing noise level when the surface dries off is essentially explained by the low- and medium frequency spectral components, due to a so far unexplained phenomenon.

To our knowledge, the lowering of the low-frequency part of the spectrum on the wet road has never been reported except incidentally by M.BERGMANN [6]. Commenting a figure that compares rolling noise spectra on the wet and the dry surface and where, along with the typical rise of the spectrum in the high frequencies, there is a significant fall in the low frequencies, he writes: Fig. 1*" shows the known fact that the presence of water on the road leads to a strong increase of the rolling noise above 1000 Hz (the level depression observed below will not be considered here as this is about a special case) "* (from the German: *"Abb.1 zeigt die bekannte Tasache, daß das auf der Straß be vorhandene Wasser zu einer sehr starken Erhöhung der Rollgräusche im Frequenzbereich oberhalb 1000 Hz führt (die darunter zu beobachtende Pegelabsenkung soll hier nicht betrachtet werden, da es sich um einen Sonderfall handelt)*").

In general, ΔL can be either positive or negative depending on the site and on the speed/gear combination. There is no general systematic influence of the driving conditions. For instance, despite the average ΔL for the car is on all sites positive or nought, it is negative for many particular speed/gear combinations. In fact, the site influence in a particular driving condition is blurred probably not only by measurement errors but also by the two competing effects resulting in erratic variations.

Now, when considering $<\Delta L>$ the average value of $L_{wet}-L_{dry}$ over all speed/gear combinations for a given vehicle and plotting it versus MPD, one gets a somewhat clearer picture of the site influence. Figure 5 shows a significant correlation between $<\Delta L>$ for the lorry and MPD. But, for the car, $<\Delta L>$ seems to be independent of texture. One notices that the negative values of $<\Delta L>$ all occur on the five gap-graded surfaces, namely the two thin layers and the three porous layers. Comparing the car and the lorry, the values of $<\Delta L>$ appear to be strikingly correlated on dense surfaces only, as Figure 6 shows.

4 - CONCLUSIONS

This investigation has revealed a fact that seems to have been overlooked so far: the presence of water on the road surface can, in certain cases, decrease the pass-by noise level of vehicles instead of increasing it as has generally been reported. Then, there are two competing effects that determine vehicle noise emission on a wet surface:

1. An increase of the noise level in the medium and high frequencies corresponding to the spray of water droplets,

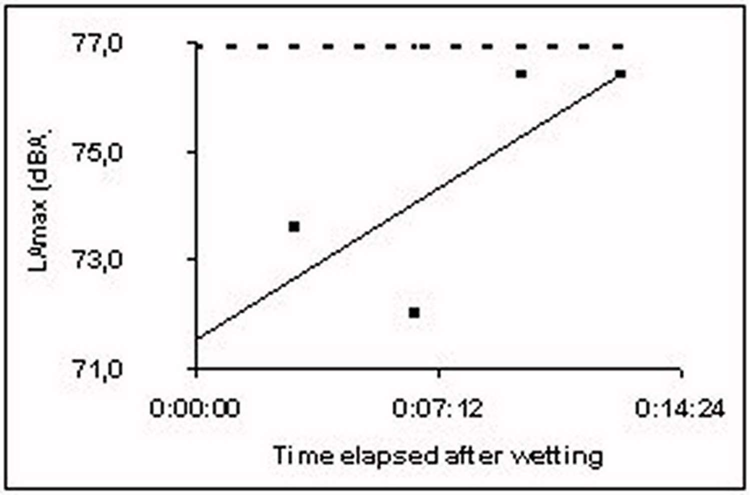

Figure 2: Another behaviour of the pass-by noise level over time on the wet surface. In this case, the wet level is initially lower than the dry level and increases to catch up the latter (car at 60 km/h − 4th gear on porous asphalt).

2. A decrease of the noise level in the low and medium frequencies due to a so far unexplained phenomenon.

The relative importance of the two effects does not seem to depend on vehicle speed, at least not in a clear, systematic way. It does depend on tyre and surface characteristics. Effect n°2 seems to be less important (less frequent in our results) with the car than with the lorry. With the lorry, in particular, this effect appears to dominate on all the gap-graded surfaces tested, while effect n°1 dominates on the dense surfaces. With the car, although effect n°2 clearly occurs in many cases, when one looks at the overall noise levels averaged over all speed/gear configurations on a given site, the average difference between the wet and the dry condition is always positive or nought.
An attempt has been made to relate the influence on vehicle noise of the presence of water on the road to the surface texture. For the lorry, a very significant linear correlation (R = 0.80) has been found which enables us to issue the following formula:
Lorry: $L_w - L_d = 5.2 - 3.4 MPD \pm 1.5$
where L_w and L_d are respectively the peak pass-by noise level in dB(A) on the wet and the dry road and MPD is the Mean Profile Depth of the road surface texture in mm. For the car, no such relationship came out. Only an average effect with no clear dependence on surface characteristics can be reported as follows:
Car: $L_w - L_d = 1.6 \pm 1.5$
The error margins are the 95% confidence intervals.
These relations hold when all kind of surfaces are included. A more detailed inspection of the data suggests that gap-graded surfaces behave differently than the dense surfaces, but the number of surfaces tested is not large enough to allow deriving significant, separate correlations.

ACKNOWLEDGEMENTS

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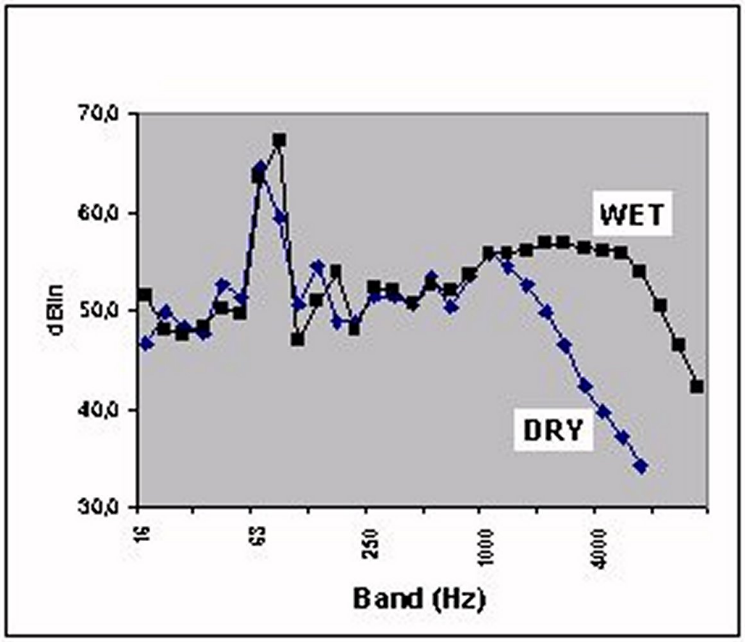

Figure 3: Typical example of pass-by noise spectra comparison between dry and wet condition where essentially the high frequencies are involved (car on smooth asphalt at 45 km/h − 3rd gear).

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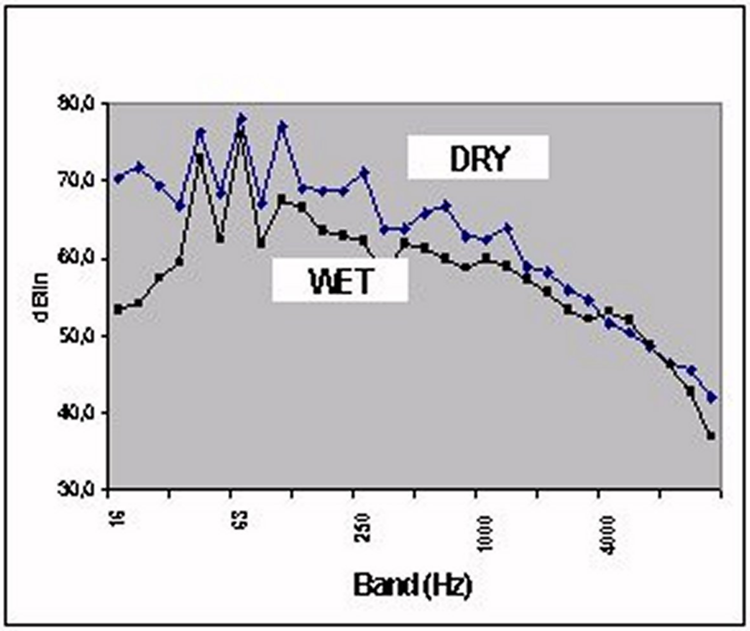

Figure 4: Typical example of pass-by noise spectra comparison between dry and wet condition where essentially low and medium frequencies are involved (lorry on porous asphalt at 75 km/h − gear 6L).

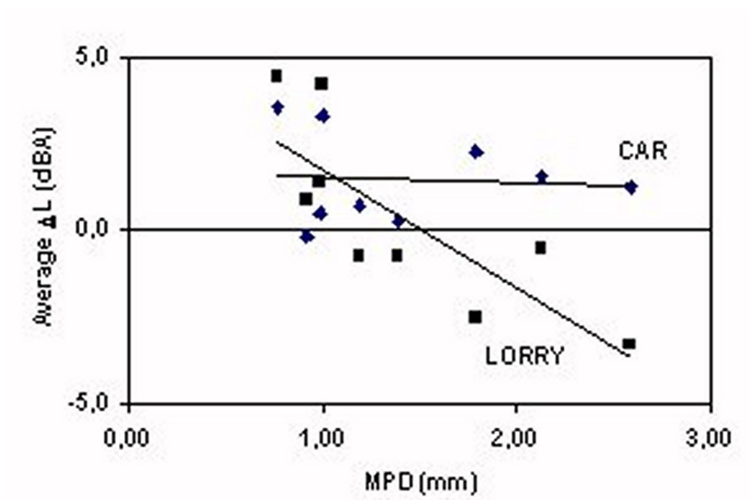

Figure 5: Correlation between <L_{wet}−L_{dry}> and pean profile depth.

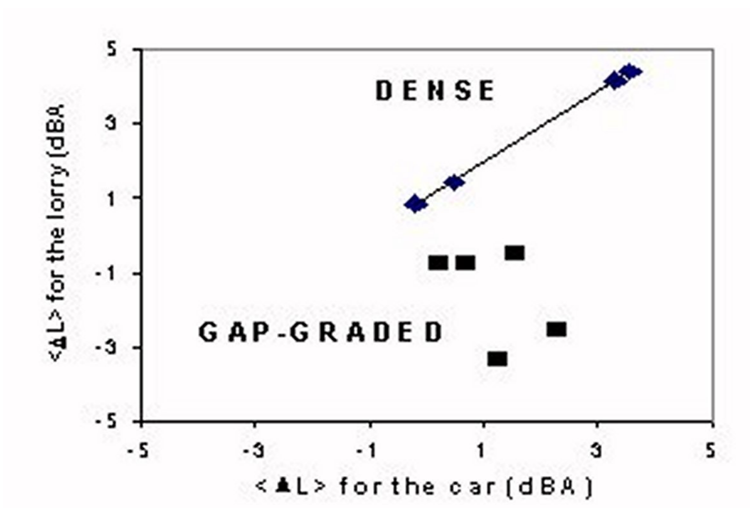

Figure 6: Comparison between the values of $<\Delta L>$ for the car and the lorry.