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Regression analysis of pavement surfaces textures on noise pollution

Ali Mansour Khaki[1], Amir Esmael Forouhid[2]*, Mehdi Zare[3] and Amirali Pirbastami[3]

[1]Civil Department, School of Civil Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran.
[2]Road and Transportation Engineering, School of Civil Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran.
[3]Road and Transportation Engineering, Azad University of Tehran-South Unit, Tehran, Iran.

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Noise is one of the physical environmental factors affecting human health in today's world. Pavement surface texture affects many vehicle and road characteristics; therefore, efforts are needed to develop more advanced techniques for evaluating pavement texture. The selection of an appropriate pavement as the best method to control the main cause of road noise, the sound absorption resulting from contact wheel vehicles and pavement is proposed. Finally, a case study is to determine and control the noise pollution level of skid resistance of asphalt pavements. In this study skid resistance of porous asphalt and conventional asphalt were measured. The linear regression was used for skid resistance and noise. The results have been confirmed by the nonparametric Kolmogorov-Smirnov test. Various pavement characteristics were measured and their effects on noise levels were evaluated using principal components regression, in addition to ordinary least-squares regression. This research confirmed that open graded pavements exhibit reduced tire noise compared to dense and gap graded mixes and quantified this reduction for typical mixes in Tehran.

Key words: Pavements, porous asphalt, conventional asphalt, British pendulum number, skid resistance, Kolmogorov-Smirnov test.

INTRODUCTION

Noise in cities is considered by the World Health Organization (WHO) to be the third most hazardous type of pollution after air and water pollution (WHO, 1999). One of the negative consequences of the increased traffic flow in roads and streets is increasing the noises caused by the movement of the vehicles. Consequentially, a large number of people, especially in urban areas, are exposed to dangerously high road traffic noise levels that significantly affect their health and quality of life (European Commission, 2011). Reduced noise for those living in and using the area adjacent to the roads will also yield a reduction in annoyance costs (Veisten and Akhtar, 2011).

Engine and exhaust systems' performance, cooling systems, noise caused by air collision with the body of the car, vibrations caused by the movement, the sound

*Corresponding author. E-mail: amiresmaelf@yahoo.com

of the tires and the interactions between the tires and the pavement, creating pressure oscillations that can be easily detected by the human ear. Studies carried out by the EU Commission show that about 20% of European people endure noises more than the standard level and about 170 million square meters of cities, are annoying areas with the effects of noise pollution caused by traffic. Unit used to describe the sound pressure oscillations, as the sound level indicator, is Decibels with the symbol of dB. Because of the increase in the number of cars and industrialization, noise pollution has also increased. Noise in cities, especially along main arteries, has reached up disturbing levels. Residences far from noise sources and near silent secondary roads are currently very popular. People prefer to live in places far from noisy urban areas (Serkan et al., 2009). As, the range of the human ear listening is between zero dB (hearing threshold) to 130 dB (pain threshold). Because of the wide range of sound hearing levels and in order to provide linear diagram of these changes, the results will be used and shown with the logarithmic unit of dB (A). Pavement surface characteristics have an important role in clarifying the state of noises emission from the contact of tires and the pavement surface (Hamet et al., 1990). Previous studies in Minnesota, have shown that at speeds above 80 km/h, noise caused by contact of tires and the pavement, as the main parameter of the sounds of the vehicle in motion is considered (Hibbs and Larson, 1996).Nilsson confirmed that the noises generated by the contact of tires and the pavement surface, in the cars is the dominant noise source (National Bureau of Standards, 1970). Similar to discrete coarse aggregate, porous pavement can reduce noise generated by contact of tires and the pavement surface (National Asphalt Pavement Association, 2003). Open-graded asphalt mixes have been used in the United States for more than 50 years, primarily because they can reduce hydroplaning, water splash and spray, and therefore can reduce wet weather accident rates. Open-graded mixes have also been shown to reduce tire/pavement noise. In the last decade, open-graded mixes have been extensively used in California to obtain these benefits, while obtaining collateral benefit from their noise reducing properties (Ongel et al., 2007).

Porous asphalt tests carried out in England in 1980 led to this result that, when the coarse porous material was poured on surface, 4 to 5.5 dB noise reduction for dry conditions in comparison with conventional dense surfaces were observed (Colwill et al., 1993). In France, at the end of 1980, researchers showed that porous asphalt pavement has 1 to 6 dB more absorption ability than the compact surfaces (Berengier et al., 1990). Therefore identifying the characteristics of various types of pavement has an undeniable impact on the noise level and is very important to noise pollution control.

The sound produced by of the vehicles on the road depends on many factors such as pavement type, porosity, size and type of aggregate, features of the vehicle, and vehicle speed. Among these parameters, two factors of the speed of the vehicle and the pavement type are the most affecting ones. By improving the texture of pavement, preserving the essential factors involved in pavement design like slippery resistance etc., partly, the noise of road surface can be reduced.

Always, achieving an appropriate texture, by increasing the porosity of the pavement, in addition to better drainage, causes less vibration of tires, reduction of noise generated by air suction and better noise absorption. To achieve high porosity, it is necessary to have an open graded asphalt surface (Sandberg, 1996). According to performed investigations, the sound produced by tyre contact with the asphalt pavement is about 2 to 5 dB lower than the concrete pavement. To obtain the lowest noise level, coarse and homogenous texture must be in minimum status (Kuemmel et al., 1997). Also the rolling of the road causes the horizontal axis orientation of pebbles and thus produce less noise on be pavement surface (Sandberg, 1996). Therefore, in this research, the characteristics of pavements and the generated sound level in various porous asphalt pavement is considered. Pavement friction characteristics are provided by pavement texture qualities. Pavement texture is divided into three parts: microtexture, macrotexture and megatexture. According to the International Organization of Standardization (ISO), macrotexture is defined as deviation from the road surface from a true planar surface with the characteristic dimensions along the surface of 0.5 mm to 50 mm, corresponding to texture wavelengths with one-third-octave bands including the range of 0.63 mm to 50 mm of center wavelengths (Sandberg, 1996). In this paper the noise levels and pavement texture in two kinds of pavements has been considered and measured and the relation between them has been obtained.

METHODOLOGY

Porous asphalt pavement type is primarily based on the two main functions that reduce the noise emissions:

Rolling noise reduction: Porous pavement texture by applying the pressure of entering air to the path reduces the generated noise of crossing tires.

Sound absorption: A layer of porous asphalt, due to special aerodynamic condition, lead to reduction of the generated noise in surrounding space. Studies in the Netherlands indicate that an average reduction of 2.5 dB can be achieved using porous asphalt with normal thickness (Dutch Innovation Program on Noise Reduction, 2005; CROW, 1999, 2004). The technical specifications for porous asphalt in the case study are shown in Figure 1 and Tables 2 and 3.

This road is approximately 20 km long in west of Sari. It is a divided 4-lane road (highway) with heavy and high-volume traffic (Roudaki, 2014).

The Statistical Pass-By (SPB) method was used in the proposed project for measuring sound of vehicles in motion. In this test, sound is measured in motion. To measure sound, a vehicle crosses

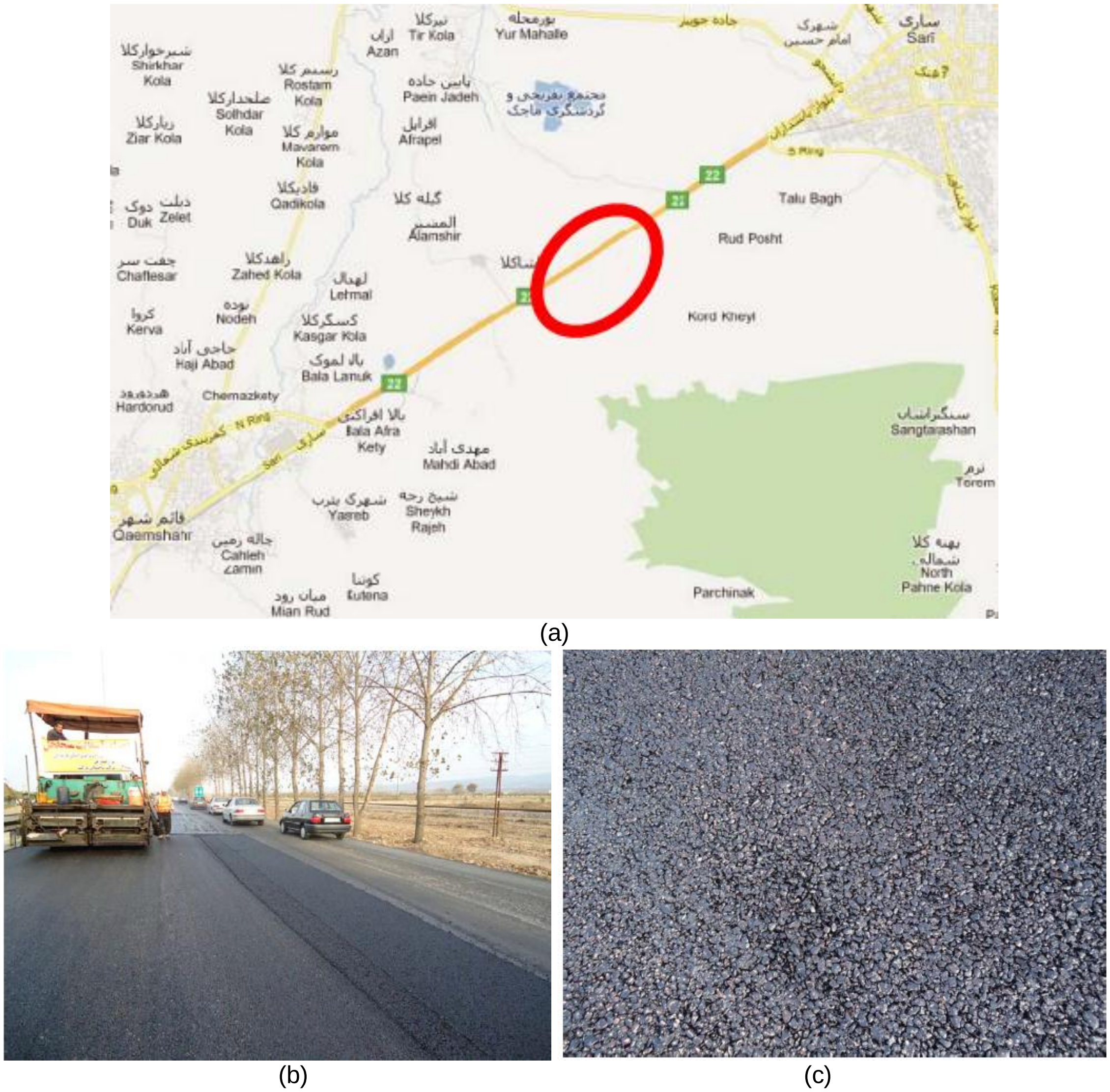


Figure 1. Porous asphalt in the test area (a) Sari-Ghaemshahr road for case study (b) the sections of road for paving porous asphalt (c) Porous asphalt after paving.

at 50 km/h at a constant RPM (Round per Mile) and sensors measure the sound automatically while it crosses throughout the relevant route. The test was conducted on porous asphalt on 25 July, 2011 and Sari-Ghaemshahr highway was blocked for 10 min after making coordination with the police several times. It is only at this time that porous asphalt was used for the area of roads and because of some reasons do not use it until now. It was performed by a Peugeot model GLX405 and the sound was measured by a B&K 2236 sound meter. The device is portable and operates from a hand or a stand, aligned perpendicular to the measured surface at a distance of approximately 7.5 and 1.2 m height from the surface. Type I was measured at the distance of 7.5 m from the car and at the height of 1.2 m from maximum level of road surface. Due to the high traffic flow of the road and time limitation, the tests had to be conducted quickly without errors. The car under test should have entered the test area at 50 km/h and the accelerator should have pushed down to its maximum to cross the 300-m route of the test. The test was carried out within two areas with porous asphalt and the results shown by Table 1 were obtained.

SKID RESISTANCE TEST FOR POROUS ASPHALT

Pavement friction depends on both the microtexture of aggregates and the macrotexture of the overall pavement surface. To adequately assess the pavement friction for operational vehicles, the effects of both the microtexture and macrotexture need to be evaluated in testing and analysis.

The British Pendulum Tester (BPT), developed by the British Road Research Laboratory (RRL, now the Transport Research Laboratory, TRL), is a dynamic pendulum impact-type tester used to measure the energy loss when a rubber slider edge is propelled over a test surface. The results are reported as British Pendulum Numbers (BPNs) to emphasize that they are specific to this tester and not directly equivalent to those from other devices. The major advantage of the tester is that it can be used in the field as well as in the laboratory. However, this tester is a low-speed device (about 10 km/h [6 mph] swing speed) that measures the skid resistance related to surface microtexture rather than macrotexture since pavement friction is affected by both of these.

Table 1. The maximum noise level on porous asphalt.

Variable	Test number 1 (dB)	Test number 2 (dB)
Device 1	70/9	73/9
Device 2	71/1	71/9

Table 2. Grading of porous asphalt in the case study.

Weight percent passing each sieve	Screen size (mm)
1	
100	19
90 – 100	12.5
49 – 62	9.5
20 – 27	4.75 (#4)
9 – 20	2.36 (#8)
4 - 7	0.075 (#200)

Table 3. The technical specifications of porous asphalt.

Technical specifications	Value
Marshal of the sample or sample gyrator	50
Percentage of void	25
Percentage of drainage pitch	25
Percent by weight of the sample at 25°C	20
Indirect tensile strength ratio (AASHTO T283)	85

Table 4. British pendulum test results on porous asphalt.

Location (km)	Lane number	British pendulum number
Beginning of the road	3	69
Beginning of the road	2	64
Beginning of the road	1	63
Middle of the road	3	65
Middle of the road	2	66
Middle of the road	1	66
End of the road	3	67
End of the road	2	63
End of the road	1	61

Skid resistance is a force that acts against skidding tires on a pavement when tires rotation is hindered. Specifications of a pavement surface, including macrotexture and microtexture, are effective in slip resistance. In fact, macrotexture under wet conditions and microtexture under dry conditions control skid resistance. A British pendulum test as per ASTM E303-74 (EN 1097-8: 2009) standard was carried out under wet conditions on different points of porous asphalt to evaluate skid resistance of porous asphalt. This tester is used for examining microtexture of a pavement. It is made of a rubber pad connected to a pendulum, which oscillates on samples of a level under study. The test result is reported as British Pendulum Number (BPN).

The British pendulum tests were carried out on porous asphalt on 6 March 2011 and 7 March 2011 almost 3 months after execution. Table 4 shows the results.

CONDUCTING FIELD TESTS ON CONVENTIONAL ASPHALT IN THREE SECTIONS IN TEHRAN

The sound test was carried out on three different sections of normal asphalt in Tehran on 17 November, 2014. In each section, 5 points

Figure 2. Case study area for field tests in Tehran.

with a distance of 200 m were selected and sound level of each point was measured. The case study area for field tests in Tehran is shown in Figure 2.

The test was conducted by a Peugeot model GLX405 and sound was measured by sound level meter TES1353. Measurements of the noise were performed using a sound level meter measuring device. The device is portable and operates from a hand or a stand, aligned perpendicular to the measured surface at a distance of approximately 7.5 and 1.2 m height from the surface. The car under test should have entered the test area at 50 km/h. Table 5 shows the results.

Skid resistance test for conventional asphalt

A British pendulum test as per ASTM E303-74 standard was carried out under wet conditions on three different points in Tehran to evaluate skid resistance. Five points with a distance of 200 m between them were selected in each section and skid resistance was measured in each point. A British pendulum test was carried out on normal asphalt in Tehran on 8 November, 2014. Table 6 shows the results. British pendulum test on conventional asphalt in Tehran is shown in Figure 3.

The steps to examine the effect of skid resistance on noise for porous asphalt of Sari-Ghaemshahr highway is as per normal asphalt.

As number of values for maximum level of sound in Sari-Ghaemshahr highway project is not sufficient, it is possible to obtain noise level – that is, y variable – by replacing BPN with x in the equation using linear regression equation for normal asphalt equation (1) obtained from SPSS output.

$$Y = 88.98 + (-0.24) \times (x)) \quad (1)$$

It should be noted that as BPN of porous asphalt consists nine values, six values were selected randomly. Table 7 shows BPNs and sound level for porous asphalt. It also shows results and analysis of SPSS for porous asphalt.

RESULTS OF STATISTICAL ANALYSIS

Here, statistical analysis for significance of the results of skid resistance test was performed. SPSS was used for examining and analyzing the relationship between BPN and noise. Simple linear regression was employed for building up relationship between data.

"*Significance Level*" (Sig) value of each parameter determines its significance, as its value for a parameter is lower than 0.05, that parameter will be significant at the confidence level of 95%. Values obtained from t-test were also reported for the parameters. In case this value for each parameter is smaller than its critical limit at that confidence level, the parameter will not be significant at that level. It should be noted that t-test is achieved by dividing the difference among mean of data into the standard deviation of their difference. Moreover, values of *Beta* column in the software output indicate effectiveness of a variable. The higher the value of a variable is, the

Table 5. The maximum noise level of conventional asphalt in Tehran.

Number	Velocity of vehicle (km/h)	Location name	Noise level (dB)
1	50	Opposite the entrance to the town Valfajr Geophysical Institute	71.5
2	50	200 m ahead across Third Street	70.3
3	50	200 m away across the street 9/7	78.6
4	50	200 m away across the street 9/3	73.2
5	50	200 m away across the street 9/1	75.7
6	50	North AmirAbad below the Hakim Highway	71.6
7	50	200 m away in front of the Atomic Energy Organization	72.5
8	50	200 m away from the National Center for Cyber Space	77.9
9	50	200 m away across the street 19	74.1
10	50	200 m away across the street 16	73.8
11	50	Dr Fatemi Street in front of the building and facilities Engineering command	75.8
12	50	200 m ahead before Sindokht Street	76.1
13	50	200 m away in front of the Iranian Fisheries Organization	79.6
14	50	200 m ahead before Etemad Zadeh Street	80.4
15	50	200 m ahead against the camp of Imam Khomeini	78.3

Table 6. British pendulum test results on conventional asphalt in Tehran.

Place of Test	Street	Lane No.	BPN
Valfajr Settlement - Opposite Institute of Geophysics			76
200 m Ahead – Opposite Street 3			74
200 m Ahead – Opposite Alley 9.7	North Amir Abad Street – North of Hakim Highway	Lane 2 (Climbing Lane)	56
200 m Ahead – Opposite Alley 9.3			68
200 m Ahead – Opposite Alley 9.1			60
North Amir Abad Street – South of Hakim Highway			59
200 m Ahead – Opposite Atomic Energy Organization			55
200 m Ahead – Opposite the National Center of Cyberspace	North Amir Abad Street – South of Hakim Highway	Lane 2 (Climbing Lane)	51
200 m Ahead – Opposite Street 19			60
200 m Ahead – Opposite Street 16			61
Fatemi Street – Opposite Buildings and Facilities Engineering Headquarter			46
200 m Ahead – Before Simindokht Street			50
200 m Ahead – Opposite Iran Fishery Organization	Fatemi Street – Karegar Junction	Lane 2 (Climbing Lane)	51
200 m Ahead – Before Etemad Zadeh Street			45
200 m Ahead – Opposite Imam Khomeini (RA) Garrison			40

higher its effectiveness is.

R^2 (R Square) expresses rate of correlation between the variables used in a regression. The closeness of the value to 1 indicates a suitable correlation among variables. The tables show the results of statistical analysis as variance analysis (ANOVA) and coefficients of the regression equation. It should be noted that the noise value mentioned by the tables is as a dependent variable and BPN was considered as independent variables.

The results of statistical analysis presented by the above table show a significant relationship between BPN and noise. In other words, *Sig* value in this mode equals 0.001 for normal asphalt and 0.000 for porous asphalt (lower than the critical value). Therefore, noise reduction for BPN is significant at the confidence level of 95%. Of course, it should be mentioned that it is not possible to accept or reject significance of a regression relation only based on a Sig value.

Research data show the effect of skid resistance on noise generation. A researcher would like to examine the question whether there is a significant relationship

Figure 3. British pendulum test on conventional asphalt in Tehran.

Table 7. The maximum noise level by placing numbers in British pendulum porous asphalt pavement in ordinary linear regression equation.

BPN for porous asphalt	Linear regression equation: Y=88.98 + (-0.24) × (x)
69	72/42
64	73/62
63	73/86
65	73/38
66	73/14
66	73/14
67	72/9
63	73/86
61	74/34
62	74/1
68	72/66
70	72/09
71	71/49
74	71/22
73	71/46

between noise generation and asphalt pavement.

To answer the fundamental question of the research, a test is conducted first as H1:ρ≠0 vs. H0: ρ=0 and then decision is made about it using the data. The following steps are taken for conducting the test of above assumption: By drawing P-P diagrams, make sure that "noise" and "skid resistance" variables are normal.

Figure 4 helps us to conclude whether these two variables are normal. (Of course, a definite conclusion on their normality is made based on a non-parametric test). Therefore, the above test should be conducted using Pearson method. The results showed a negative and significant relationship between "*noise*" and "*skid resistance*" variables. Now, we would like to discover the relationship using a regression method. Fitting stages of the regression model and its verification are as follows:

Independent variable (y) and dependent variable (x) of the research are determined first (y is noise and x is skid resistance).

Scatter diagram (which is used to know how the two variables affect each other) is as shown by Figure 5.

Table 8 shows the result of Pearson correlation test. As the significance value of the above test (Sig=0.000) is lower than 0.05, it can be concluded that the assumption H0 based on correlation (ρ≠0) between the two variables is rejected at the significance level of 0.05.

Negative value of Pearson correlation coefficient (-0.782), (-0.994) shows a negative correlation between the two variables.

Table 9 shows "percentage of data", which is explained

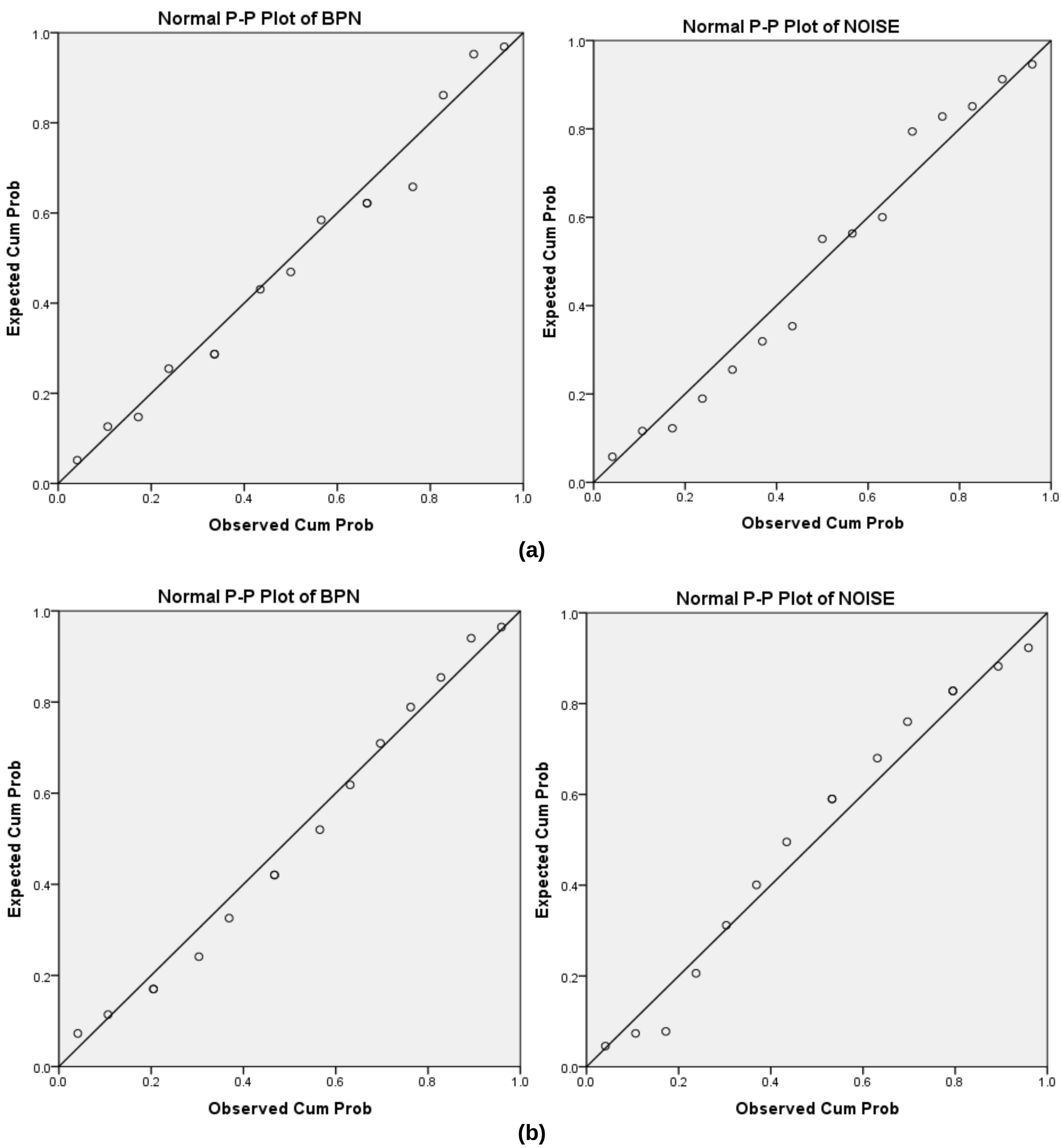


Figure 4. P-P plots (a) Conventional asphalt (b) Porous asphalt.

and described by the regression model.

It can be concluded from the adjusted correlation coefficient that 58.1 and 98.7% of the data are explained by the regression model, which is of course a favorable percentage. A test called ANOVA is used for suitability of the regression model. In fact, the test is as follows:

H0: All non-constant coefficient of a regression model equal zero vs. H1: At least one of the non-constant coefficient of the model is not zero.

The above test is known as regression model suitability. Here, it is evident that we are interested in rejecting H0 assumption. The significance value of the test (Sig=0.001, 0/000) proves suitability of the regression model at the significance level of 0.05. Table 10 shows estimate coefficients of regression model (Column B) and significance value of the test related to the coefficients. With respect to the significance value of the test concerning the constant value (Sig= 0.000), assumption of zero for the test based on the zero value is not

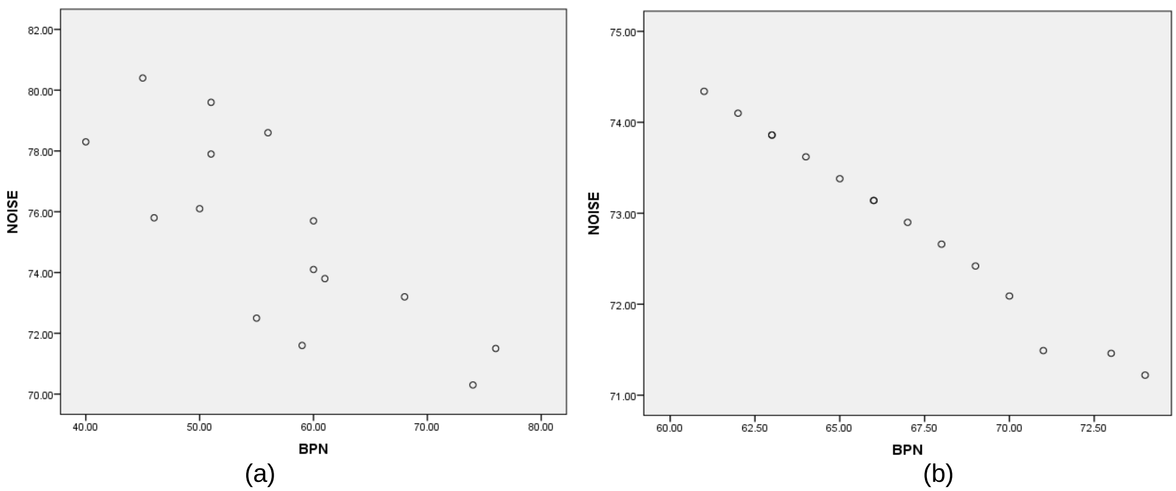


Figure 5. The scatter diagram of skid resistance and noise level (a) Conventional asphalt (b) Porous asphalt.

Table 8. Output of the correlation.

Correlations		Conventional asphalt		Porous asphalt	
		NOISE	**BPN**	**NOISE**	**BPN**
Pearson Correlation	NOISE	1.000	-0.782	1.000	-0.994
	BPN	-0.782	1.000	-.994	1.000
Sig. (1-tailed)	NOISE	.	0.000	.	0.000
	BPN	0.000	.	0.000	.
N	NOISE	15	15	15	15
	BPN	15	15	15	15

Table 9. Percent values explained by the regression model.

Model	R	R^2	Adjusted R^2	Standard error of the estimate
Model summary (Conventional asphalt)				
1	0.782[a]	0.611	0.581	2.05521
Model summary (Porous asphalt)				
1	0.994[a]	0.988	0.987	0.11430

[a] Predictors: (Constant), BPN.

accepted at the significance level of 0.05. However, with respect to the significance value related to the independent variable coefficient (Sig=0.001, 0/000), assumption of zero for the test based on the zero value of the coefficient is accepted at the significance level of 0.05. Therefore, the regression model fitted for the data will be Equations (2) and (3).

$$y = -0.241x + \varepsilon \quad (2)$$

$$y = -0.250x + \varepsilon \quad (3)$$

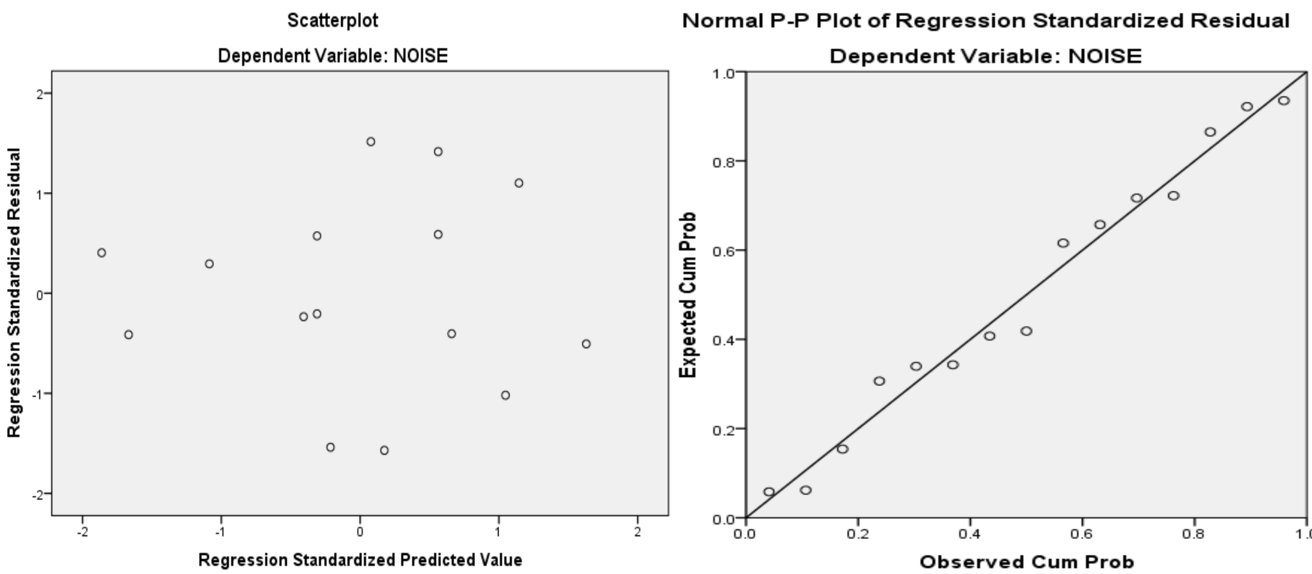
Figure 6 shows a verification of the hypotheses concerning fixed value of variance and normality.

As no specific trend is seen in the remaining diagram against the fitted (predicted) values (scatter diagram), fixed amount of variance of remaining can be concluded. The above P-P diagram shows normality of remaining. As mentioned above, the result obtained from the diagram is

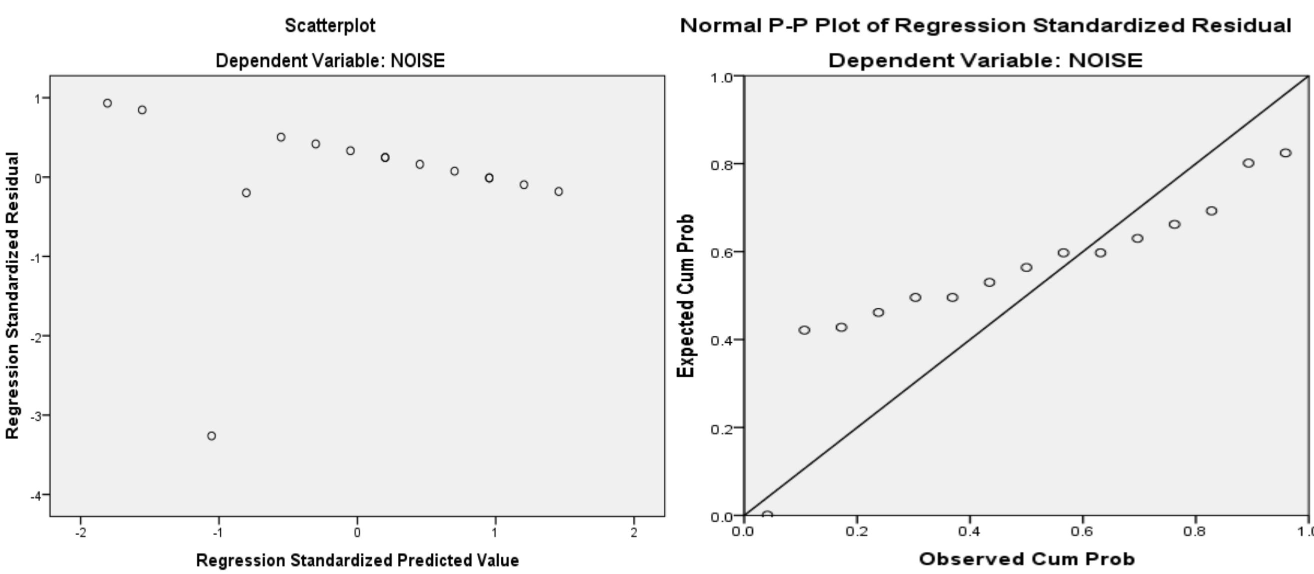
Table 10. Estimate coefficients of regression model.

Model		Unstandardized coefficients		Standardized coefficients	t	Significance
		B	Standard error	Beta		
Coefficients [a] (Conventional asphalt)						
1	(Constant)	88.975	3.072		28.963	0.000
	BPN	-.241	0.053	-0.782	-4.522	0.001
Coefficients [a] (Porous asphalt)						
1	(Constant)	89.598	0.513		174.716	0.000
	BPN	-0.250	0.008	-0.994	-32.592	0.000

[a] Dependent Variable: NOISE.



(a)



(b)

Figure 6. Scatter diagram and p-p diagram of noise (a) Conventional asphalt (b) Porous asphalt.

Table 11. Non-parametric Kolmogorov-Smirnov test.

Parameter		Standardized residual
One-Sample Kolmogorov-Smirnov Test (Conventional asphalt)		
N		15
Normal parameters[a,b]	Mean	0.0000000
	Std. Deviation	0.96362411
Most extreme differences	Absolute	0.118
	Positive	0.118
	Negative	-0.100
Kolmogorov-Smirnov Z		0.456
Asymp. Sig. (2-tailed)		0.985
One-Sample Kolmogorov-Smirnov Test (Porous asphalt)		
N		15
Normal parameters[a,b]	Mean	0.0000000
	Standard deviation	0.96362411
Most extreme differences	Absolute	0.352
	Positive	0.167
	Negative	-0.352
Kolmogorov-Smirnov Z		1.363
Asymp. Sig. (2-tailed)		0.049

[a]: Test distribution is normal. [b]: Calculated from data.

not sufficient by itself and the result should be confirmed by the nonparametric Kolmogorov-Smirnov test.

The importance of normal distribution is undeniable since it is an underlying assumption of many statistical procedures such as t-tests, linear regression analysis. When the normality assumption is violated, interpretation and inferences may not be reliable or valid. The three common procedures in assessing whether a random sample of independent observations of size n come from a population with a normal distribution are: graphical methods, numerical methods and formal normality tests. Kolmogorov- Smirnov (KS) test is one of the methods that has been used in this analysis. The normal quantile-quantile plot is the most commonly used and effective diagnostic tool for checking normality of data. The Kolmogorov–Smirnov test (hereafter the KS test) is a much used goodness-of-fit test. In particular, it is often employed to test normality, second reason for implementing normality tests is that many statistical procedures require or are optimal under the assumption of normality, and it is therefore of interest to know whether or not this assumption is fulfilled. A recent example of such a use of a normality test is given in Sanders and Lea (2005) in their study of hurricane activity.

Result in Table 11 shows conducting the non parametric Kolmogorov-Smirnov test on the reserved remaining (which are on the last column called .ZRE_1).

As the significance value (Sig=0.985) exceeds 0.05, there is no reason for rejecting assumption (H0) based on normality of remaining at the significance level of 0.05. Therefore, the normality assumption of remaining is valid.

As the significance value (Sig=0.049) do not exceed 0.05, therefore, the normality assumption of remaining is valid.

Assumption of independence of remaining and/or independence of remaining on time is examined by drawing a time series diagram of the reserved remaining as follows:

Figure 7 shows minor trend of the relationships between remaining. Of course, the trend is extremely slight and negligible. The above results can be summarized as follows:

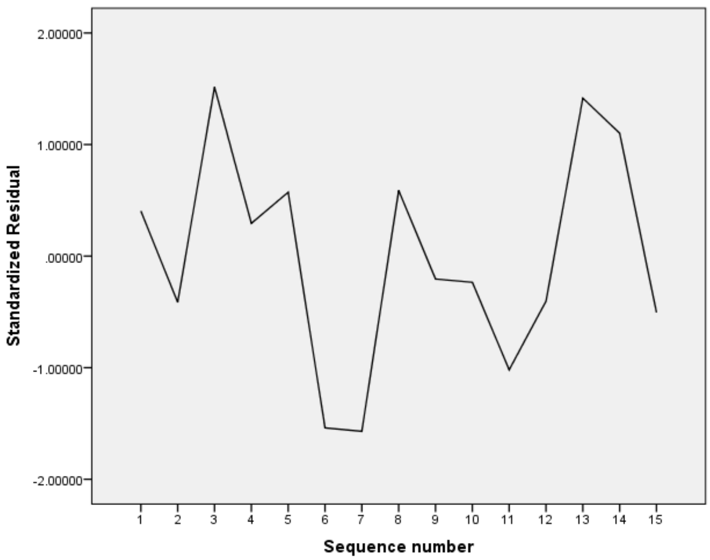
The fitted model is on the linear relationship between *noise* and *skid resistance* variables as Equations (4) and (5).

$$y = -0.24x + \varepsilon \quad (4)$$

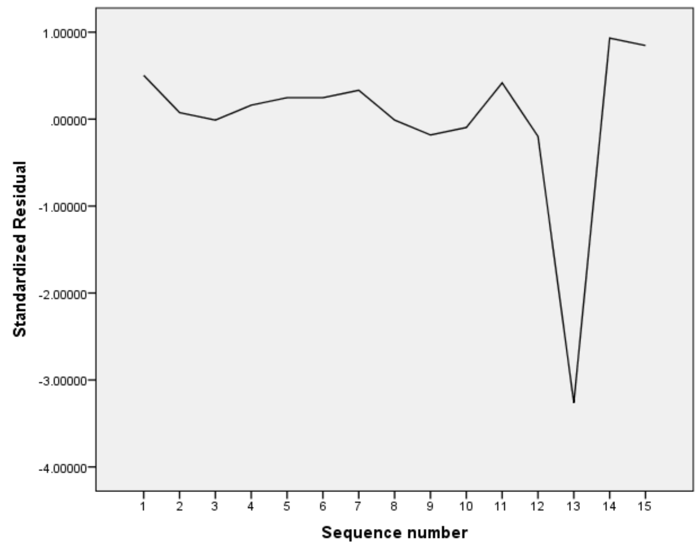
$$y = -0.25x + \varepsilon \quad (5)$$

Conclusion

This article mainly aimed at examining the sound generated on pavements caused by crossing vehicles and studying the effects of different parameters on it. Selecting type of pavement is the major parameter in reducing the generated sound. Some of the pavements such as porous asphalt, double-layer porous asphalt, and



(a)



(b)

Figure 7. Time series diagram of the reserved remaining (a) Conventional asphalt (b) Porous asphalt.

stone matrix asphalt were introduced as the ones with noticeable effect on reducing sound levels. If they are selected and maintained correctly, it will be possible to reduce about 8 dB of the sound generated by crossing vehicles. As the unit used for levels of the generated sound is a logarithm-based unit, the slightest change in it can be perceived and distinguished by human ear. According to the international standard, open-graded asphalt is commonly used as the most silent pavement. Skid resistance of surface level is of the major parameters on roads noise pollution topic. It means that whenever there is not sufficient friction coefficient between contact surface of car tire and pavement, there will be more noise. In particular, humidity of pavement surface increases skidding of vehicles and the generated noise. Therefore, by examining and measuring skid resistance of pavements, the areas with unfavorable skid resistance may be identified and special measures may be taken to remove it. This research studied frictional specifications of porous-graded and normal-graded asphalt mixtures and the results are as follows:

i) A British pendulum tester can be used for examining and comparing skid resistance of asphalt surfaces.
ii) Skid resistance of porous-graded asphalt pavements is higher than the normal asphalt pavement. Here, PBN of porous-graded asphalt pavements is on average about 10 higher than the one of normal asphalt pavements.

By examination of surface of asphalt pavements, one may conclude that porous asphalt pavement, due to having macrotexture as compared with microtexture normal asphalt pavement, has a higher skid resistance on aggregates surface and causes further noise reduction. Roadways paved with open graded asphalt mixes typically generate lower traffic noise levels as compared to other types of pavements.

iii) Sound intensity measurements indicate that open-graded mixes may reduce the tire/pavement noise, compared with other asphaltic mixes. Open-graded mixes typically have higher air-void contents, permeability, and surface macrotexture than gap or dense-graded mixes.

These results indicate that the best approach for noise reduction is probably relatively thin open graded mixes with somewhat lower air void contents. These mixes will likely have greater durability due to the lower air void contents.

Tire/pavement noise is evidently affected by the characteristics of the tires and of the pavement. Only the latter factor is addressed in this paper. The physical properties of the materials that constitute the upper structural layer of the pavement play a major role in the generation of noise. Pavement mixes with higher air void contents porosity are known to reduce noise levels. There are two noise reduction mechanisms for open graded porous surfaces: noise absorption and noise propagation. The presence of air voids in the surface layer helps dissipate trapped air in the tire's tread grooves. This results in reduced air pumping, and therefore decreased noise emissions.

Conflict of Interest

The authors have not declared any conflict of interest.

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