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Analysis of Noise Characteristics of Double and Single-layered Porous Pavement with CPX Method
-National Route 1, Sejong-Si Section-

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CPX방법에 의한 복층 및 단층 다공성포장의 소음특성 분석
-국도 1호선 세종시 구간-

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Abstract Road traffic noise is a major complaint. Porous pavement (PP) has been proposed as an effective method for reducing road traffic noise, but it has not been applied much due to the lack of quantitative evaluation. In this study, the noise reduction of single-layer porous pavement (SLPP) and double-layer porous pavement (DLPP) was evaluated. The noise was measured using the CPX method, and the driving speed was measured every 10km/h from 50km/h to 80km/h. The differences in noise level between the two PPs were statistically significant. The driving speed had no significant effect on the difference in noise between the two PPs. The DLPP showed a 6.6dB(A) reduction in average and a 6.3dB(A) reduction at the 95% confidence level compared to the SLPP. Reducing noise by 5dB(A) is equivalent to reducing traffic to 1/3 or lowering the vehicle's speed to 1/2. Sensitively, it is possible to recognize a 3dB(A) and 5dB(A) difference. The DLPP and SLPP were very effective in reducing traffic noise.

요 약 도로교통 소음은 주요 민원의 대상이 되고 있다. 다공성 포장은 도로교통 소음에 효과적인 방안으로 제안되었지만 정량적인 평가의 부족으로 인해 많이 적용되지는 않았다. 본 연구에서는 단층 다공성 포장과 복층 다공성 포장의 소음저감 성능을 평가하였다. 소음은 CPX 방법으로 측정되었으며, 주행 속도는 50km/h부터 80km/h까지 10km/h마다 측정하였다. 분석을 통해 복층 다공성 포장과 단층 다공성 포장의 소음 수준은 통계적으로 유의한 차이를 나타내었다. 도로포장 소음수준은 포장 유형에 관계없이 주행 속도에 비례했으며, 주행 속도는 두 포장의 소음 차이에 통계적으로 유의한 영향을 미치지 않는 것으로 나타났다. 복층 다공성 포장은 단층 다공성 포장에 비해 평균 6.6dB (A), 95% 신뢰수준에서 6.3dB(A) 감소하는 것으로 나타났다. 도로교통 소음을 5dB(A) 저감한다는 것은 교통량을 1/3로 줄이거나 차량의 속도를 1/2로 낮추는 것에 상당한다. 감각적으로도 3dB(A)의 차이에서 변화의 인지가 가능하고 5dB(A)의 차이에서는 명확한 변화인지가 가능하다. 일반포장에 비해 3dB(A)의 교통소음을 저감하는 단층 다공성 포장보다도 6dB(A) 이상을 추가로 저감하는 복층 다공성 포장은 교통소음 저감에 매우 효과적인 공법이다.

Keywords : Double-layer Porous Pavement, Traffic Noise, SPB, Traffic Speed, Traffic Volume

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1. Introduction

Noise sources in residential areas are diverse and are influenced by various conditions to reach the residential area. Among them, traffic noise is the most common and always occurring. In particular, due to the development of a high-density residential complex, the distance between the road and the residential area is gradually getting closer, and the traffic volume is increasing. In contrast, urban development means building structures that are vulnerable to noise, such as the expansion of underground roads due to traffic-oriented transportation policies. As a result, complaints related to noise are increasing naturally. Local governments, Korea Expressway Corporation, and Land Housing Corporation, which are responsible for noise management, are investing a lot of effort and budget in establishing measures.

In the meantime, noise countermeasures have been entirely dependent on sound-proof walls and sound-proof tunnels. However, with the generalization of high-rise apartments, noise barriers made it difficult to control noise in high floors areas. Sound-proof tunnels are not accessible alternatives due to severe installation conditions and high initial investment costs and difficulty in long-term maintenance. Accordingly, the porous pavement has recently attracted attention as a new alternative.

The porous pavement is an asphalt mixture designed with a porosity of 20% or more and provides a function to reduce friction noise between the pavement and the tire. The beginning of porous pavement began with drainage pavement technology developed in England in the 1950s to prevent the occurrence of waterways on airplane runways. Afterward, as noise reduction performance became an important function, technological advancement has been made in various forms such as ultra-thin and multi-layer design, mixing of unique materials, and non-draining, low-noise pavement. Among them, the one that shows the best performance is a two-layered porous pavement, which has been introduced mainly by local governments, Land Housing Corporation, and Korea Expressway Corporation. However, from the standpoint of relatively high unit price and the continuity, stability, and economic efficiency of the effect, there is still no precise procedure for introduction and methodology for operation management, which leads to difficulties in the applications.

Therefore, in this study, we tried to lay the foundation for subsequent studies by quantitatively grasping the functionality that is the basis of the introduction of porous pavement; that is, the noise reduction effect. The test section is a double layer porous pavement section on the National Route 1 in Sejong City. It is constructed at the same time as the neighboring single layer porous pavement and has a similar pavement and noise environment. The noise measurement and procedure are in ISO11819-2 (tire/road friction sound proximity measurement method), which evaluates the noise reduction performance. Of course, the pavement's noise level is affected by the aging, breakage, friction, and void condition of the surface layer, so it is necessary to secure more samples and follow-up from a long-term perspective. This study introduces noise measurement techniques based on international standards and has significance as a first step toward modeling long-term performance changes in the porous pavement.

2. Related Research

The study on the measurement of traffic noise on the road is divided into two, one is the method of measuring the vehicle noise on the side of the road, and the other is the method of measuring the vehicle near the tire and the road surface(The Close Proximity method; CPX method). The method of measuring on the side of the road reflects overall noise of the road include tire, engine, and air and CPX reflects only the noise between tire and pavement.

Measuring the noise level by CPX method, Kim[1] reported that the concrete pavement produces about 3dB(A) higher than the asphalt pavement and the asphalt pavement generates 3dB(A) higher than the porous pavement. Moon[2] tested various types of roads and showed that porous pavement asphalt pavement reduced 4-6dB(A) in heavy vehicles, 4-7dB(A) in heavy vehicles and 6-10dB(A) in passenger cars.

Jung[3] reconstructed the general road near the newly built apartment of the new city with double-layered porous pavement to measure the noise reduction and analyze the effect on each apartment household. As a result, the noise reduction of double-layered porous pavement was 4.3dB(A), and 32% of all generations were affected by porous pavement. Lee[4] who studied the reduction of road traffic noise by indoor experiments, demonstrated that it showed a maximum reduction of 7.8dB(A) for small cars and 6.8dB(A) for medium cars.

Cho[5], Yang[6], Cho[7], and Kang[8] documented some researches to find an efficient method by comparing the cost increase due to the application of low-noise pavement and the construction cost due to the sound barrier wall construction.

Summarizing the previous research, it seems clear that porous pavement reduces road traffic noise than conventional pavement. The problem is that there is no data of quantitative evaluation of noise reductions between porous pavement and conventional pavement and between double-layered porous pavement and single-layered porous pavement to be guaranteed considering the variability of data. It is necessary to evaluate the amount of noise reduction considering the variability through the objective and statistical analysis of factors affecting the noise reduction of porous pavement.

3. Location and measuring method

3.1 Location

The purpose of this study is to evaluate the noise reduction of double-layered porous pavement compare to single-layered porous pavement by measuring the noise under the same conditions in the section where the double layer porous pavement was constructed and the adjacent single-layered porous pavement. The measurement was made on the section of Sejong-city section on National Road No. 1. Fig. 1 shows the location of the double and single-layered porous pavement section in Sejong-city.

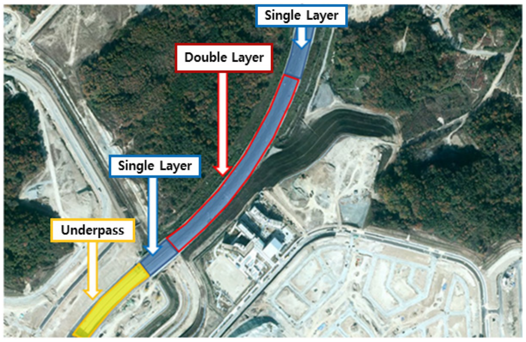


Fig. 1. Status of Double and Single-layered porous pavement in Sejong City

3.2 Characteristics of porous pavement

The asphalt binder was the modified asphalt binder, RSBS that meets the binder standards of the production and construction guidelines for Drainage Asphalt Mixture, which is the standard of the Ministry of Land, Infrastructure and Transport. Drainage pavement refers to replacing the 5cm thick surface of a typical asphalt pavement with a porous asphalt mixture. In this study, the single-layer porous pavement is a pavement with a porous asphalt mixture of 5 cm thickness and a porosity of 20% with a maximum diameter of 13 mm. Double-layer porous pavement is a pavement composed of a porous surface layer divided into a 2cm upper layer and a 3cm lower layer. The maximum diameter of the upper layer aggregate was 8mm, the maximum diameter of the lower layer aggregate was 13mm, and the porosity was set to 20%. By forming several small pores in the upper layer and relatively large pores in the lower layer, noise reduction and pore clogging can be improved. Fig. 2 is a photograph of a multi-layer porous pavement structure using X-rays, and Table 1 shows the results of analyzing the size and number of voids in the mixture.

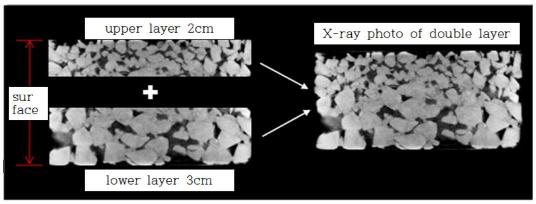


Fig. 2. X-Ray Photo of Double Layered Porous Asphalt Mixture

Table 1. Size and Number of Air Void in Double Layered Porous Asphalt Mixture

Voids	Upper Layer 2cm (max aggregate 8㎜)	Lower Layer 3cm (max aggregate 13㎜)
Size	3 ± 1 ㎜	6 ± 2 ㎜
Number	74 ± 10	40 ± 5

3.3 Measurement method of road traffic noise

The measurement methods of Road traffic noise vary depending on their purpose but are largely classified into a close noise measurement method (CPX) and a statistical pass-by method (SPB). The CPX is a method of directly measuring the noise between the tire and the road by installing a microphone near the tire.

In Korea, the Ministry of Environment provides only the measuring method of traffic noise limit on a road, which is a passing vehicle measuring method as a standard of traffic noise and vibration. In this study, we measured and evaluated the CPX noise to compare the noise generated from the different pavements.

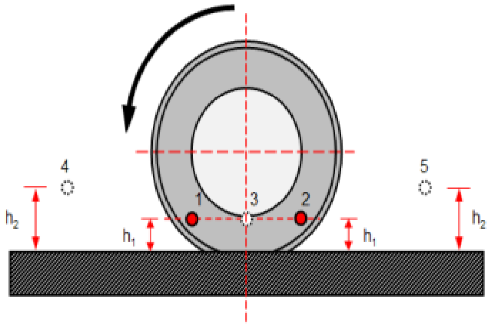
CPX, a near noise measurement method, is a tire-surface noise measurement method specified in ISO 11819-2. Since there are no regulations on tire-surface noise in Korea, there is a slight difference in the installation position of microphones by each institution. However, the basic concept is to install a microphone as close as possible to the tire to measure tire-surface noise while running at a constant speed.

The CPX method is a method of measuring the average sound pressure level, LA (A characteristic sound pressure level) by placing the microphone close to the tire in a vehicle driving. At least two microphones should be installed. The height and location of the microphones shall be by Fig. 3 and Table 2. Installation at points 1 and 2 is mandatory. Installation of points 1 and 2 is preferred to be 45 ± 5 ° and 135 ± 5 ° in the direction of vehicle travel, respectively.

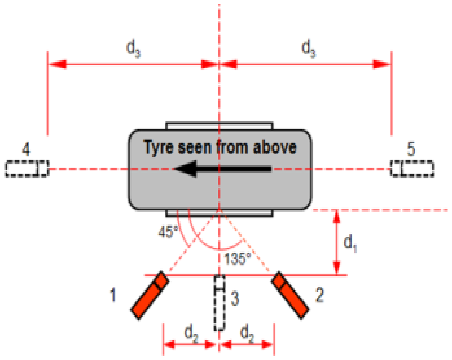
When measuring, the vehicle speed should be 40 km/h, 50 km/h, 80 km/h, 100 km/h. But it is recommended to measure by using the appropriate speed suitable for the site conditions. Measuring tires are recommended for the use of tires as defined in ISO/TS 11819-3. Tires shall be mounted so that the mark, including the year of production, faces the microphone. The measuring tires must travel at least 200km before use.

At least one of the tires of the measuring vehicle should be equipped with a microphone, and a separate device should be equipped with a case to prevent background noise, wind noise, and passing vehicle sounds. Also addition, there are constraints on the measurement interval to operate the CPX method. That is, the speed to be measured before 10m must be maintained. The preferable measurement length is 100m and should be at least 20m.

In this study, we measured the noise level between the tire and the road surface while the vehicle was driving by, installing a noise meter near the rear wheel. In the CPX method, the speed of 50~80km/h was measured four times per speed for both directions at 10km/h intervals.



(a) Microphone position when looking directly at the tire



(b) Microphone position when the tire is viewed from above

Fig. 3. Microphone Installation Location

Table 2. Distance of the microphone from the tire and the road surface

(Unit: m)

Phone	h_1	h_2	h_3	h_4	h_5
1, 2	0.10		0.20	0.20	
3	0.10		0.20	0.00	
4, 5		0.2			0.65

3.3 Measurement Results

Using the CPX method, the noise was measured and analyzed in double-layered porous pavement and single-layered one in Sejong City. Table 3 below shows the results of the CPX measurement.

Table 3. Measurement results of CPX Noise Level in Sejong-city District

Direct.	Speed (km/h)	Noise Level(dB(A))		
		Double-layered	Single-layered	Diff. in Noise
Daejeon → Chochiwon	50	88.4	94.2	5.8
	60	89.9	96.4	6.5
	70	92.1	98.8	6.7
	80	94.8	101.0	6.2
	50	88.3	93.2	4.9
	60	89.7	96.3	6.6
	70	92.2	98.5	6.3
	80	93.2	100.6	7.4
Chochiwon → Daejeon	50	87.0	93.4	6.4
	60	89.8	96.3	6.5
	70	91.8	98.6	6.8
	80	92.3	100.1	7.8
	50	86.7	92.9	6.2
	60	89.6	95.9	6.3
	70	91.1	98.4	7.3
	80	93.0	100.2	7.2

4. Analysis of noise level results

Before entering statistical analysis on measured data, conduct a descriptive statistical analysis of the overall situation, and conduct a variance to verify whether there are significant differences between variables. If there is a significant difference between the results, the t-test will be performed. The results of the analysis of averages will be presented graphically, and the coefficients of determination and regression models will be developed.

4.1 Descriptive Analysis

It is difficult to judge at a glance the noise measurement results presented in Table 4.

Therefore, you can use tables and figures to understand the data effectively. First, the measurement results in Table 3 can be summarized, as shown in Table 4 to understand the overall situation of the data. In this table, the difference in the noise level between the double layer and single layer porous pavement is about 6.56dB (A)).

Table 4. Summary of the Close Proximity Noise Level

Class	Speed (km/h)	Double Layer	Single Layer
Average	65	90.61875	97.175
Std. Error	2.886751	0.580174	0.68596
Median	65	90.5	97.4
Std. Dev.	11.54701	2.320695	2.743842
Variance	133.3333	5.385625	7.528667
Range	30	8.1	8.1
Maximum	50	86.7	92.9
Minimum	80	94.8	101
Sum	1040	1449.9	1554.8
Obs.	16	16	16
C/L(95.0%)	6.152965	1.236611	1.46209

Also, as shown in Fig. 4, the measurement results can be clearly expressed through the box whisker diagram. The box plot draws a box using the maximum and minimum data and the first quartile (Q1) and the third quartile (Q3). In Fig. 4, the double-layered porous pavement and single-layered pavement tend to increase with increasing driving speed, and these two pavements show a noticeable difference in noise level, and the range of variation does not overlap each other.

4.2 Analysis of Variance (ANOVA)

In the previous descriptive statistical analysis, if you have identified the overall situation, this time, you should examine whether there are significant differences between the variables. In other words, there is a significant difference when the difference between the variables is larger than the difference within the variables, and when the variation within the variables is larger than variations among variables, there is no significant difference. It is called the analysis of variance (ANOVA).

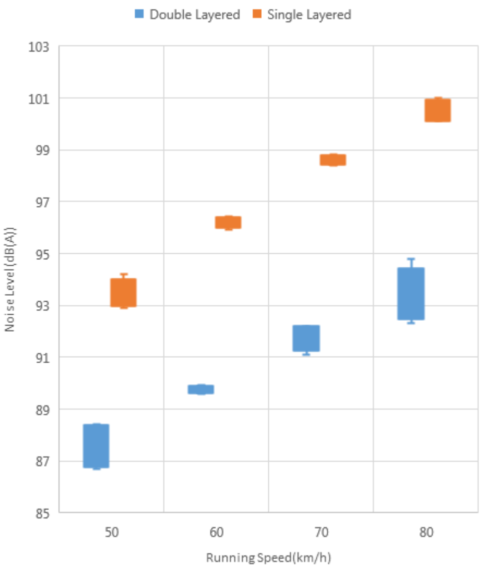


Fig. 4. Box Whisker diagram of noise levels of two types of pavements

Table 5. ANOVA: Two Way ANOVA

Factors of Variance	Sum of Square	DoF	Squared Average	F Ratio	P-value	F Rejection Value
Factor A(rows)	183.7234	3	61.24115	181.2874	1.28E-16	3.008787
Factor B(Col.)	343.8753	1	343.8753	1017.947	3.63E-21	4.259677
Interaction	1.883437	3	0.627812	1.858464	0.163624	3.008787
Residuals	8.1075	24	0.337813			
Sum	537.5897	31				

Table 5 shows the results of the analysis of variance using the two-way ANOVA method with repetition of noise level measurement results. The results show that the p-values for rows and columns are close to zero, so the average difference between types of pavement and speed is almost 100% certain. Also, the p-value was 0.16 for the interaction between the types of pavement and driving speed. This p-value bigger than 0.05 means that the interaction between the driving speed and types of pavement is not significant.

4.3 Average Analysis

In the previous analysis of variance, there was a significant difference between the variables. This time, quantitative differences between the variables can be obtained by t-test pair comparison. Table 6 shows the results of the t-test of the noise levels of the double and single-layered noise pavements. From the t-test result of table 6, Hypothesis average difference of two pavements is 6.26 dB(A) at 95% confidence level. The average difference between the two pavements was about 6.56 dB(A), but this is the difference of 50% in confidence and a noise level that does not account for variation.

Table 6. t-test: Pair Comparison

Classification	Single-layered	Double-layered
Average	97.175	90.61875
Variance	7.528667	5.385625
Observations	16	16
Pierson Coefficient	0.97721	
Hypothesis Average Difference	6.256	
DOF	15	
t Statistic	1.75316	
P(T<=t) one side test	0.04999	
t rejection Value one side test	1.75305	
P(T<=t) two side test	0.099981	
t Rejection Value Two side test	2.13145	

By t-test pair comparison, the hypothetical mean difference between double and single-layered porous pavements at 95% reliability level is shown in Table 7. In Table 7, Pearson's correlation coefficient is relatively large, which means that the noise levels of the double and single-layered porous pavements are highly correlated as is seen.

Table 7. Comparison of t-test results by Driving Speed

Driving Speed (km/h)	Pierson's coeff.	Hyp. ave. diff.	t stats	P(T<=t) one side test
50	0.6504	5.042	2.3541	0.049964
60	0.8733	6.326	2.3682	0.049329
70	0.6288	6.291	2.3535	0.049993
80	0.9456	6.349	2.3535	0.049993

4.4 Correlation Analysis

Correlation analysis is a means of expressing the explanatory power of the relationship between two variables. The degree of correlation is expressed as a correlation coefficient. And a regression equation(Table 8) is derived according to the least-squares method. Fig. 5 shows the regression analysis of the double and single-layered porous pavements in terms of speed and noise levels. In Fig. 5, we can clearly distinguish the difference between the noise level of the double and single-layered porous pavement and the slope of the regression equation of single-layered pavement becomes steeper than the double-layered pavement, so the noise difference becomes larger as the speed increases.

Table 8. Results of regression analysis by pavement types

Pavement Type	R/ Equation	R^2
Single-layered	y = 0.235x+81.9	0.9927
Double-layered	y = 0.1923x+78.1	0.9943

In Fig. 5, it can be seen that there is a big difference in the noise level between the double and single-layered porous pavements, but the quantitative difference is not known. Fig. 5 shows the difference between the noise levels of these two pavements. Fig. 5 distinguishes the difference between the noise level for the mean value and the noise level difference for the 95% confidence level. The difference in noise level with respect to the mean value is an analysis that does not consider the variance of data, and the analysis of 95% confidence level is an analysis that considers the variance of data.

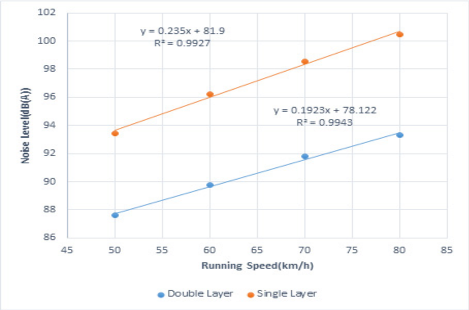


Fig. 5. Noise levels of double and single-layered porous pavements by driving speeds

Table 9. Results of Regression Analysis on Noise Level by Confidence Level

Confidence Level	R Equation	R^2
50% confidence	y=0.0428x+3.7775	0.9703
95% confidence	y=0.0389x+3.4761	0.6136

In Fig. 6, the difference of the mean noise levels between the double and single-layered porous pavements increase linearly with driving speed, but the difference of 95% confidence noise level does not linearly increase. This lack(Table 9) of confidence of prediction means that we need some more researches to guarantee the reduction of noise of double-layered porous pavement with confidence.

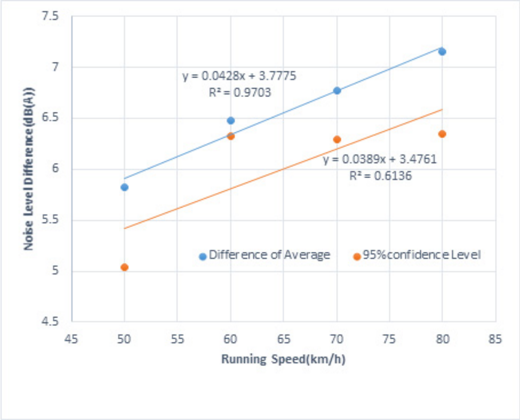


Fig. 6. Differences in noise level between double and single-layered porous pavements by the confidence levels

5. CONCLUSION

To evaluate the noise reduction of double-layered porous pavement compares to the single-layered one, we measured the CPX noise under the same conditions in Sejong city National Route no. 1. The results were analyzed, and the following conclusions were made.

As a result of the analysis of variance, there were significant differences in road pavement type, i.e., double and single-layered porous pavement and for driving speeds for each 10km/h from 50km/h to 80km/h. It is confirmed that there is no significant interaction with each other at the 95% confidence level.

The results of the average analysis show that the double layer porous pavement reduces the noise of 6.56 dB(A) compared to the single-layered pavement. The noise reduction effect at 95% confidence level considering data dispersion was 6.26dB(A).

Reducing noise by 5dB(A) is equivalent to reducing traffic to 1/3 or lowering the vehicle's speed to 1/2. Sensitively, it is possible to recognize the change in the difference of 3dB(A), and it can be recognized the definite change in the difference of 5dB(A). The double layer porous pavement that further reduces 6dB(A) or more than the single layer porous pavement that reduces traffic noise of 3dB(A) compared to general pavement is very effective measure in reducing traffic noise.

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〈Research Interests〉
Asset Management, Utility pavement