A study on comparison of noise reduction effect of single-layer drainage asphalt pavement and double-layer drainage asphalt pavement : Part 1 sound power level and frequency characteristic in initial construction

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ABSTRACT

This paper describes noise reduction effect of the double-layer drainage asphalt pavement that is one of the measures of road traffic noise. The data used in the study was researched in 1999-2003.The purpose is to study sound power level and the frequency characteristic in initial construction by comparing the single-layer drainage asphalt pavement with double-layer drainage asphalt pavement. Result of the comparison of the two types, it was found that double-layer drainage asphalt pavement have the noise reduction effect, about 3dB at light vehicles and slight effect at heavy vehicles. Peak frequency of the double-layer drainage asphalt pavement is around 500-630Hz. In addition to, in the near 1000Hz, A-weighted power spectrum of double-layer drainage asphalt pavement is lower than that of single-layer drainage asphalt pavement by 7dB.

Keywords: Double-layer drainage asphalt pavement, Frequency characteristic, Power level
I-INCE Classification of Subjects Number(s): 52.3

1. INTRODUCTION

Since 1999, the authors' group have been conducting follow-up studies and issuing interim reports [1-5] on noise at experimental construction sites with a double-layer drainage pavement applied to the roads, as shown in Fig. 1.1. In this study, the results from these follow-up studies are compared with ASJRTN-Model 2008 [6] drainage pavement with respect to their noise reduction effect and performances.

The double-layer drainage pavement has two structural layers. The top layer comprises aggregate particles of relatively small diameter mainly for the purpose of noise reduction. The bottom layer comprises relatively large aggregate particles to secure the structural strength of the pavement. The double-layer structure retains a series of continuous voids from the top layer through the bottom layer and is effective in noise reduction.

Recently, double-layer drainage pavement has developed beyond the experimental pavement stage to being used in a gradually increasing number of actual construction sites, primarily, in places where better noise reduction than that provided by conventional drainage pavements is required. As such, the double-layer drainage pavement is being adopted by construction sites as the anti-noise measure of the future.

Recognizing that double-layer drainage pavement has entered the practical stage, this study involved collecting data from experimental construction sites and re-examining power level formulae, the noise reduction effect and the frequency characteristics in initial construction. This paper presents

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the results from our comparisons of the reanalyzed data for the double-layer drainage pavement with the drainage pavement models summarized in ASJ RTN-Model 2008 (hereinafter referred to as ASJ 2008).

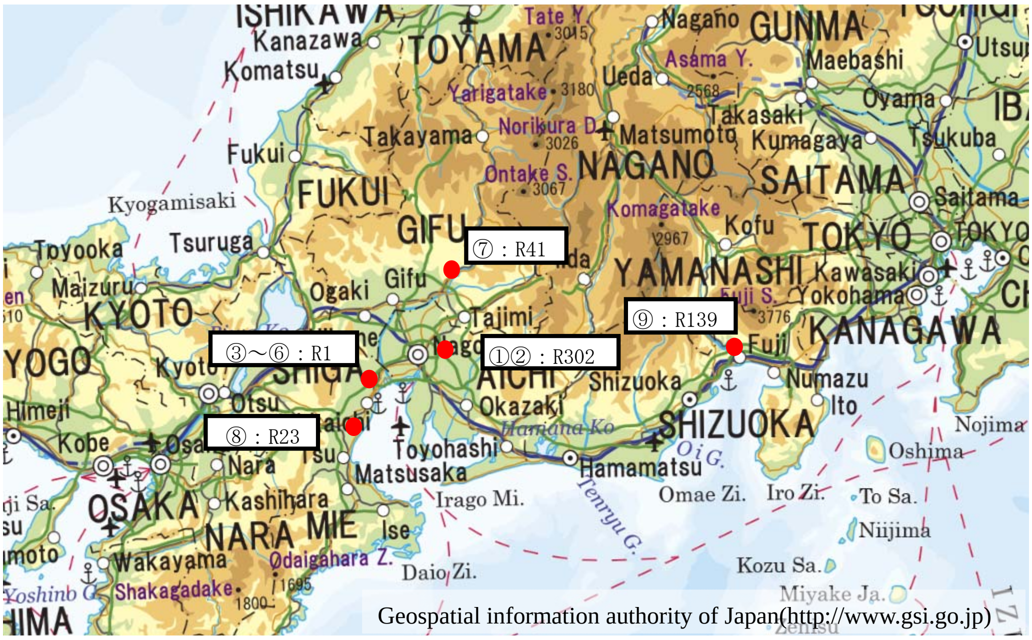

Fig. 1.1 Locations of data collection sites

2. DATA FOR STUDY

2.1 Study target place

Table 2.1 summarizes the details of the reanalyzed target sites. Regarding the power level formulae for the initial construction (one year or less after construction), data labels ①, ③, ④, ⑦, ⑧, and ⑨ were used for examining the double-layer drainage pavement (hereafter referred to as the Double Layer), data labels ② and ⑤ were used for examining the conventional drainage pavement (hereafter referred to as the Single Layer), and data label ⑥ was used for examining a noise-reduction pavement that sets a high value on durability and having a bottom layer of the double-layer composed of typical dense asphalt pavement (hereafter referred to as the Thin Layer).

Table 2.1 Pavement history and structure of data-collected places

Data-collected place		Pavement structure					
Route No.	Constraction date	No.	Thickness of pavement (mm)		Maximum chipping (mm)	Void content (%)	Types of pavement
R302	1999/6/21	①	Top	20	5	23	Double-layer
			Bottom	30	13	25	
		②	–	50	13	20	Single-layer
R1	2000/2/26	③	Top	15	5	23	Double-layer
			Bottom	45	20	23	
		④	Top	15	5	20	Double-layer
			Bottom	35	13	20	
		⑤	–	50	13	20	Single-layer
		⑥	Top	15	5	20	Thin layer
			Bottom	35	20	– (asphalt)	
R41	2002/10/25	⑦	Top	20	8	23	Double-layer
			Bottom	30	13	20	
R23	2002/11/20	⑧	Top	20	8	20	Double-layer
			Bottom	30	13	20	
R139	2003/2/24	⑨	Top	20	5	23	Double-layer
			Bottom	30	13	20	

2.2 Data collection method

Data were collected according to JIS D 1024, which stipulates the methods of measuring the noise emitted by accelerating road vehicles on a road attached to a flat-structured sidewalk without any reflectors. A microphone was set up at a point (on the left side of the moving direction) 7.5 m away horizontally from the center of the measurement target lane and 1.2 m above the road surface.

Measurement of the noise level was performed with a method found in JIS Z 8731. We measured the maximum values LA, Fmax of noise levels emitted by general vehicles and a test passenger car, which were separately and steadily running, and the power levels were calculated with the following formula (Peak Method).

$$L_{WA} = L_{\mathrm{A,Fmax}} + 8 + 20\log_{10} r \qquad (1)$$

where r is, as shown in Fig. 2.1, the minimum distance (m) between the center of nearby traffic lane and the microphone. The driving speeds were obtained by measuring with a stopwatch the times taken to travel a fixed distance.

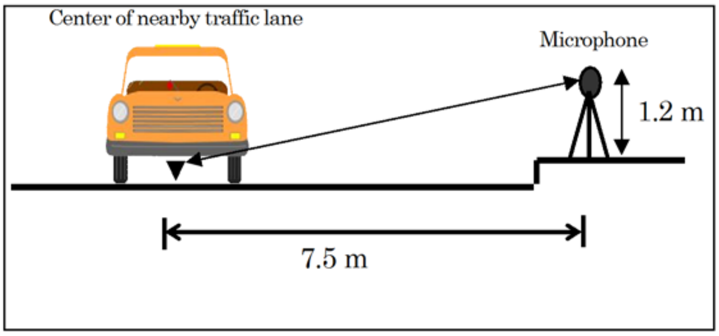

Fig. 2.1 Arrangement of the target vehicle and the microphone

3. COMPARISON OF THE PERFORMANCE OF THE DOUBLE-LAYER DRAINAGE PAVEMENT

3.1 Comparison of the pavement structures

As shown in Fig. 3.1, the top layer of the Double Layer is composed of aggregate particles of relatively small diameter. However, to secure the same void content while maintaining the durability of the pavement surface, large diameter aggregate particles are advantageous. Thus, 13 mm of top aggregate (the common name for aggregate containing mostly particles that pass through a 13 mm sieve used for screening crushed stones) has typically been used for top layers, with increasing popularity as a pavement that provides noise reduction effects.

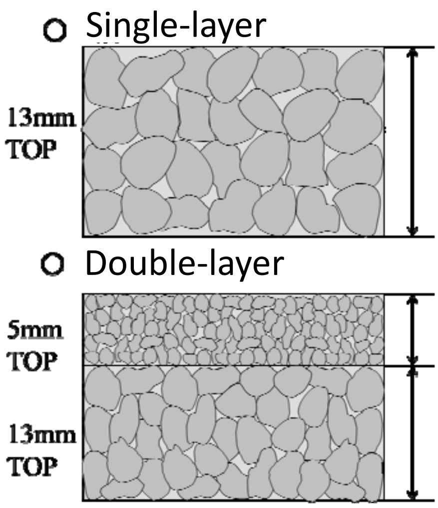

Fig. 3.1 Structures of Single-Layer and Double-Layer drainage pavements

Follow-up studies on the long-term changes of the Single Layer however, conducted in recent years, have revealed that while the Single Layer maintains its noise reduction effectiveness as long as the void content endures, the roughness of the aggregate at the surface results in a noise increase, chiefly in the low-frequency area, if voids become choked. [6]

Therefore, to ensure the presence of the voids required for noise reduction while maintaining the required strength of the pavement, the Double Layer was developed with a top layer of 5 mm top aggregate and a bottom layer of conventional 13 mm top aggregate. This pavement was experimentally tested and finally brought to practical use.

3.2 Comparison of power levels in initial construction

For the Double Layer pavements constructed between 1999 and 2003 inclusively, study data collected in the period immediately after construction (within one year) were reanalyzed, and the driving velocity dependence of the Double Layer's power level was examined. Table 3.1 shows the study data.

Table 3.1 Objects of power level study

Light vehicles		Heavy vehicles	
Small-sized vehicles (unit)	17	Large-sized vehicles (unit)	203
Passenger car (unit)	280	Medium-sized vehicle (unit)	66
Velocity (km/h)	69.39 (98)	Velocity (km/h)	65.42 (79)

3.2.1 Power levels of light vehicles

Table 3.2 and Fig. 3.2 show the velocity dependence of light vehicle power levels.

Ninety percent or more of the light vehicles in the study were passenger cars, making the velocity dependence [28 logV] if all the light vehicles data are evenly and simply sorted. However, the velocity dependence becomes [32 logV] if the ratio of passenger cars to small-sized vehicle is assumed to be 4:1.

The velocity dependence (at up to 60 km/h) on ordinary roads, as in the ASJ 2008, appears to be roughly [30 logV]. Moreover, as shown in the figure, the Double Layer shows a noise reduction effect of 8.6 and 2.9 dB, compared to the dense asphalt pavement and Single Layer values in the ASJ 2008, respectively, at a speed of 60 km/h.

When the data show a velocity dependency in ASJ 2008 of approximately [30 logV], the standard deviation, i.e., the dispersion of the data, slightly increases. However, the observational data still roughly conform to the model as seen in Fig 3.2.

Table 3.2 Power level velocity dependence of light vehicles

	Inclination	Interception	Correlation coefficient	Standard deviation
Passenger car	28	42.4	0.618	2.4
Small-sized vehicle	50	5.1	0.733	2.2
Light vehicle (Total)	28	42.3	0.600	2.4
[P. C. 4: S. F. C. 1]	32	34.9	-	-
30 log Corres.*	30	38.1	0.600	2.5

* Corresponding to the inclination in the ASJ 2008.

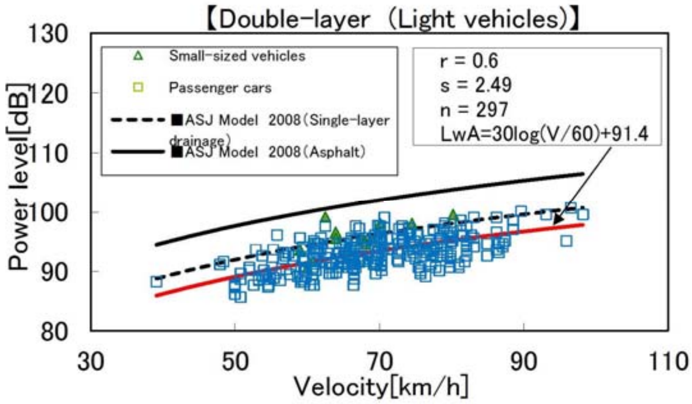

Fig. 3.2 Velocity power level dependency of Double Layer (for light vehicles)

3.2.2 Power level of heavy vehicles

Table 3.3 and Fig. 3.3 show the velocity dependence of heavy vehicles' power levels.

As 70 percent or more of the heavy vehicles' data is of large-sized vehicles, the velocity dependence is [21 logV] if all of the heavy vehicles' data are simply and evenly sorted, whereas it becomes [19 logV] if the composition ratio of the large-sized vehicles and the medium-sized vehicles is assumed to be 1:1. This indicates that the velocity dependence of the heavy vehicles is approximately [20 logV], smaller than [30 logV] in the ASJ 2008. Moreover, as shown in the figure, the Double Layer shows a noise reduction effect of 4.1 and 0.2 dB when compared to the dense asphalt pavement and Single Layer values in the ASJ 2008, respectively, at a speed of 60 km/h.

When the data approaches [30 logV] velocity dependency in the ASJ 2008, the standard deviation, i.e., dispersion of the data, slightly increases. However, the data from our observations roughly conform to the model with respect to light vehicles.

Table 3.3 Power level velocity dependence of heavy vehicles

	Inclination	Interception	Correlation coefficient	Standard deviation
Large-sized vehicle	15	75.8	0.312	1.8
Medium-sized vehicle	23	59.4	0.555	2.1
Heavy vehicles (Total)	21	65.9	0.394	2.2
[Large 1: Medium 1]	19	67.6	-	-
30 log Corres.*	30	49.1	0.394	2.3

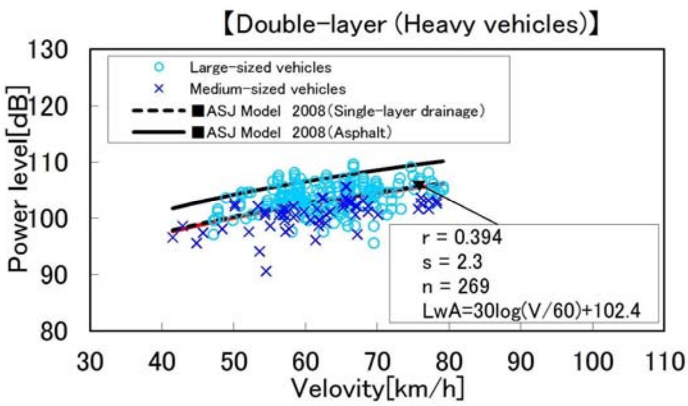

Fig. 3.3 Velocity power level dependency of Double Layer (for light vehicles)

3.3 Comparison of the pavement structures

To examine differences in frequency characteristics among pavement types, we compared the power levels of a test passenger car (Fig. 3.4) being driven at a speed of 50 km/h on each type of pavement as well as the ASJ 2003 (dense asphalt pavement). The study took place on a national road —Route 1— comprising all the pavement types.

Figure 3.4 The test passenger car used for the frequency characteristics test

Figure 3.5 shows a comparison of results of the test passenger car frequency characteristics. A comparison of the frequency characteristics of each pavement type in initial construction (after eight months) demonstrates that the Double Layer and Thin Layer pavements have similar frequency characteristics, and show a small sharp peak at 500 to 630 Hz.
The Single Layer noise level appears to be approximately 7 dB higher than that of the Double Layer at approximately 1000 Hz, eight months after construction.

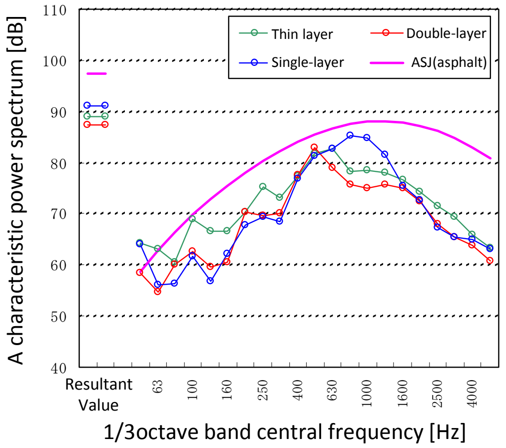

Fig. 3.5 Frequency characteristics of the test passenger car on drainage pavements (8 months after construction)

4. CONCLUSION

This paper presents follow-up study results on double-layer drainage pavements that were experimentally constructed between 1999 and 2003. Data on these pavements was re-sorted and examined, and corrections were made for the drainage pavement road surfaces in the ASJ 2008, and for the frequency spectrum with respect to the drainage pavements. The results are as follows.

An analysis of the running velocity power level dependency, based on actual measurements of the power levels of general vehicles in steady traffic flow (40 to 80 km/h) on the double-layer drainage pavement constructed on current roads showed that the velocity dependence is approximately 30 logV for light vehicles and approximately 20 logV for heavy vehicles. The value for the light vehicles almost matched that in the ASJ 2008.

In addition, the noise reduction effect, as compared to that for the Single Layer in the ASJ 2008, demonstrates that the Double Layer is better in light vehicles by approximately 3 dB and slightly better in heavy vehicles.

The frequency characteristics of the Double Layer in initial construction were examined for test passenger cars and showed a peak in the frequency at 500 to 630 Hz. The Single Layer's noise level appeared to be 7 dB higher compared with that of the Double Layer at approximately 1000 Hz.

5. FUTURE RESEARCH

In future work, we first plan to update the actual noise reduction effect of the Double Layer. In this study, we analyzed Double Layers that had been constructed 10 years ago or more. Since then, many numbers of the Double Layer have been constructed. With new products continuously being developed, the noise reduction effects and durability have improved from initial conditions. Studies of various current pavement structures and road traffic conditions are necessary to determine the actual noise reduction effects of the latest Double Layer.

Second, we intend to address issues in the application of Double Layer as a noise reduction measure. The achievement rate for environmental standards for noise is increasing, however, have nearly reached a certain critical level [7]. Moreover, the achievement rate for noise reduction in road-proximity spaces is rather low, and there is some consideration being given to requiring prioritized measures in the future. In response, eco-friendly cars are proliferating, stand-alone tire noise regulations are being introduced, and pavement improvements are being promoted, especially at road intersections. These efficiency measures will enhance convenience, visibility, and safety for drivers and pedestrians. The construction of the Double Layer pavement at road intersections would be effective in raising the overall rate of achieving environmental standards.

However, we also know that the Double Layer, due to its use of small aggregates in the top layer, is inferior to the Single Layer in its durability against road stresses caused by vehicles changing directions. In addition to continued research and development of pavements that provide both noise reduction effects and durability, the investigation of the noise reduction effect in non-steady traffic flow sections will also be important.

REFERENCES

1. Ueta, Ishiwata, Ishikawa, Kaneki, Matsuoka. Noise Reduction Effect of Double-Layer Drainage Pavement (Fourth Report). The Acoustical Society of Japan, Lecture papers. 2003.9; p. 811-812.
2. Ishikawa, Hosokawa, Ueta, Kaneki, Matsuoka. Sustainability of Noise Reduction Effect of Double-Layer Drainage Pavement on Ordinary Roads. The Acoustical Society of Japan, Lecture papers. 2003.9; p. 813-814.
3. Ueta, Ishikawa, Ohtani, Ohya, Kaneki, Matsuoka. Sustainability of Noise Reduction Effect of Double-Layer Drainage Pavement on Ordinary Roads (Second Report). The Acoustical Society of Japan, Lecture papers. 2004.9; p.929-930.
4. Ishikawa, Ishiwata, Ueta, Kodama, Ohya, Kaneki, Fukui. Sustainability of Noise Reduction Effect of Double-Layer Drainage Pavement on Ordinary Roads (Third Report). The Acoustical Society of Japan, Lecture papers. 2005.9; p. 895-896.
5. Daimoto, Ishikawa, Ueta, Kaneki, Fukui. Sustainability of Noise Reduction Effect of Double-Layer Drainage Pavement on Ordinary Roads (Fourth Report). The Acoustical Society of Japan, Lecture papers. 2006.9; p. 11.
6. Road Traffic Noise Research Committee. The Acoustical Society of Japan "Road Traffic Noise Prediction Model" ASJ RTN-Model 2008. The Acoustical Society of Japan Journal. 2009.4. 65; pp 179-232.
7. Ministry of the Environment. Published data, "Automobile Traffic Noise Status in 2011.” 2013. pp