Investigation into road vehicle noise reduction by drainage asphalt pavement

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Regarding the reduction of road vehicle noise by drainage asphalt pavement, two kinds of experimental investigations were performed. Firstly, sound propagation was observed on two types of drainage asphalt pavements and a dense asphalt pavement. In this experiment, an omnidirectional sound source was located under the body of a passenger car and a heavy truck. As a result, it was found that the excess noise reduction on drainage asphalt pavement can be attributed to the sound absorption during multiple reflection under the vehicle body and this effect depends on the vehicle type. Secondly, pass-by tests were performed on the three kinds of pavements using the same test vehicles. In this experiment, tire/road noise was measured on each pavement and by comparing the results, the reduction of tire/road noise due to the porosity of drainage asphalt pavement was estimated. Based on the results of these investigations, a calculation model for the prediction of vehicle noise propagation on drainage asphalt pavement has been proposed.

Keywords: Road vehicle noise, Drainage asphalt pavement, Prediction model, Sound propagation, Excess reduction

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1. INTRODUCTION

Recently, it has been known that drainage asphalt pavement is effective for the reduction of road traffic noise and this type of road surface treatment is often applied to highways and roadways. Regarding this acoustic performance, a lot of researches have been made until now and acoustic characteristics of the pavement and sound propagation property on it have been clarified to some extent.1—5) However, in order to establish a precise prediction model for road vehicle noise propagation on drainage asphalt pavement, further examinations are necessary to know the acoustic phenomena in the vicinity of the noise source in detail. In this study, these points have been investigated by the field experiments using an artificial sound source and two types of road vehicles. From the results of these experimental investigations, a calculation model for the noise propagation from a road vehicle on drainage asphalt pavement has been proposed.

2. EXPERIMENTAL INVESTIGATIONS

2.1 Conditions of the Field Experiments

The field experiments were carried out at the test track of Public Works Research Institute. The road surface of the test track is paved with various types of surface treatments. Among them, three kinds of pavements were chosen for the experiment. Table 1 shows the data of their composite (the maximum chipping size of aggregate, void content and thickness of the pavements). Figure 1 shows
the macrotexture of each pavement measured using a laser profilometer, in which it can be seen that the profile of the drainage asphalt pavement much varies with the difference of chipping size.

Figure 2 shows the sound absorption coefficient of each pavement measured using a reverberation chamber of 1.65 m³ air volume. The absorption coefficient of the dense asphalt pavement is less than 0.2 in the frequency range from 500 Hz to 8 kHz, whereas in the case of the two drainage asphalt pavements, the coefficient peaks in the frequency range from 500 Hz to 1 kHz. The peak value is about 0.7 for the drainage asphalt pavement A and about 0.4 for the drainage asphalt pavement B. In the frequency range above 2 kHz, a tendency that the absorption coefficient gradually increases is seen in both cases.

2.2 Experiment Using an Artificial Sound Source
Road vehicles have almost all dominant noise sources under their body and therefore it is necessary to examine the sound propagation from the lower part of a vehicle including the shielding effect and multiple reflection between the body and the road surface. In order to investigate these problems, an omnidirectional sound source (a hexagonal loudspeaker of 40 cm in diameter) shown in Fig. 3 was placed at the positions of engine and tire under the test vehicle and the sound pressure level (S.P.L.) was measured around the vehicle. Based on the results of our previous experiments, the main source positions of a vehicle were assumed to be on the road surface just under the engine and near the contact patch of each tire. In this experiment, two types of road vehicles, a passenger car (2,000 cc engine swept volume) and a heavy truck (8 ton gross vehicle

Table 1 Test road surfaces.

<table>
<thead>
<tr>
<th>Test road</th>
<th>Maximum chipping size (mm)</th>
<th>Void content (%)</th>
<th>Thickness (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense asphalt pavement</td>
<td>13</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Drainage asphalt pavement A</td>
<td>10</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>Drainage asphalt pavement B</td>
<td>20</td>
<td>20</td>
<td>5</td>
</tr>
</tbody>
</table>

Fig. 1 Macrotexture of the test road surfaces.

Fig. 2 Sound absorption characteristics of the test road surfaces.

Fig. 3 Hexagonal loudspeaker.
Fig. 4 Positions of the loudspeaker.

Fig. 5 Measurement points of sound pressure level.

(a) Dense asphalt pavement  (b) Drainage asphalt pavement A

Fig. 6 S.P.L. contour maps in 630 Hz band in cases I and II.
weight), were used to examine the effect of the difference of vehicle shape.

The measurements were carried out under the following sound source positions as shown in Fig. 4.

Case I : without the vehicle
Case II : under the engine of the test vehicle
Case III : near the contact patch of the left front tire
Case IV : near the contact patch of the right front tire

As shown in Fig. 5, the measurement of sound pressure level was made at 30 points in the vertical plane including the front axis of the test vehicle. From the measurement results around the test vehicle, S.P.L. contour maps were obtained. Figure 6 shows two examples of the measurement results for Case I and Case II in 1/3 octave band of 630 Hz, in which (a) and (b) indicate the results measured on the dense asphalt pavement and on the drainage asphalt pavement A, respectively. On both of the pavements, the contours are much different between the results for Case I and Case II. This fact indicates that the shielding effect by the vehicle body is very serious for the sound propagation from the sound source under the body. To see the results of Case II, the contours are much different between the results for the passenger car and the heavy truck. This fact indicates that the shielding effect depends on the shape of vehicle.

Figure 7 shows the S.P.L. contour maps around

![S.P.L. contour maps in 630 Hz band in cases II, III and IV (passenger car).](image-url)

(a) Dense asphalt pavement
(b) Drainage asphalt pavement A
the passenger car on the dense asphalt pavement (a) and the drainage asphalt pavement A (b), respectively. These results indicate that the shielding effect much differs by the difference of the position of the sound source. In these results, however, the patterns of S.P.L. contour map in each case of source position are very similar both on the dense asphalt pavement and on the drainage asphalt pavements. Therefore, in case of incorporating the shielding effect into the vehicle noise calculation model on drainage asphalt pavement, the vehicle noise directivity on dense asphalt pavement and on the drainage asphalt pavements. Therefore, in case of incorporating the shielding effect into the vehicle noise calculation model on drainage asphalt pavement, the vehicle noise directivity on dense asphalt pavement and on the drainage asphalt pavements. Therefore, in case of incorporating the shielding effect into the vehicle noise calculation model on drainage asphalt pavement, the vehicle noise directivity on dense asphalt pavement and on the drainage asphalt pavements. Therefore, in case of incorporating the shielding effect into the vehicle noise calculation model on drainage asphalt pavement, the vehicle noise directivity on dense asphalt pavement and on the drainage asphalt pavements.

From the S.P.L. contour maps as shown in Fig. 6 and Fig. 7, the S.P.L. values on the straight line from the center point under the vehicle body to the point of 7.5 m and 1.2 m above the ground (see Fig. 5) were obtained by interpolation. Figure 8 shows two examples (cases of the passenger car and the heavy truck in Case II, 630 Hz in 1/3 octave band). In these results, it can be clearly seen that there are level differences between the results for the three types of pavements. To see the S.P.L. decrease in distance on each pavement, the slope of the S.P.L. decrease was examined. In case of passenger car, it is 4.0 dB/d.d. (double distance) for the dense asphalt pavement, 4.4 dB/d.d. for the drainage asphalt pavement A and 4.3 dB/d.d. for the drainage asphalt pavement B, respectively. Thus, the slopes are almost the same. These tendencies were found in all other cases. From these results, the following conditions were assumed.

1) The slope of S.P.L. decrease in distance on the two kinds of drainage asphalt pavements is equal to that on the dense asphalt pavement.
2) The differences between S.P.L. distributions on the drainage asphalt pavements and that on the dense asphalt pavement are caused by the sound absorption during the multiple reflection under the vehicle body.

Next, in order to see the extent of the effect of sound reduction due to sound absorption during the multiple reflection on the drainage asphalt pavements, the S.P.L. differences between on the dense asphalt pavement and on the two types of drainage asphalt pavements at a point of 1.5 m from the sound source were obtained from the results shown in Fig. 8. The results are shown in Fig. 9 (passenger car) and Fig. 10 (heavy truck). In this calculation for the sound propagation from the tire position, the energy-mean value of the results for Case III and Case IV was calculated for each pavement and S.P.L. differences were obtained by the same procedure.

2.3 Vehicle Pass-by Tests
As the second field experiment, the tire/road noise generated when the test vehicles run on the three kinds of pavements was measured at the test track.
In this experiment, the value of FAST maximum S.P.L. was measured at a point 7.5 m apart from the running path and 1.2 m above the road surface when the test vehicle passed by under the condition of engine switched off (inertia running) and almost constant speed of 60 km/h.

The results for the passenger car and the heavy truck are shown in Fig. 11 and Fig. 12, respectively, in which the A-weighted values of S.P.L. in each 1/3 octave band are shown. In each figure, the solid line indicates the result obtained on each drainage asphalt pavement and the broken line indicates that on the dense asphalt pavement.

From these measurement results, the reduction of tire/road noise due to the porosity of the drainage asphalt pavement was estimated under the following assumptions.

1) The effect of noise reduction by drainage asphalt pavement consists of the reduction of tire/road noise (the sound directly generated from the tire being excited by the road surface) and that caused by the sound absorption during the multiple reflection under the vehicle body.

2) The dense asphalt pavement has no effect of sound absorption and therefore there is no reduction by sound absorption during the multiple reflection under the vehicle body.

Then, the effect of reduction of tire/road noise due to sound absorption in each 1/3 octave band shown in Fig. 9 and Fig. 10 was added to the results measured on the drainage asphalt pavements A and B. The results are shown by the dotted line in Fig. 11 (the passenger car) and Fig. 12 (the heavy truck). In these figures, Zone A indicates the effect of sound reduction due to sound absorption. From these results, it can be considered that the difference
between the broken line (the results measured on the dense asphalt pavement) and the dotted line corresponds to the reduction of tire/road noise due to the porosity of the drainage asphalt pavement under the assumption mentioned above. In case of the drainage asphalt pavement A shown in Fig. 11(a) and Fig. 12(a), the difference is positive (in Zone B) over a wide frequency range. In this case, the tire/road noise is reduced by the drainage asphalt pavement. On the other hand, in case of the drainage asphalt pavement B shown in Fig. 11(b) and Fig. 12(b), the difference is negative (in Zone C) in the frequency range up to 1.6 kHz or 800 Hz. In this case, the tire/road noise is increased on the drainage asphalt pavement, and this might be attributed to the fact that the chipping size of aggregate of this pavement
is larger than that of the drainage asphalt pavement A and therefore the power exciting the tire might be increased.

3. CALCULATION MODEL FOR THE VEHICLE NOISE PROPAGATION ON DRAINAGE ASPHALT PAVEMENT

Based on the results of the investigations mentioned above, a calculation model of vehicle noise propagation on drainage asphalt pavement was assumed by separating the engine noise and tire/road noise as follows.

Regarding the engine noise:

\[ L_{pe}(r) = L_{WE} - 20 \log r - 8 - \Delta L_E \]  

where,

- \( L_{pe}(r) \): S.P.L. by the engine noise at a point \( r(m) \) apart from the running path,
- \( L_{WE} \): sound power level of the engine noise measured on the dense asphalt pavement,
- \( \Delta L_E \): excess attenuation for engine noise due to sound absorption during the multiple reflection under the vehicle body on the drainage asphalt pavement.

Regarding the tire/road noise:

\[ L_{pt}(r) = L_{WT} - \Delta L_{WT} - 20 \log r - 8 - \Delta L_T \]

where,

- \( L_{pt}(r) \): S.P.L. by the tire/road noise at a point \( r(m) \) apart from the running path,
- \( L_{WT} \): sound power level of the tire/road noise measured on the dense asphalt pavement,
- \( \Delta L_{WT} \): reduction of sound power level of the tire/road noise by the effect of drainage asphalt pavement,
- \( \Delta L_T \): excess attenuation for tire/road noise due to sound absorption during the multiple reflection under the vehicle body on the drainage asphalt pavement.

![Fig. 13](image1.png)

**Fig. 13** Measured and estimated results of pass-by noise (passenger car, 60 km/h).

![Fig. 14](image2.png)

**Fig. 14** Measured and estimated results of pass-by noise (heavy truck, 60 km/h).
In these equations, \( L_{WE} \) and \( L_{WT} \) are measured on the dense asphalt pavement. That is, \( L_{WT} \) is obtained by the pass-by test under the condition of engine switched off and \( L_{WE} \) is obtained by subtracting the value of \( L_{WT} \) from the sound power level of total noise measured under the running condition of engine switched on.

The S.P.L. of the total noise from a vehicle under stationary running condition \( L_p(r) \) is calculated as follows under the assumption that vehicle noise consists of engine noise and tire/road noise.

\[
L_p(r) = 10 \log \left( 10^{L_{WT}(r)/10} + 10^{L_{er}(r)/10} \right)
\]  

(3)

In order to confirm the validity of the calculation model mentioned above, the values of S.P.L. on the two types of drainage asphalt pavements at a point of 7.5 m from the running path and 1.2 m above the road surface calculated by the model and those actually measured were compared. The results for the passenger car and the heavy truck are shown in the form of time history of pass-by noise (unit pattern) in Fig. 13 (the passenger car) and Fig. 14 (the heavy truck), respectively. In these figures, it can be seen that the calculated and measured unit patterns are fairly in good agreement in almost all cases.

In order to estimate the change of vehicle noise due to the difference of such road surface characteristics as chipping size of aggregate, void content and thickness of the pavement, it is necessary to make further experimental studies and improve the calculation model.

4. CONCLUSIONS

In order to investigate the noise propagation from road vehicles on drainage asphalt pavement, field experiments using an artificial sound source and two types of vehicles were performed on a dense asphalt pavement and two kinds of drainage asphalt pavements. Based on the results obtained in these experiments, a calculation model for the vehicle noise propagation on drainage asphalt pavement was considered. From these results, the following conclusions have been obtained.

1) The S.P.L. distribution around a vehicle is much different between a passenger car and a heavy truck due to the difference of vehicle shape.

2) The rate of S.P.L. decrease in distance can be considered equal both on the dense asphalt pavement and on the drainage asphalt pavement.

3) The reduction of engine noise on the drainage asphalt pavement can be attributed to the sound absorption during the multiple reflection under the vehicle body.

4) The reduction of tire/road noise on the drainage asphalt pavement can be divided into two factors; one is the reduction of noise radiation itself due to the porosity of drainage asphalt surface and the other is the sound absorption during the multiple reflection under the vehicle body similar as in case of engine noise.

5) The calculation model assumed based on the findings mentioned above is proper for the prediction of vehicle noise propagation on drainage asphalt pavement.

This study was performed only on two kinds of drainage asphalt pavements and hence the exact effects of sound absorption and reduction of tire/road noise on each drainage asphalt pavement have to be examined for each case. The reduction of tire/road noise was examined only for the running condition of 60 km/h in this study and it should be examined under different running speed condition.

REFERENCES

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