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# Analysis of Traffic Noise for Single and Double Layered Porous Pavement with SPB Method
## -National Route 1, Sejong-Si Section-

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# SPB측정법에 의한 복층 및 단층 다공성포장의 소음분석
## -국도 1호선 세종시 구간-

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**Abstract** Porous pavement (PP) has attracted attention as a new alternative measure against road traffic noise. PP refers to pavement that reduces the fines in the asphalt mixture to form voids. These voids can reduce traffic accidents and friction noise. For active application, verification of the noise reduction effect is required. In this study, the noise reduction of single-layer PP(SLPP) and double layer PP(DLPP) was analyzed. First, the Sejong section was selected, and traffic noise was measured using the SPB method on the roadside. The traffic volume, speed, and mixing ratio of large vehicles were measured. As a result, the DLPP was evaluated to be 7.95 dB(A) smaller on average and 7.57dB(A) smaller at the 95% reliability level than the SLPP. The traffic volume was more influential than the speed and the mixing rate of large vehicles. As the traffic volume increased, the noise increased, but the difference in noise between the two pavements decreased gradually. The results showed that the most effective way to reduce road traffic noise is to change the road pavement rather than reduce traffic speed, restrict traffic for heavy vehicles, or reduce traffic volume.

**요 약** 최근 도로 교통소음 대책으로 다공성포장이 새로운 대안으로 주목받고 있다. 다공성포장은 아스팔트 혼합물 속에 세립자의 비율을 줄여서 여러 개의 공극을 형성하게 하는 포장을 말한다. 이 공극으로 물이 배수되게 하여 교통사고를 줄이고 타이어 노면의 마찰 소음을 줄여주는 역할을 하게 된다. 저소음포장이 일반적으로 활발히 적용되기 위해서는 소음저감 효과에 대한 많은 검증이 필요하다. 본 연구에서는 단층 저소음포장과 복층 저소음포장의 소음저감 효과를 분석하기 위해서 수행되었다. 먼저 단통 저소음포장과 복층 저소음포장이 시공되어 있는 세종구간을 선정하고 도로변에서 도로교통 소음을 측정하는 방식인 SPB방법으로 교통소음을 측정하였다. 교통영향요소로는 교통량, 속도 그리고 중차량 혼입률을 측정하였다. 측정결과, 복층저소음포장이 단층저소음포장보다 평균 7.95dB(A) 작게 평가되었다. 95% 신뢰도 수준에서는 7.57dB(A) 작게 평가되었다. 도로교통 소음에 미치는 영향요소로는 속도나 대형차 혼입률 보다는 교통량이 가장 크게 영향을 미쳤다. 교통량이 증가할수록 소음은 모두 증가했지만 두 포장 사이의 소음차이는 점차 감소하였다. 도로교통소음에 영향을 미치는 요소로는 교통요소보다 도로포장의 차이가 가장 크게 나타났다. 본 연구를 통해서 도로교통 소음을 줄이기 위한 대책으로 교통속도를 줄이거나 중차량의 통행을 제한하거나 교통량을 줄이는 것보다 도로포장을 바꾸는 것이 가장 효과적인 방법임을 알았다. 이를 검증하고 정량화하기 위한 광범위한 연구가 필요하다.

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

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## 1. Introduction

We carefully consider whether it is sufficiently safe from floor noise, traffic noise, and other external noise pollution as a requirement for a suitable residence. It means that noise in residential areas is becoming an essential factor in determining the quality of life, and noise is an important control factor for local governments, roads, and land developers. Noise countermeasures, in the meantime, were only soundproof walls and soundproof tunnels. However, they harmed landscapes, ventilation, and sunlight in the downtown area, and managers also needed new alternatives due to the initial investment cost of facilities and long-term maintenance problems. As a solution to this, low-noise pavement is emerging. The main factor that differentiates low-noise pavement from existing noise countermeasures such as soundproof walls and soundproof tunnels is that it reduces the noise source itself, not the half difference or shielding of noise(Han[1]). These advantages are gradually gaining attention in line with the increasing high-rise apartment design and active civil complaints of residents who want a comfortable environment.

The low-noise pavement has various types such as single-layer, double-layer, ultra-thin, mixed with unusual materials, non-drainage type, depending on the material and design characteristics. The single-layer low-noise pavement is a drainage pavement type designed with a porosity of 20% or higher. It is a relatively natural alternative to managers, such as the Ministry of Land, Infrastructure, and Transport, with relevant construction guidelines (MOLOT[2]). The noise reduction effect is recognized internationally as the 3dB (A) level compared to the general pavement (Han[1]). On the other hand, multi-layer low-noise pavement means a pavement with two layers with different aggregate sizes, and the construction process is complicated. In particular, the disadvantage of this method is that the unit cost is relatively high because there is much loss in the production of small-diameter aggregate (8mm) in the upper part. However, previous studies have shown excellent initial noise reduction performance of 7 ~ 11dB (A) compared to the general pavement (Han[1]). From the manager's point of view to prepare for noise countermeasures, there are two alternatives, single or double layer porous pavements. The single-layer low-noise pavement is similar in cost to existing drainage pavement. It is inexpensive. The double-layer low-noise pavement that can have a definite effect even if it is expensive. To make a decision, a preliminary evaluation of the effectiveness of the two noise countermeasures needs quantitative performance comparison for the pavement types. Mainly, the performance variation is a crucial input variable in noise simulation as well as average performance because of its confidence.

Therefore, in this study, we tried to present the deviation quantitatively by comparing the noise generation characteristics of two pavements. Here, the equivalent conditions are

1. the distance between the noise source and the noise collection point,
2. climatic conditions such as temperature, humidity, wind speed,
3. noise reflector, road geometry, ambient noise environment,
4. traffic volume, traffic speed.

The characteristics of traffic flow were the ratio of large vehicles, traffic volume, and speed. In order to evaluate the performance of noise reduction of a low-noise pavement, it is common to use the tire/road close measurement method (CPX: Close Proximity Method) specified in ISO11819-2 (ISO[3]). However, in this study, the SPB (Statistical Pass-By) (ISO[4]) method was adopted to comprehensively and empirically reflect the traffic flow conditions affecting the noise reduction effect.

The critical point of this study is that it provides a function to compare and evaluate the expected effect of traffic flow characteristics in the target section of porous pavement as a noise reduction effect for each alternative that changes depending on the traffic flow characteristics. This study is meaningful as a fundamental study to support the diversification of traffic noise countermeasure design and optimization from an economic point of view and to promote the spread of low-noise pavement further.

## 2. Related Research

Traditionally, noise and vibration have been in the areas of environment, machinery, and automobiles. However, traffic noise has emerged as a social issue in recent years. Pavement technology has tried to cope with this problem, such as research on materials and design methods. Also, noise reduction performance evaluation and simulations for predicting effects in residential areas have been increasingly active. Besides, as the public budget grows, it is expanding into the economic analysis field to secure the feasibility of introducing this new technology. This section will briefly introduce prior studies in the field.

Kim[5] conducted noise studies on concrete pavement, asphalt pavement, and low-noise pavement for highways. As a result, the absolute noise level was in the order of concrete pavement-normal pavement-porous pavement and reported that there was a variation of 3dB (A) level for each pavement type. In particular, it is meaningful to find out in which band deviation occurred through frequency analysis for each pavement.

Jeong[6] compared and analyzed the effect of low-noise pavement before and after installation for each household in a high-rise apartment building in downtown. As a result, the noise reduction effect of low-noise pavement reduced 4.3 dB (A) on average, and it reported that the effect occurred in 32% of households. It means that this is the first example of measuring the effectiveness in each apartment. We can also see that it is not easy to expect the effect on the entire residential complex by constructing some sections in question.

Lee[7] conducted a study on the variation in noise level between double-layer and single-layer low-noise pavement. Considering that it is not easy to expect the effect on the upper floor of a high-rise apartment as a soundproof wall, the roof of the apartment was a measuring point. The analysis shows that there is a deviation of 2dB (A). However, it is unreasonable to make a perfect comparison because of the variations in traffic characteristics and surrounding environmental factors before and after construction.

Lee[8] tried to identify the noise reduction characteristics of low-noise pavement through an indoor test rather than a field survey conducted in general on-road sections. The effect analysis depends on the vehicle model, and as a result, it reported that there was an effect of up to 7.8dB (A) in small cars and up to 6.8dB (A) in mid-sized cars. It is meaningful that it was a laboratory test that was easy to control the external conditions, but, regrettably, a large car that takes a large part of the noise missed. Accordingly, Moon[9] conducted an effect analysis by vehicle type through field surveys. They reported that porous pavement reduced the traffic noise by 4-6dB (A) for large vehicles, 4-7dB (A) for heavy vehicles, also 6-10dB (A) for ordinary vehicles.

On the other hand, Cho[10], Yang[11], Cho[12], and Kang[13] are trying to solve the realistic curiosity of managers who want to introduce low-noise pavement by comparing the economics of the low-noise pavement alternative with the soundproof wall alternative.

As described above, research on the low-noise pavement is being promoted independently in various aspects such as material, design, performance evaluation, and economic efficiency of the pavement itself. However, we have to consider all of these comprehensively to prepare and spread the applications of low-noise pavement. In particular, it is appropriate that research on performance evaluation is crucial, and economic analysis and alternative design optimization should be made based on the results of the research.

## 3. Location and measuring method

### 3.1 Location and cross section

The purpose of this study is to evaluate the noise levels of double-layered porous pavement(below PP) and Single layered PP. To evaluate the noise level of double and single-layered porous pavement, we measured the noise levels under the same conditions in the section where the two types of pavement were constructed. The section to be measured is the section of Sejong city on National Road 1; Fig. 1 shows the measuring location on Sejong city.

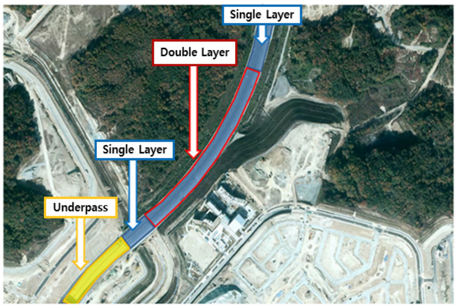


Fig. 1. Status of Double and Single-layered Porous Pavement in Sejong City

### 3.2 Characteristics of low noise pavement

Asphalt binders used for low-noise pavement were modified asphalt using RSBS that satisfies 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 the replacement of a typical asphalt pavement with a porous asphalt mixture of 5 cm thick. In this study, the single layer low noise pavement is a road pavement with a void of 20% with a porous asphalt mixture of 5 cm thick and a maximum aggregate diameter of 13 mm. The double-layered low-noise pavement was constructed by dividing the porous surface layer 5 cm into 2 cm upper layers and 3 cm lower layers with simultaneous installation equipment. The maximum aggregate diameter of the upper layer was 8 mm, and the maximum particle diameter of the lower layer was 13 mm. The porosity was set to 20%. By forming several small pores in the upper layer and large pores in the lower layer, noise reduction and pore clogging can be improved. Fig. 2. is a photograph of the double-layer structure using X-rays, and Table 1 is the result of analyzing the size and number of voids in the mixture.

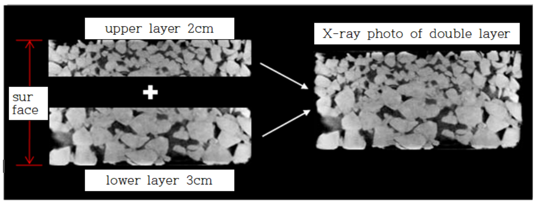


Fig. 2. X-Ray Photo of Double Layered Porous Asphalt Mixture

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 |

### 3.2 Measurement method of road traffic noise

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

In Korea, the measurement method for road traffic noise is in the noise and vibration test standards established by the Ministry of Environment. However, here, only one measuring method, which is a passing vehicle measurement method and is like SPB, is presented. In this study, road traffic noise was measured and evaluated by passing vehicle measurement method, which is a road traffic noise measuring method established by the Ministry of Environment.

Road traffic noise is composed of various noise combinations and uses the concept of equivalent noise level to compare them. Equivalent noise level (LAeq) defined in the Ministry of Environment Noise and Vibration Test Criteria refers to the noise level obtained by equivalently converting the total energy of variable noise generated during an arbitrary measurement time into the energy of normal noise within the same time. It is a noise measuring method that records not only road traffic noise but also the noise of the whole living environment.

## 3.3 Measurement Variables

The noise measurement for evaluating the noise levels of double and single-layered PP was done by the road traffic noise limit measurement method. Since roadside noise is affected by traffic volume, driving speed, large vehicle mixing rate, temperature, and wind speed, the measurement time is extended to minimize the difference caused by these factors.

Road traffic noise varies depending on the traffic characteristics such as the traffic volume, the vehicle's driving speed, and the mixing ratio of large vehicles. In this measurement, traffic volume and driving speed survey were conducted to identify these traffic characteristics. In the traffic characteristic survey, NC-97 equipment, which is a traffic characteristic survey equipment, was installed to each lane to analyze traffic volume, driving speed, and large vehicle mixing rate. The traffic characteristics were confirmed by analyzing the driving speed and the mixing ratio of large vehicles. The following Fig. 3 shows the noise measurements of road traffic in Sejong city.

Fig. 3. Measuring noise level at the roadside

## 3.4 Measurement Results

The noise level was averaged every 30 minutes, and the noise levels of double and single-layered PP was evaluated. Table 2 shows the results of each measurement.

Table 2. Data Measured in Sejong City

| No. | Noise Level (dB(A)) | | Traff. Vol. (Vehicles) | Large Car Ratio (%) | Speed (km/h) |
|---|---|---|---|---|---|
| | Double Layer | Single Layer | | | |
| 1 | 69.2 | 76.5 | 556 | 11 | - |
| 2 | 69.8 | 76.8 | 607 | 12 | - |
| 3 | 68.4 | 76.8 | 589 | 9 | - |
| 4 | 68.3 | 76.9 | 629 | 6 | - |
| 5 | 68.1 | 77.0 | 584 | 4 | - |
| 6 | 68.3 | 77.3 | 782 | 2 | - |

| | | | | | |
|---|---|---|---|---|---|
| 7 | 65.7 | 74.8 | 251 | 11 | 76.5 |
| 8 | 66.1 | 74.6 | 282 | 9 | 71.3 |
| 9 | 65.6 | 74.1 | 206 | 11 | 76.0 |
| 10 | 65.3 | 73.2 | 156 | 11 | 67.0 |
| 11 | 71.3 | 77.7 | 656 | 17 | 72.1 |
| 12 | 70.3 | 77.1 | 615 | 15 | 73.9 |
| 13 | 70.2 | 77.1 | 603 | 16 | 73.6 |
| 14 | 70.6 | 76.9 | 611 | 14 | 72.3 |
| 15 | 70.3 | 77.1 | 591 | 15 | 72.7 |
| 16 | 70.2 | 77.1 | 607 | 13 | 73.7 |
| 17 | 69.7 | 77.5 | 727 | 13 | 73.9 |
| 18 | 69.9 | 77.7 | 781 | 13 | 74.4 |
| 19 | 70.0 | 78.0 | 965 | 9 | 73.5 |
| 20 | 69.1 | 76.8 | 759 | 10 | 70.8 |
| 21 | 68.2 | 75.9 | 609 | 8 | 70.0 |
| 22 | 67.1 | 75.1 | 502 | 9 | 71.2 |
| 23 | 66.9 | 75.3 | 429 | 9 | 70.6 |
| 24 | 66.6 | 75.1 | 371 | 10 | 70.4 |
| 25 | 65.8 | 74.4 | 323 | 9 | 71.7 |
| 26 | 65.2 | 73.4 | 235 | 17 | 70.3 |

## 4. Analysis of noise level results

Analysis of the result consists of three analysis. First one is a descriptive statistical analysis which shows overall statistics. The second one is an average analysis which shows statistical analysis of averages. And the last one is regression analysis, which shows relation among variables.

### 4.1 Descriptive Analysis

The noise levels and traffic conditions were measured 26 times per 30 minutes to evaluate noise levels of double and single-layered PP. As for the measurement of noise, the noise was measured for double-layered PP, and single-layered PP and the difference between the two types of pavement was calculated. As traffic conditions, traffic volume, large vehicle mix ratio, and driving speed were considered. A summary of the measured results in Table 2 is given in Table 3.

In the statistical summary of the data, a range including the mean, standard deviation, and maximum and minimum was selected and refined. This summary shows that the vehicle's speed ranges between 67km/h and 76.5km/h. Also, the traffic volume is about 156-965 vehicles, and the mixing ratio of large cars ranged from 2-17%. The noise level was 73.2-78 dB (A) in single-layered PP and 65.2-71.3 dB (A) in double-layered PP. The average difference was 7.85 dB (A).

It can be seen from the Table 3 that the standard deviations for double and single-layered PPs are very small. Even when the traffic conditions change, the noise level shows less

Table 3. Descriptive Statistical Summary of Data

| Class | Double Layered | Single Layered | Difference | Traffic Volume | Large Car Ratio | Driving Speed |
|---|---|---|---|---|---|---|
| Mean | 68.31538 | 76.16154 | 7.85 | 539.4615 | 10.88462 | 72.295 |
| Std. Err | 0.373577 | 0.274455 | 0.163637 | 39.7816 | 0.723936 | 0.499604 |
| Median | 68.35 | 76.8 | 7.95 | 597 | 11 | 72.2 |
| Mode | 68.3 | 77.1 | 8.4 | 607 | 9 | 73.9 |
| Std. Dev. | 1.904876 | 1.39945 | 0.834386 | 202.8472 | 3.691362 | 2.234296 |
| Variance | 3.628554 | 1.958462 | 0.6962 | 41146.98 | 13.62615 | 4.992079 |
| Kurtosis | -1.29595 | -0.64513 | -0.7684 | -0.37206 | 0.27573 | 0.522721 |
| Skewness | -0.305 | -0.75501 | -0.32562 | -0.26908 | -0.36101 | -0.19083 |
| Range | 6.1 | 4.8 | 3 | 809 | 15 | 9.5 |
| Minimum | 65.2 | 73.2 | 6.2 | 156 | 2 | 67 |
| Maximum | 71.3 | 78 | 9.2 | 965 | 17 | 76.5 |
| Sum | 1776.2 | 1980.2 | 204.1 | 14026 | 283 | 1445.9 |
| Observs | 26 | 26 | 26 | 26 | 26 | 20 |
| CL(95.0%) | 0.769396 | 0.56525 | 0.337016 | 81.93175 | 1.490973 | 1.045683 |

deviation. This suggests that road pavement noise is affected by traffic, but the impact is not so great. And although the average noise difference between the two types of PP is 7.85 dB (A), this means a difference at 50% confidence level. More fundamental statistical analysis can be used to derive more information from this data.

## 4.2 Average Comparison

The difference in the noise level between the two types of PP was 7.85 dB (A) on average. This is an average value without considering the variance of the data, meaning that 50% of the data can be larger than this value and the remaining 50% can be smaller than this value. The meaning may vary depending on the variance representing the scatter of the data. Depending on the variance of the two groups, the average difference between the two groups should be taken into account again.

Analyzing the mean of the two groups in consideration of the variance is the t-test. To perform the t-test, the two groups must be tested for normality, and equality and independence must be verified. The three can be easily satisfied because they are measured in one place over 26 times and compared in pairs. Table 4 was obtained by performing a t-test on paired comparisons, considering the significance level of 5% with a confidence level of 95%.

According to Table 4, the one-tail test shows that double-layered PP can lower noise level by more than 7.57 dB (A) than the single-layered PP at the significance level of 5% and confidence level of 95%. The 95% confidence level is the probability of 95 successes after 100 measurements and its value changes with the variance of data. So statistical analysis can be used to describe noise reduction along with reliability, which means that mean and variance are both considered.

Table 4. t-Test: Pair Comparison

| Class | Single Layered PP | Double Layered PP |
|---|---|---|
| Mean | 76.16154 | 68.31538 |
| Variance | 1.958462 | 3.628554 |
| Observs | 26 | 26 |
| Pierson's Coeff. | 0.922287 | |
| Mean Diff. Assumed | 7.57199 | |
| DoF | 25 | |
| t - Stat | 1.708163 | |
| P(T<=t) One Tail | 0.049998 | |
| t Reject One Tail | 1.708141 | |
| P(T<=t) Two Tail | 0.099996 | |
| t Rejection Two Tail | 2.059539 | |

## 4.3 Regression analysis

It is known that not only the type of pavement but the traffic conditions affect the road traffic noise. In the data measured earlier, the noise level difference between the double-layered PP and single-layered PP is clearly shown as an average of 7.85 dB (A). This time, using the regression analysis, we can know the correlation among variables. Table 5 shows the regression analysis of noise levels by traffic factors. From Table 5, among the traffic factors, only the traffic volume has a p-value less than 0.05, which means significant at significant level 5% of 95% confidence level. The road traffic noise of two types of pavement increase with traffic volume.

Fig. 4 shows the linear graph increasing noise level with traffic volume. And we can know R square which means the power of explaining is bigger in single-layered PP than double layered PP. And the slop of the line is steeper in the double-layered PP than the single-layered PP. So the difference between the two types of pavement will decrease with the increase in traffic volume.

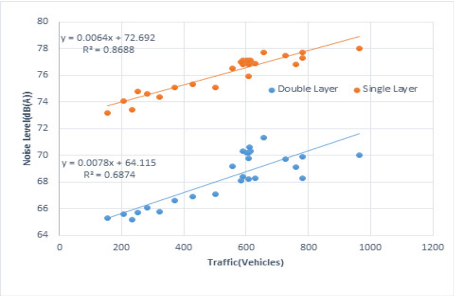


Fig. 4. Noise levels for double and single-layered porous pavement

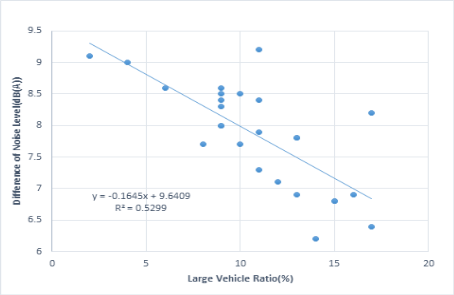


Fig. 5. Difference of noise levels for double and single-layered porous pavements by large vehicle ratio(%)

Table 6 shows the result of the regression analysis of noise levels difference among traffic factors. The regression analysis of the noise difference between the two types of pavements, only the large vehicle mix ratio was significant among traffic factors. In other words, the p-value of a large vehicle mix ratio is less than 0.05, which means significant at 95% confidence level. So Fig. 5 shows the trend of the difference in the noise level of two types of pavement with increase the large vehicle mix ratio. The R square is not so big as 0.5299, but we can see that the more large vehicle is in the traffic, the less the difference of noise level of the two types of pavement.

We have evaluated the effect of the traffic factors on the noise level of the pavements. This time we evaluate the inter relation between the two types of pavements, i.e., the double-layered PP and the single-layered PP by regression analysis. Table 7 shows the result of the regression analysis of noise levels of two type of pavement.

Table 5. Regression Analysis of Noise Levels by Traffic Factors

(A) Overall Fit

| Multiple R | R Square | Adjusted R Square | Standard Error | Observations |
|---|---|---|---|---|
| 0.322807 | 0.104204 | 0.06688 | 1.840075 | 26 |

(B) Analysis of variation(ANOVA)

| Class | DoF | SS | MS | F | sig F |
|---|---|---|---|---|---|
| Regression | 1 | 09.45278 | 9.452780 | 2.791826 | 0.107737 |
| Residual | 24 | 81.26107 | 3.385878 | | |
| Total | 25 | 90.71385 | | | |

(C) Regression

| | coeff. | std. err | t stat | P-value | lower 95% | upper 95% |
|---|---|---|---|---|---|---|
| DL Noise | 66.50222 | 1.143586 | 58.15236 | 2.43E-27 | 64.14198 | 68.86247 |
| Large Car | 0.16658 | 0.099696 | 1.670876 | 0.107737 | -0.03918 | 0.372343 |
| DL Noise | 64.11537 | 0.616246 | 104.0419 | 2.22E-33 | 62.8435 | 65.38724 |
| Volume | 0.007786 | 0.001072 | 7.264015 | 1.67E-07 | 0.005573 | 0.009998 |
| DL Noise | 51.22372 | 15.99835 | 3.201813 | 0.004943 | 17.61244 | 84.83501 |
| Speed | 0.30894 | 0.234453 | 1.317709 | 0.204127 | -0.18363 | 0.801507 |
| SL Noise | 76.08854 | 0.887538 | 85.72986 | 2.28E-31 | 74.25675 | 77.92033 |
| Large Car | 0.006707 | 0.077374 | 0.086677 | 0.931648 | -0.15299 | 0.166399 |
| SL Noise | 72.69249 | 0.293281 | 247.8594 | 2.03E-42 | 72.08719 | 73.2978 |
| Volume | 0.006431 | 0.00051 | 12.60682 | 4.47E-12 | 0.005378 | 0.007483 |
| SL Noise | 55.7888 | 10.673 | 5.227097 | 5.69E-05 | 33.36566 | 78.21195 |
| Speed | 0.278805 | 0.147564 | 1.889379 | 0.07506 | -0.03122 | 0.588826 |

Table 6. Regression Analysis of Noise level difference by traffic factors

(A) Overall Fit

| Multiple R | R Square | Adjusted R Square | Standard Error | Observations |
|---|---|---|---|---|
| 0.319049 | 0.101792 | 0.064367 | 0.807086 | 26 |

(B) Analysis of variation(ANOVA)

| | DoF | SS | MS | F | sig F |
|---|---|---|---|---|---|
| Regression | 1 | 1.771698 | 1.771698 | 2.719882 | 0.112135 |
| Residual | 24 | 15.6333 | 0.651388 | | |
| Total | 25 | 17.405 | | | |

(C) Regression

| Class | coeff. | std. err | t stat | P-value | lower 95% | upper 95% |
|---|---|---|---|---|---|---|
| Diff. Noise | 8.557972 | 0.457532 | 18.70466 | 8.14E-16 | 7.613673 | 9.502271 |
| Volume | -0.00131 | 0.000796 | -1.64921 | 0.112135 | -0.00295 | 0.00033 |
| Diff. Noise | 9.640917 | 0.362891 | 26.56695 | 2.62E-19 | 8.891946 | 10.38989 |
| Large Car | -0.16454 | 0.031636 | -5.20086 | 2.50E-05 | -0.22983 | -0.09924 |
| Diff. Noise | 7.994486 | 6.188981 | 1.291729 | 0.212792 | -5.00808 | 20.99705 |
| Speed | -0.00366 | 0.085569 | -0.04275 | 0.966368 | -0.18343 | 0.176114 |

Table 7. Regression Analysis of Noise levels of the two type of PP

(A) Overall Fit

| Multiple R | R Square | Adjusted R Square | Standard Error | Observations |
|---|---|---|---|---|
| 0.922287 | 0.850614 | 0.84439 | 0.751426 | 26 |

(B) Analysis of variation(ANOVA)

| Class | DoF | SS | MS | F | sig F |
|---|---|---|---|---|---|
| Regression | 1 | 77.16248 | 77.16248 | 136.6577 | 2.14E-11 |
| Residual | 24 | 13.55137 | 0.56464 | | |
| Total | 25 | 90.71385 | | | |

(C) Regression

| Class | coeff. | std. err | t stat | P-value | lower 95% | upper 95% |
|---|---|---|---|---|---|---|
| D Layer | -27.2964 | 8.180214 | -3.33688 | 0.002752 | -44.1795 | -10.4132 |
| S Layer | 1.255381 | 0.107389 | 11.69007 | 2.14E-11 | 1.033742 | 1.47702 |

From the analysis, we can see the p-value is 2.14E-11, which much less than 0.05. The correlation between the noise levels of the two types of pavement under the condition of this study is strongly related, as shown in Fig. 6. This suggests that even though the various traffic factors affect road-noise, only the type of pavement creates this highly correlated relationship.

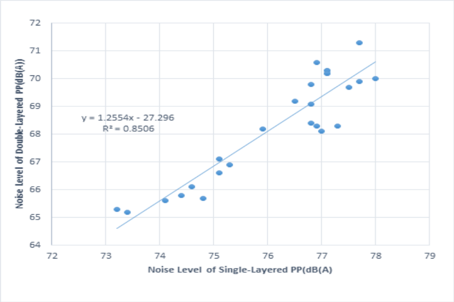


Fig. 6. Noise levels of double and single-layered porous pavement

## 5. CONCLUSION

To evaluate the noise levels of double-layered PP and the single-layered PP, the road traffic noise was measured under the same conditions in the section where the two type of pavements constructed on National Route 1, Sejong city section. And some conclusions were made after some statistical analysis like this.

In the given condition, the average noise level of the double-layered PP compare to single-layered PP is 7.95 dB(A) lower and 7.57 dB(A) lower at 95% confidence level.

Among the traffic factors such as traffic volume, large vehicle mix ratio, and driving speed, only the traffic volume was significant to the affection of the noise level of the two types of pavements. The other traffic factors were not significant to the noise level of the pavement. As the traffic volume increase, the noise level difference increased.

Among the traffic factors such as traffic volume, large vehicle mix ratio, and driving speed, only the large vehicle mix ratio was significant to the affection of the difference of noise level between the two types of pavements. The other traffic factors were not significant to the difference in the noise level of the pavement. As the large vehicle increase in traffic, the difference between the two types of pavement decreased.

The relation of the double and single-layered pavements was very good, i.e., R square was 0.8506, which means they explain well each other. So we can see the noise level of road traffic is almost governed by the type of pavement, even though they change a little with the traffic factors.

In other word, as a factor influencing road traffic noise, the difference in pavement was the largest compared to traffic factor. Through this study, we found that the most effective way to reduce road traffic noise is to change road pavement rather than reducing traffic speed, restricting traffic for heavy vehicles, or reducing traffic volume. Extensive research is needed to verify and quantify these results.

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