The Evaluation of Traffic Noise on Indonesian Toll Road (Case Study of Padaleunyi Toll Road)

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Abstract : The negative impact of the toll road is traffic noise. Which that can be predicted using a mathematical model and noise mitigation that can be guided by Pt-T-16-2005-B. Study locations are located at Padaleunyi Toll Road.

The result of the analysis shows that the noise levels are 74 dB(A) for level roads and 77 dB(A) for uphill roads. The mathematical model shows that percentage of vehicles (X2) and average speed (X3) are the most influential factors of noise on uphill roads. Traffic noise mitigation can be done by increasing the height of the fence made of precast concrete panel walls by 4 m to reduce the noise by 19 dB(A), and planting pringgodani bamboo to reduce the noise by 4.9 dB(A).

Other types of noise barriers that can be researched are Photovoltaic Noise Barries which have the function of reducing noise and producing renewable energy simultaneously.

Keywords: Factors for road noise, Leq, distance of noise measurement, road slopes.

1. INTRODUCTION

Toll roads are provided as infrastructure for making movements to meet needs. In meeting their needs, humans need movement if these needs cannot be met in a place or location. Humans, in moving from each location to another, mostly use transportation as a means, both motorized and non-motorized vehicles and roads as infrastructure. In the operation of a motorized vehicle on a road, sounds will arise, both from vehicle engines and vehicle horns and sounds generated by vehicle movements. In general, if the flow of vehicles on a road is still a little, the sound of vehicles is not so disturbing, however, if the traffic flow on a road is dense it will cause noise pollution, namely noise. Noise is defined as unwanted sound whose impact will affect the physical and psychological health of people who are exposed to continuous noise, such as depression, sleep disorders, high blood pressure, diabetes, and irregular heartbeat (Ongel A, 2016). The noise that is most felt at this time is the noise caused by motorized vehicles. It cannot be denied that a developed area will have toll roads. This is done to support the ease of economic movement in the region. However, from the other side, there is a negative impact on the noise from toll road traffic for residents in the area. Therefore it is necessary to pay attention so that the noise level does not exceed the safe limit that can be accepted by the human ear. Proper control measures can minimize noise so as to improve comfort for residents who live around toll roads.

The study area in this research is the Padaleunyi (Padalarang-Cileunyi) toll road because there are several settlements located close to the toll road. In addition, this toll road has hilly contours, so there are several climbs and descents. The Padaleunyi toll road has a length of 64.4 kilometers which is located in the city of Bandung and is a continuation of the Jakarta-Cikampek toll road so that this toll road has a fairly high daily traffic density. Based on this background, this research was conducted to determine the noise level on the Padaleunyi toll road which is affected by the slope of the road (flat and uphill), to find out the traffic factors that affect the noise level, and to determine the appropriate mitigation to reduce the noise impact felt by residents around the toll road.

2. LITERATURE REVIEW

2.1 Highway Noise

According to Mediastika, 2005, the determining factors for road noise can come from a high number of vehicle flows, a higher number of heavy vehicles, a higher number of motorbikes, vehicle speed, road surface quality, road slope, traffic regulation, conditions in right and left side of the road, use of sidewalks for parking areas and informal trade.

2.2 Noise Level Measurement

The guidelines used in this study use guidelines from FHWA, 2017. Measurement steps are determining the measurement point, installing the Sound Level Meter tool, checking all equipment settings, initial calibration of the Sound Level Meter tool, documenting meteorological conditions, filling in data sheets in the field, taking traffic volume data and vehicle speed, final calibration of the Sound Level Meter tool.

2.3 Noise Mitigation

According to the Decree of the Minister of Environment no. Kep-48 / MENLH / 11/1996, noise level standards have been set for each specific area. This noise level is measured based on the average equivalent noise level measurement (Leq). The noise level standard for each area has been determined as follows.

Table 1. Noise level standards

No.	Area Allocation	Noise level dB (A)
a.	Area Allocation :	
	1. Housing and Settlements	55
	2. Trade and Services	70
	3. Office and Trade	65
	4. Green Open Space	50
	5. Industry	70
	6. Government and Public	60
	Facilities	70
	7. Recreation	60
	8. Special :	-
	- Airport	-
	- Railway station	70
	- Seaports	60
	- Cultural heritage	
b.	Activity Environment :	
	1. Hospital or the like	55
	2. School or the like	55
	3. Places of worship or the like	55

Source: Minister of Environment Decree no. Kep-48 / MENLH / 11/1996

From the standard noise level in Table 1, if the noise generated from traffic activities has exceeded or is greater than the standard noise level for each area, it is necessary to propose to carry out noise handling.

According to Pt-T-16-2005-B, noise mitigation can be done by using natural barriers, and a barrier in the form of Noise Absorbing Buildings (NAB).

The natural barrier can be a plant barrier. Plants used to apply the deadline must have sufficient and even leaf density and dense from the soil surface to the expected height. For this reason, it is necessary to regulate ground cover crops, shrubs and trees or a combination with other materials so that the barrier effect is optimal.

Table 2. Noise reduction effectiveness by plants

Types of Plants	Leaf Cover Volume (m^3)	Distance From Noise Source To Plants (d) (m)	Height Measurement (m)	Average Noise Reduction, IL (dBA)
Acacia (*Acacia Mangium*)	114,39	18.20	1.2	2.5
		30.20	4.00	4.1
	118.23	18.20	1.20	2.7
		24.60	4.00	4.1
Pringgodani Bamboo (*Bambusa Sp*)	122.03	7.0	1.20	1.1
		16.40	2.50	4.9
	366.08	35.4	1.2	14.7
Black-Wood Cassia (*Casia Siamea*)	60.74	9.8	1.20	0.3
		17.0	3.60	3.2
	83.24	9.6	1.20	0.20
Likuan-yu (*Vermenia Obtusifolia*)	2.464	8.20	1.20	2.3
Sapphire Showers (*Durante Repens*)	1.680	9.80	1.20	0.8
Ashoka (*Ixora Sp*)	1.350	11.20	1.20	0.9
Creeping Fig (*Ficus Pumila*)	1.105	4.60	1.20	0.9
False Bird Of Paradise (*Heliconia Sp*)	1.792	3.2	1.20	3.4
Siamese Acalypha	11.10	6	1.20	2.1
Be parenthesized :				
a. Siamese Acalypha	13.88	6	1.20	2.7
b. False Bird Of	2.75	9	1.20	3.8
Paradise	16.65	6	1.20	4.2
(*Heliconia Sp*)	33.3	9	1.20	5.0

Source: Pt-T-16-2005-B

The artificial barrier type is a suitable choice for locations such as toll roads, arterial roads, or those with narrow alignments, bridges and roads over embankments. Such artificial barriers can consist of continuous barriers, non-continuous barriers, combination of continuous and non-continuous barriers, and artistic barriers. In order for a noise-canceling building to work properly, the building must be high and long enough to reduce the propagation of noise to listeners, for example, for a house on a surface that is much higher than the surface of the road pavement, the construction of noise suppression needs to be built higher. The average barrier building effectiveness based on laboratory tests for the shadow zone is shown in the following table.

Table 3. The effectiveness of artificial barrier noise reduction

No.	Type	Material	Dimension W = Min. Width H = Min. Height	Effectiveness IL = dB(A)
1	Continuous Barrier	a. Barrier made of brick	W = 0,5 m H = 2,5 m	Good IL = 15 - 16
		b. Reinforced concrete	W = 0,35 m H = 3 - 4 m	Good–Optimum IL = 17 - 19
		c. Wood with or without absorbent material	W = 0,3 m H = 2 - 3 m	Good IL = 18 - 19
		d. Aluminum or steel with an absorbent material	W = 0,3 m H = 4 - 5 m	Optimum 20 - 22
		e. Fiber, Glass	W = 0,5 m H = 3 - 4 m	Good IL = 16 - 17
2	Non-Continuous Barrier	a. Reinforced concrete	W = 1 - 2 m H = 3 - 4 m	Optimum IL = 17 - 18
		b. Aluminum or steel with an absorbent material	W = 1,0 m H = 3 - 4 m	Optimum IL = 18 - 19
		c. a combination of materials a and b with fiber	W = 2,0 m H = 3 - 4 m	Optimum IL = 20 - 22
3	Combination of Continuous and Non-Continuous Barriers	a. Barrier made of brick	W = 0,5 m H = 2,5 m	Good IL = 15 - 16
		b. Reinforced concrete	W = 0,35 m H = 3 - 4 m	Good-Optimum IL = 17 - 19
		c. Wood with or without absorbent material	W = 0,3 m H = 2 - 3 m	Good IL = 18 - 19
		d. Aluminum or steel with an absorbent material	W = 0,3 m H = 4 - 5 m	Optimum 20 - 22
		e. Fiber	W = 0,5 m H = 3 - 4 m	Good IL = 16 - 17
		f. Reinforced concrete	W = 1 - 2 m H = 3 - 4 m	Optimum IL = 17 - 18
		g. Aluminum or steel with an absorbent material	W = 1,0 m H = 3 - 4 m	Optimum IL = 18 - 19
		h. a combination of materials a and b with fiber	W = 2,0 m H = 3 - 4 m	Optimum IL = 20 - 22
4	Architectural Barriers	The combination of shape design and artistic color design	W = Variable 0,5 m H = Variable	Good IL = 14 - 16

Source: Pt-T-16-2005-B

3. RESEARCH METHODOLOGY

The measurement of the noise level on the Padaleunyi toll road is carried out using a noise measuring device, namely the Sound Level Meter. According to the Guidelines for Mitigating the Impact of Noise Due to Road Traffic, Pt-T-16-2005-B, for the measurement of noise on toll roads based on the recommended noise-reducing building approach, which is at least 10 meters from the edge of the pavement, the Sound Level Meter is placed 10 m from the edge of the pavement or at a distance of ± 18 m from the center line of the toll road with a Sound Level Meter height of ± 1.2 m from the ground, and as a variation of the noise level results obtained, noise measurements are also carried out at a distance of ± 23 m from the center line of the toll road. The distance measurement is carried out starting from the center line of the toll road because vehicles are moving more in the middle of the lane than walking on the shoulder of the toll road.

The data required in this study consists of noise level data (Leq) with a recording duration of every 5 minutes for 2 peak hours in the morning, afternoon, and evening. Meanwhile, the traffic data required is traffic flow (vehicle/hour), vehicle percentage (%), and average vehicle speed (km/hour). These data are used to create a mathematical model in the form of a multiple linear regression model which aims to predict noise levels due to traffic conditions on a level road and uphill road location. The formation of a regression model and testing the regression model using IBM SPSS Statistics 25 software by looking at the smallest significant value of the regression model and the largest R square value of the regression model. In addition, this research also conducts noise handling based on Pt-T-16-2005-B by evaluating noise levels in accordance with Kep-48 / MENLH / 11/1996, and taking mitigation measures in the form of giving Noise Absorbing Buildings (NAB) or natural barrier.

4. DATA ANALYSIS AND DISCUSSION

4.1 Noise Level Modeling

In this study, the dependent variable is Leq which is divided into two different measuring distances, namely at a distance of 18 meters which is symbolized by Y1, and Leq at a distance of 23 meters which is symbolized by Y2. Likewise, the independent variables in the study were divided into two different directions of traffic movement, namely the traffic movement in the direction of Cileunyi and the direction of Padalarang. The first step to take is to determine representative data on noise levels, whether the flow of vehicles heading to Cileunyi or the flow of vehicles heading to Padalarang on a level road and uphill road. As an example of the analysis phase, the results of the correlation of vehicle flows on a level roads location will be displayed.

Table 4. Correlation of vehicle flow against Leq 18 m, level roads

Correlations				
		Leq 18	The Flow Of Vehicles In The Direction Of Cileunyi	The Flow Of Vehicles In The Direction Of Padalarang
Leq 18	Pearson Correlation	1	0.637**	0.204*
	Sig. (2-tailed)		0.000	0.017
	N	136	136	136
The Flow Of Vehicles In The Direction Of Cileunyi	Pearson Correlation	0.637**	1	0.327*
	Sig. (2-tailed)	0.000		0.000
	N	136	136	136
The Flow Of Vehicles In The Direction Of Padalarang	Pearson Correlation	0.204*	0.327**	1
	Sig. (2-tailed)	0.017	0.000	
	N	136	136	136

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 5. Correlation of vehicle flow against Leq 23 m, level roads

Correlations

		Leq 23	The Flow Of Vehicles In The Direction Of Cileunyi	The Flow Of Vehicles In The Direction Of Padalarang
Leq 23	Pearson Correlation	1	0.599**	0.232**
	Sig. (2-tailed)		0.000	0.006
	N	141	141	141
The Flow Of Vehicles In The Direction Of Cileunyi	Pearson Correlation	0.599**	1	0.345**
	Sig. (2-tailed)	0.000		0.000
	N	141	141	141
The Flow Of Vehicles In The Direction Of Padalarang	Pearson Correlation	0.232**	0.345**	1
	Sig. (2-tailed)	0.006	0.000	
	N	141	141	141

**. Correlation is significant at the 0.01 level (2-tailed).

The results of the two correlations above indicate that the current correlation in Cileunyi has a strong correlation value with noise levels. Likewise, the correlation between the current to Cileunyi on the uphill road shows a strong correlation with noise levels. So that the flow of vehicles to Cileunyi is considered to represent the X1 variable which will be included in the regression model.

The second step is to examine the correlation of the percentage of vehicles heading to Cileunyi to Y1 and Y2 on flat roads and uphill road locations. For example, the correlation results for the percentage of vehicles at a road location level will be shown.

Table 6. Correlation of % of vehicles against Leq 18 m, level roads

Correlations

		Leq 18	Light vehicle	Heavy vehicle over two axles
Leq 18	Pearson Correlation	1	-0.685**	0.684**
	Sig. (2-tailed)		0.000	0.000
	N	136	136	136
Light vehicle	Pearson Correlation	-0.685**	1	-1.000**
	Sig. (2-tailed)	0.000		0.000
	N	136	136	136
Heavy vehicle over two axles	Pearson Correlation	0.684**	-1.000**	1
	Sig. (2-tailed)	0.000	0.000	
	N	136	136	136

**. Correlation is significant at the 0.01 level (2-tailed).

Table 7. Correlation of % of vehicles against Leq 23 m, level roads

Correlations

		Leq 23	Light vehicle	Heavy vehicle over two axles
Leq 23	Pearson Correlation	1	-0.717**	0.717**
	Sig. (2-tailed)		0.000	0.000
	N	141	141	141
Light vehicle	Pearson Correlation	-0.717**	1	-1.000**
	Sig. (2-tailed)	0.000		0.000
	N	141	141	141
Heavy vehicle over two axles	Pearson Correlation	0.717**	-1.000**	1
	Sig. (2-tailed)	0.000	0.000	
	N	141	141	141

**. Correlation is significant at the 0.01 level (2-tailed).

Tables 6 and 7 show that the percentage of vehicles weighing more than two axles has a strong correlation value with the expected value. Likewise with the location of the uphill road which also has a strong correlation value with noise levels. Thus it can represent the independent variable X2. From the correlation test of X1 and X2, it can be concluded that what is included in the multiple linear regression analysis is the average speed of heavy vehicles on two axes, and can represent the independent variable X3. The third step is to test the correlation of the three independent variables on Y1 and Y2. As an example of the analysis phase, the results of the correlation X1, X2, and X3 will be displayed on an even road location.

Table 8. Analysis of correlation and significance of Y1, level roads

Correlations					
		Y1	X1	X2	X3
Pearson Correlation	Y1	1.000	0.637	0.684	-0.542
	X1	0.637	1.000	0.305	-0.319
	X2	0.684	0.305	1.000	0.004
	X3	-0.542	-0.319	0.004	1.000
Sig. (1-tailed)	Y1		0.000	0.000	0.000
	X1	0.000		0.000	0.000
	X2	0.000	0.000		0.000
	X3	0.000	0.000	0.000	
N	Y1	136	136	136	136
	X1	136	136	136	136
	X2	136	136	136	136
	X3	136	136	136	136

Table 9. Analysis of correlation and significance of Y2, level roads

Correlations					
		Y2	X1	X2	X3
Pearson Correlation	Y2	1.000	0.599	0.717	-0.661
	X1	0.599	1.000	0.529	-0.341
	X2	0.717	0.529	1.000	-0.518
	X3	-0.661	-0.341	-0.518	1.000
Sig. (1-tailed)	Y2		0.000	0.000	0.000
	X1	0.000		0.000	0.000
	X2	0.000	0.000		0.000
	X3	0.000	0.000	0.000	
N	Y2	141	141	141	141
	X1	141	141	141	141
	X2	141	141	141	141
	X3	141	141	141	141

The above correlation results indicate that X1, X2, and X3 have a strong correlation value to noise levels. It can be seen from the Pearson Correlation results which show a value of more than 0.5 with the appropriate sign and a significance value of less than 0.05. Thus, all independent variables can be entered into a multiple linear regression model.

4.2 Multiple Linear Regression Analysis

The method used is the forward selection method, with the analysis stage starting by entering the independent variable that has the highest correlation with the dependent variable. The next step is to add variables by evaluating the significance of the independent variables on the model, provided that the significance value is <0.05. Following are the results of multiple linear regression analysis at a level roads and uphill roads location.

Table 10. Multiple linear regression

No.	Model	Significance (p value)	R Square
Level Roads			
1	Y1 = 76.251 + 0.0002 X1 + 0.034 X2 - 0.045 X3	0.000	0.577
2	Y2 = 72.869 + 0.0001 X1 + 0.041 X2 - 0.032 X3	0.000	0.674
Uphill Roads			
1	Y1 = 79.960 + 0.0002 X1 + 0.038 X2 - 0.066 X3	0.000	0.822
2	Y2 = 76.662 + 0.0001 X1 + 0.044 X2 - 0.079 X3	0.000	0.691

Table 10 shows that all variables have a significance value <0.05, and the R^2 value in each of the Y1 and Y2 models is close to one, so that the dependent variable and the independent variable have a strong relationship. There are two requirements for verification of the linear regression model, namely the linearity test and the normality test so that the model can be said to be valid.

Table 11. Linearity test and multiple linear regression normality test

No	Measuring Distance	Model	Linearity Test: Deviation from Linearity	Normalitas Test: Kolmogorov - Smirnov	Normalitas Test: Shaphiro-Wilk
Level Roads					
1	18 m	Y1 = 76.251 + 0.0002 X1 + 0.034 X2 - 0.045 X3	X1 = 0.612, X2 = 0.091, X3 = 0.152	0.200	0.433
2	23 m	Y2 = 72.869 + 0.0001 X1 + 0.041 X2 - 0.032 X3	X1 = 0.0111, X2 = 0.091, X3 = 0.118	0.200	0.577
Uphill Roads					
1	18 m	Y1 = 79.960 + 0.0002 X1 + 0.038 X2 - 0.066 X3	X1 = 0.095, X2 = 0.777, X3 = 0.082	0.200	0.572
2	23 m	Y2 = 76.662 + 0.0001 X1 + 0.044 X2 - 0.079 X3	X1 = 0.078, X2 = 0.976, X3 = 0.090	0.200	0.324

Table 11 shows that all variables meet the requirements of significance >0.05 on both the linearity test and the normality test, so it can be concluded that all variables in the model can be used. Besides the model verification test, another test that must be fulfilled is the model validity test.

Table 12. Multiple linear regression model error test

No.	Measuring Distance	Model	Average Error
Level Roads			
1	18 m	Y1 = 76.251 + 0.0002 X1 + 0.034 X2 - 0.045 X3	0.002
2	23 m	Y2 = 72.869 + 0.0001 X1 + 0.041 X2 - 0.032 X3	0.000
Uphill Roads			
1	18 m	Y1 = 79.960 + 0.0002 X1 + 0.038 X2 - 0.066 X3	0.002
2	23 m	Y2 = 76.662 + 0.0001 X1 + 0.044 X2 - 0.079 X3	0.001

From Table 12, it is found that the average error value is close to 0, so that the four models are valid for use and in accordance with the noise value that occurs in reality.

4.3 Discussion of Regression Models

The purpose of this regression analysis is to predict the magnitude of the influence of vehicle flow, percentage of heavy vehicles is more than two axles, and also the average speed of heavy vehicle over two axles on highway noise. From the four models, it can be seen that the regression coefficient X1 and X2 are positive, which means that an increase in vehicle flow and percentage of heavy vehicle over two axles can increase noise. While the value of the regression coefficient X3 is negative, which means that a decrease speed of heavy vehicle over two axles can increase noise.

In the resulting model at an uphill roads location, the regression coefficient of variable X2 (percentage of heavy vehicles is more than two axles) and variable X3 (the average speed of heavy vehicles is more than two axles) has a greater value than on a level roads location, this can happen because on an uphill roads the vehicle engine position is required at low gear with high engine speed, resulting in higher noise.

4.4 Noise Evaluation and Mitigation

The highest noise level when measuring at a level roads location of 74 dB (A) and at an uphill roads of 77 dB (A) has exceeded the threshold set by Kep-48 / MENLH / 11/1996 for residential and residential areas, which is not more of 55 dBA.

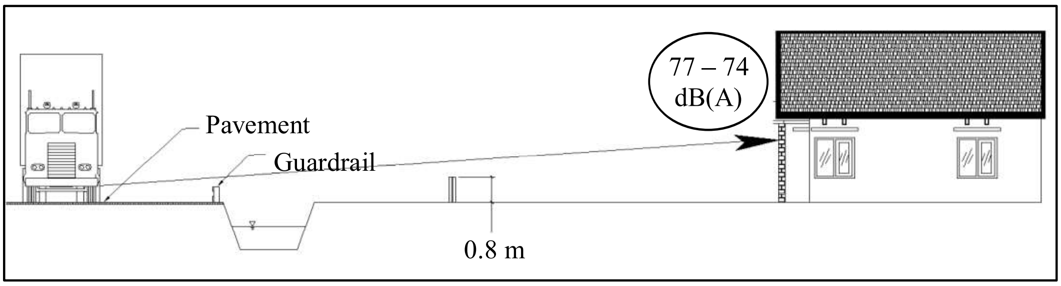

Figure 1. Conditions Before Granting Noise Absorbing Buildings

Mitigation is carried out by increasing the existing space of the road fence wall to 4 m. The wall is made of precast concrete panels and is capable of reducing noise by 19 dB (A). To maximize noise reduction, a plant barrier in the form of Pringgodani bamboo is added which can reduce noise by 4.9 dB (A). So that the noise on the Padaleunyi toll road adjacent to the settlement can be reduced to 50.1 dB (A) on flat road locations and 53.1 dB (A) on uphill road locations. Both of these values have met the predetermined noise threshold.

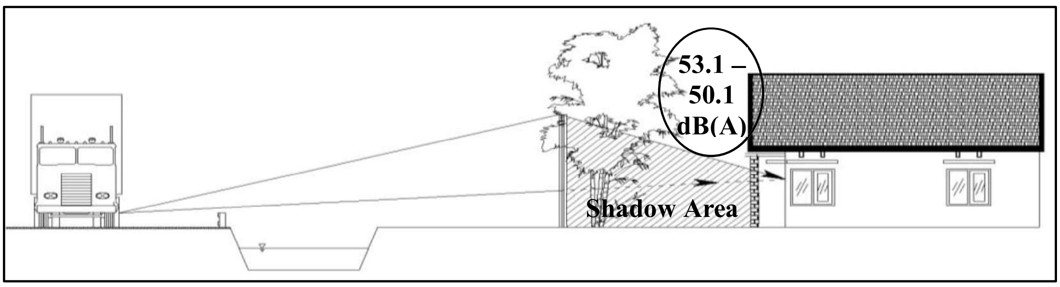

Figure 2. Conditions with Noise-Absorbing Building and Plants

5. CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

- The noise measurement shows the noise level in the uphill roads locations is higher than the noise level in the level roads locations.
- From the four models produced, it can be concluded that it is true that the noise on the uphill roads has an influence on the vehicle speed factor.
- The highest noise level has exceeded the threshold set by Kep-48 / MENLH / 11/1996 for residential areas.
- The recommended Noise Absorbing Buildings (NAB) based on PtT-16-2005-B is to increase the height of the reinforced concrete walls located in the space belongs to the road and add a barrier in the form of Pringgodani bamboo.

5.2 Recommendation

There are several suggestions that can be considered in evaluating traffic-induced noise, namely it is hoped that in future studies it can measure noise in the form of basic noise, so that the noise value can be analyzed into majority noise and background noise. Also, it is necessary to conduct research on other types of noise mitigation that are effective and environmentally friendly, for example by using Photovoltaic Noise Barriers.

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Revision Report

Paper ID: PP2751

Paper title: The Evaluation of Traffic Noise on Indonesian Toll Road (Case Study of Padaleunyi Toll Road)

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Revision report for "Paper Category A"

No.	Location Line no./ figure/table	Reviewer's comment/request/question	Your resulting revision
1	3. Research Methodology, paragraph 2, line 1-4.	Please indicate when and how long the data was collected. The total number of data used is shown in Table 4 and Table 5, but please also describe it in the text.	The data required in this study consists of noise level data (Leq) with a recording duration of every 5 minutes for 2 peak hours in the morning, afternoon, and evening. Data collection was carried out for 2 days, namely on weekdays (Wednesday) and on holidays (Saturday). So the total data as a whole amounted to 144 data.
2	4.2. Multiple Linear Regression Analysis, Table 11, paragraph 2.	The R Square value of Model No. 1 of Level Roads is 0.577, which is not high accuracy. What could be the main reason for this?	According to the literature in Table 4, the R value is included in the medium category, which means that 57.70% of the independent variables are still more dominantly influenced by the dependent variable, while 42.30% of the independent variables are influenced by other factors not included in this study.
3		The following table numbers are not shown in the text. Please specify. Table 2, 3, 5, 6, 9, 10	• Revisions for explanations of Table 2 are in 2.3 Noise Mitigation, paragraph 4. • Revisions for explanations of Table 3 are in 2.3 Noise Mitigation, paragraph 5. • Revisions for explanations of Table 5 and Table 6 are in 4.1 Noise Level Modeling, paragraph 2. • Revisions for explanations of Table 9 and Table 10 are in 4.1 Noise Level Modeling, paragraph 5.

4	4.4 Noise Evaluation and Mitigation, paragraph 2.	Did this section show the results of actual noise reduction work and verification? Or is it a section to recommend an example of countermeasure construction? The purpose of this section is unknown.	According to Pt-T-16-2005-B in Table 2 and Table 3, an example of mitigation that can be done is to increase the existing space of the road fence wall to 4 m as shown in Figure 2. The wall is made of precast concrete panels and is capable of reducing noise by 19 dB (A). To maximize noise reduction, a plant barrier in the form of Pringgodani bamboo is added which can reduce noise by 4.9 dB (A). So that the noise on the Padaleunyi toll road adjacent to the settlement can be reduced to 50.1 dB (A) on flat road locations and 53.1 dB (A) on uphill road locations. Both of these values have met the predetermined noise threshold.

The Evaluation of Traffic Noise on Indonesian Toll Road (Case Study of Padaleunyi Toll Road)

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Abstract : The negative impact of the toll road is traffic noise. Which that can be predicted using a mathematical model and noise mitigation that can be guided by Pt-T-16-2005-B. Study locations are located at Padaleunyi Toll Road.

The result of the analysis shows that the noise levels are 74 dB(A) for level roads and 77 dB(A) for uphill roads. The mathematical model shows that percentage of vehicles (X2) and average speed (X3) are the most influential factors of noise on uphill roads. Traffic noise mitigation can be done by increasing the height of the fence made of precast concrete panel walls by 4 m to reduce the noise by 19 dB(A), and planting pringgodani bamboo to reduce the noise by 4.9 dB(A).

Other types of noise barriers that can be researched are Photovoltaic Noise Barries which have the function of reducing noise and producing renewable energy simultaneously.

Keywords: Factors for road noise, Leq, distance of noise measurement, road slopes.

1. INTRODUCTION

Toll roads will increase economic growth, one of which is by increasing population settlements around toll roads. But on the other hand, this also brings some negative impacts for residents, such as noise due to traffic caused by motorized vehicles. Noise is defined as unwanted sound whose impact will affect the physical and psychological health of people who are exposed to continuous noise, such as depression, sleep disturbances, high blood pressure, diabetes, and irregular heartbeat (Ongel A, 2016). Therefore it is necessary to pay attention so that the noise level does not exceed the safe limit that can be accepted by the human ear. Appropriate control measures can minimize noise so as to increase comfort for residents living around toll roads.

The study area in this research is the Padaleunyi (Padalarang-Cileunyi) toll road because there are several settlements located close to the toll road. In addition, this toll road has hilly contours, so there are several climbs and descents. The Padaleunyi toll road has a length of 64.4 kilometers which is located in the city of Bandung and is a continuation of the Jakarta-Cikampek toll road so that this toll road has a fairly high daily traffic density. Based on this background, this research was conducted to determine the noise level on the Padaleunyi toll road which is affected by the slope of the road (flat and uphill), to find out the traffic factors that affect the noise level, and to determine the appropriate mitigation to reduce the noise impact felt by residents around the toll road.

2. LITERATURE REVIEW

2.1 Highway Noise

According to Mediastika, 2005, the determining factors for road noise can come from a high number of vehicle flows, a higher number of heavy vehicles, a higher number of motorbikes, vehicle speed, road surface quality, road slope, traffic regulation, conditions in right and left side of the road, use of sidewalks for parking areas and informal trade.

2.2 Noise Level Measurement

The guidelines used in this study use guidelines from FHWA, 2017. Measurement steps are determining the measurement point, installing the Sound Level Meter tool, checking all equipment settings, initial calibration of the Sound Level Meter tool, documenting meteorological conditions, filling in data sheets in the field, taking traffic volume data and vehicle speed, final calibration of the Sound Level Meter tool.

2.3 Noise Mitigation

According to the Decree of the Minister of Environment no. Kep-48 / MENLH / 11/1996, noise level standards have been set for each specific area. This noise level is measured based on the average equivalent noise level measurement (Leq). The noise level standard for each area has been determined as follows.

Table 1. Noise level standards

No.	Area Allocation	Noise level dB (A)
a.	Area Allocation :	
	1. Housing and Settlements	55
	2. Trade and Services	70
	3. Office and Trade	65
	4. Green Open Space	50
	5. Industry	70
	6. Government and Public	60
	Facilities	70
	7. Recreation	60
	8. Special :	-
	- Airport	-
	- Railway station	70
	- Seaports	60
	- Cultural heritage	
b.	Activity Environment :	
	1. Hospital or the like	55
	2. School or the like	55
	3. Places of worship or the like	55

Source: Minister of Environment Decree no. Kep-48 / MENLH / 11/1996

From the standard noise level in Table 1, if the noise generated from traffic activities has exceeded or is greater than the standard noise level for each area, it is necessary to propose to carry out noise handling.

According to Pt-T-16-2005-B, noise mitigation can be done by using natural barriers, and a barrier in the form of Noise Absorbing Buildings (NAB).

As shown in Table 2, the natural barrier can be a plant barrier. Plants used to apply the deadline must have sufficient and even leaf density and dense from the soil surface to the expected height. For this reason, it is necessary to regulate ground cover crops, shrubs and trees or a combination with other materials so that the barrier effect is optimal.

Table 2. Noise reduction effectiveness by plants

Types of Plants	Leaf Cover Volume (m^3)	Distance From Noise Source To Plants (d) (m)	Height Measurement (m)	Average Noise Reduction, IL (dBA)
Acacia (*Acacia Mangium*)	114,39	18.20	1.2	2.5
		30.20	4.00	4.1
	118.23	18.20	1.20	2.7
		24.60	4.00	4.1
Pringgodani Bamboo (*Bambusa Sp*)	122.03	7.0	1.20	1.1
		16.40	2.50	4.9
	366.08	35.4	1.2	14.7
Black-Wood Cassia (*Casia Siamea*)	60.74	9.8	1.20	0.3
		17.0	3.60	3.2
	83.24	9.6	1.20	0.20
Likuan-yu (*Vermenia Obtusifolia*)	2.464	8.20	1.20	2.3
Sapphire Showers (*Durante Repens*)	1.680	9.80	1.20	0.8
Ashoka (*Ixora Sp*)	1.350	11.20	1.20	0.9
Creeping Fig (*Ficus Pumila*)	1.105	4.60	1.20	0.9
False Bird Of Paradise (*Heliconia Sp*)	1.792	3.2	1.20	3.4
Siamese Acalypha	11.10	6	1.20	2.1
Be parenthesized :				
a. Siamese Acalypha	13.88	6	1.20	2.7
b. False Bird Of Paradise (*Heliconia Sp*)	2.75	9	1.20	3.8
	16.65	6	1.20	4.2
	33.3	9	1.20	5.0

Source: Pt-T-16-2005-B

The artificial barrier type is a suitable choice for locations such as toll roads, arterial roads, or those with narrow alignments, bridges and roads over embankments. Such artificial barriers can consist of continuous barriers, non-continuous barriers, combination of continuous and non-continuous barriers, and artistic barriers. In order for a noise-canceling building to work properly, the building must be high and long enough to reduce the propagation of noise to listeners, for example, for a house on a surface that is much higher than the surface of the road pavement, the construction of noise suppression needs to be built higher. The average barrier building effectiveness based on laboratory tests for the shadow zone is shown in the Table 3.

Table 3. The effectiveness of artificial barrier noise reduction

No.	Type	Material	Dimension W = Min. Width H = Min. Height	Effectiveness IL = dB(A)
1	Continuous Barrier	a. Barrier made of brick	W = 0,5 m H = 2,5 m	Good IL = 15 - 16
		b. Reinforced concrete	W = 0,35 m H = 3 - 4 m	Good–Optimum IL = 17 - 19
		c. Wood with or without absorbent material	W = 0,3 m H = 2 - 3 m	Good IL = 18 - 19
		d. Aluminum or steel with an absorbent material	W = 0,3 m H = 4 - 5 m	Optimum 20 - 22
		e. Fiber, Glass	W = 0,5 m H = 3 - 4 m	Good IL = 16 - 17
2	Non-Continuous Barrier	a. Reinforced concrete	W = 1 - 2 m H = 3 - 4 m	Optimum IL = 17 - 18
		b. Aluminum or steel with an absorbent material	W = 1,0 m H = 3 - 4 m	Optimum IL = 18 - 19
		c. a combination of materials a and b with fiber	W = 2,0 m H = 3 - 4 m	Optimum IL = 20 - 22
3	Combination of Continuous and Non-Continuous Barriers	a. Barrier made of brick	W = 0,5 m H = 2,5 m	Good IL = 15 - 16
		b. Reinforced concrete	W = 0,35 m H = 3 - 4 m	Good-Optimum IL = 17 - 19
		c. Wood with or without absorbent material	W = 0,3 m H = 2 - 3 m	Good IL = 18 - 19
		d. Aluminum or steel with an absorbent material	W = 0,3 m H = 4 - 5 m	Optimum 20 - 22
		e. Fiber	W = 0,5 m H = 3 - 4 m	Good IL = 16 - 17
		f. Reinforced concrete	W = 1 - 2 m H = 3 - 4 m	Optimum IL = 17 - 18
		g. Aluminum or steel with an absorbent material	W = 1,0 m H = 3 - 4 m	Optimum IL = 18 - 19
		h. a combination of materials a and b with fiber	W = 2,0 m H = 3 - 4 m	Optimum IL = 20 - 22
4	Architectural Barriers	The combination of shape design and artistic color design	W = Variable 0,5 m H = Variable	Good IL = 14 - 16

Source: Pt-T-16-2005-B

2.4 Coefficient of Determination Test (R Square)

The coefficient of determination serves to determine the percentage of the dependent variable that can be predicted using the independent (independent) variable. The value of R square ranges from 0-1, which means the smaller the value of R square, the weaker the relationship between the two variables. Conversely, if the R square is getting closer to 1, then the relationship between the two variables is getting stronger. The regression model is getting better if the R square value in the Summary Model in SPSS software is close to 1. To make it easier to assess the value of R square can be seen in the Table 4, namely the interpretation of the value of R square.

Table 4. The interpretation of the value of R square

R^2 Value Interval	Correlation Level
$0 \leq R^2 < 0.2$	Very low
$0.2 \leq R^2 < 0.4$	Low
$0.4 \leq R^2 < 0.6$	Medium
$0.6 \leq R^2 < 0.8$	Strong
$0.8 \leq R^2 \leq 1$	Very strong

Source: Sugiyono, 2010

3. RESEARCH METHODOLOGY

The measurement of the noise level on the Padaleunyi toll road is carried out using a noise measuring device, namely the Sound Level Meter. According to the Guidelines for Mitigating the Impact of Noise Due to Road Traffic, Pt-T-16-2005-B, for the measurement of noise on toll roads based on the recommended noise-reducing building approach, which is at least 10 meters from the edge of the pavement, the Sound Level Meter is placed 10 m from the edge of the pavement or at a distance of ± 18 m from the center line of the toll road with a Sound Level Meter height of ± 1.2 m from the ground, and as a variation of the noise level results obtained, noise measurements are also carried out at a distance of ± 23 m from the center line of the toll road. The distance measurement is carried out starting from the center line of the toll road because vehicles are moving more in the middle of the lane than walking on the shoulder of the toll road.

The data required in this study consists of noise level data (Leq) with a recording duration of every 5 minutes for 2 peak hours in the morning, afternoon, and evening. Data collection was carried out for 2 days, namely on weekdays (Wednesday) and on holidays (Saturday). So the total data as a whole amounted to 144 data. Meanwhile, the traffic data required is traffic flow (vehicle/hour), vehicle percentage (%), and average vehicle speed (km/hour). These data are used to create a mathematical model in the form of a multiple linear regression model which aims to predict noise levels due to traffic conditions on a level road and uphill road location. The formation of a regression model and testing the regression model using IBM SPSS Statistics 25 software by looking at the smallest significant value of the regression model and the largest R square value of the regression model. In addition, this research also conducts noise handling based on Pt-T-16-2005-B by evaluating noise levels in accordance with Kep-48 / MENLH / 11/1996, and taking mitigation measures in the form of giving Noise Absorbing Buildings (NAB) or natural barrier.

4. DATA ANALYSIS AND DISCUSSION

4.1 Noise Level Modeling

In this study, the dependent variable is Leq which is divided into two different measuring distances, namely at a distance of 18 meters which is symbolized by Y1, and Leq at a distance of 23 meters which is symbolized by Y2. Likewise, the independent variables in the study were divided into two different directions of traffic movement, namely the traffic movement in the direction of Cileunyi and the direction of Padalarang. The first step to take is to determine representative data on noise levels, whether the flow of vehicles heading to Cileunyi or the flow of vehicles heading to Padalarang on a level road and uphill road. For example, the analysis phase will be shown in Table 5 for the results of the correlation of vehicle flows on level road locations with a measurement distance of 18 meters, and in Table 6 for the results of the correlation of vehicle flows on flat road locations with a measurement distance of 23 meters.

Table 5. Correlation of vehicle flow against Leq 18 m, level roads

Correlations				
		Leq 18	The Flow Of Vehicles In The Direction Of Cileunyi	The Flow Of Vehicles In The Direction Of Padalarang
Leq 18	Pearson Correlation	1	0.637**	0.204*
	Sig. (2-tailed)		0.000	0.017
	N	136	136	136
The Flow Of Vehicles In The Direction Of Cileunyi	Pearson Correlation	0.637**	1	0.327*
	Sig. (2-tailed)	0.000		0.000
	N	136	136	136
The Flow Of Vehicles In The Direction Of Padalarang	Pearson Correlation	0.204*	0.327**	1
	Sig. (2-tailed)	0.017	0.000	
	N	136	136	136

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 6. Correlation of vehicle flow against Leq 23 m, level roads

Correlations				
		Leq 23	The Flow Of Vehicles In The Direction Of Cileunyi	The Flow Of Vehicles In The Direction Of Padalarang
Leq 23	Pearson Correlation	1	0.599**	0.232**
	Sig. (2-tailed)		0.000	0.006
	N	141	141	141
The Flow Of Vehicles In The Direction Of Cileunyi	Pearson Correlation	0.599**	1	0.345**
	Sig. (2-tailed)	0.000		0.000
	N	141	141	141
The Flow Of Vehicles In The Direction Of Padalarang	Pearson Correlation	0.232**	0.345**	1
	Sig. (2-tailed)	0.006	0.000	
	N	141	141	141

**. Correlation is significant at the 0.01 level (2-tailed).

The correlation results in Table 5 and Table 6 show that the current correlation in Cileunyi has a strong correlation value with noise level. Likewise, the correlation between the current to Cileunyi on the uphill road shows a strong correlation with noise levels. So that the flow of vehicles to Cileunyi is considered to represent the X1 variable which will be included in the regression model.

The second step is to examine the correlation of the percentage of vehicles heading to Cileunyi to Y1 and Y2 on flat roads and uphill road locations. For example, the correlation results for the percentage of vehicles at a road location level will be shown.

Table 7. Correlation of % of vehicles against Leq 18 m, level roads

Correlations

		Leq 18	Light vehicle	Heavy vehicle over two axles
Leq 18	Pearson Correlation	1	-0.685**	0.684**
	Sig. (2-tailed)		0.000	0.000
	N	136	136	136
Light vehicle	Pearson Correlation	-0.685**	1	-1.000**
	Sig. (2-tailed)	0.000		0.000
	N	136	136	136
Heavy vehicle over two axles	Pearson Correlation	0.684**	-1.000**	1
	Sig. (2-tailed)	0.000	0.000	
	N	136	136	136

**. Correlation is significant at the 0.01 level (2-tailed).

Table 8. Correlation of % of vehicles against Leq 23 m, level roads

Correlations

		Leq 23	Light vehicle	Heavy vehicle over two axles
Leq 23	Pearson Correlation	1	-0.717**	0.717**
	Sig. (2-tailed)		0.000	0.000
	N	141	141	141
Light vehicle	Pearson Correlation	-0.717**	1	-1.000**
	Sig. (2-tailed)	0.000		0.000
	N	141	141	141
Heavy vehicle over two axles	Pearson Correlation	0.717**	-1.000**	1
	Sig. (2-tailed)	0.000	0.000	
	N	141	141	141

**. Correlation is significant at the 0.01 level (2-tailed).

Tables 7 and 8 show that the percentage of vehicles weighing more than two axles has a strong correlation value with the expected value. Likewise with the location of the uphill road which also has a strong correlation value with noise levels. Thus it can represent the independent variable X2. From the correlation test of X1 and X2, it can be concluded that what is included in the multiple linear regression analysis is the average speed of heavy vehicles on two axes, and can represent the independent variable X3. The third step is to test the correlation of the three independent variables on Y1 and Y2. As an example of the analysis phase, the results of the correlation X1, X2, and X3 will be displayed on level road location in Table 9 and Table 10.

Table 9. Analysis of correlation and significance of Y1, level roads

Correlations

		Y1	X1	X2	X3
Pearson Correlation	Y1	1.000	0.637	0.684	-0.542
	X1	0.637	1.000	0.305	-0.319
	X2	0.684	0.305	1.000	0.004
	X3	-0.542	-0.319	0.004	1.000
Sig. (1-tailed)	Y1		0.000	0.000	0.000
	X1	0.000		0.000	0.000
	X2	0.000	0.000		0.000
	X3	0.000	0.000	0.000	
N	Y1	136	136	136	136
	X1	136	136	136	136
	X2	136	136	136	136
	X3	136	136	136	136

Table 10. Analysis of correlation and significance of Y2, level roads

Correlations					
		Y2	X1	X2	X3
Pearson Correlation	Y2	1.000	0.599	0.717	-0.661
	X1	0.599	1.000	0.529	-0.341
	X2	0.717	0.529	1.000	-0.518
	X3	-0.661	-0.341	-0.518	1.000
Sig. (1-tailed)	Y2		0.000	0.000	0.000
	X1	0.000		0.000	0.000
	X2	0.000	0.000		0.000
	X3	0.000	0.000	0.000	
N	Y2	141	141	141	141
	X1	141	141	141	141
	X2	141	141	141	141
	X3	141	141	141	141

The correlation results in Table 9 and Table 10 show that X1, X2, and X3 have a strong correlation value to the noise level. It can be seen from the Pearson Correlation results which show a value of more than 0.5 with the appropriate sign and a significance value of less than 0.05. Thus, all independent variables can be entered into a multiple linear regression model.

4.2 Multiple Linear Regression Analysis

The method used is the forward selection method, with the analysis stage starting by entering the independent variable that has the highest correlation with the dependent variable. The next step is to add variables by evaluating the significance of the independent variables on the model, provided that the significance value is <0.05. Following are the results of multiple linear regression analysis at a level roads and uphill roads location.

Table 11. Multiple linear regression

Level Roads			
No.	Model	Significance (p value)	R Square
1	Y1 = 76.251 + 0.0002 X1 + 0.034 X2 - 0.045 X3	0.000	0.577
2	Y2 = 72.869 + 0.0001 X1 + 0.041 X2 - 0.032 X3	0.000	0.674
Uphill Roads			
No.	Model	Significance (p value)	R Square
1	Y1 = 79.960 + 0.0002 X1 + 0.038 X2 - 0.066 X3	0.000	0.822
2	Y2 = 76.662 + 0.0001 X1 + 0.044 X2 - 0.079 X3	0.000	0.691

Table 11 shows that all variables have a significance value of <0.05, and the R2 value in each of the Y1 and Y2 models has the lowest value of 0.577. According to the literature in Table 4, the R value is included in the medium category, which means that 57.70% of the independent variables are still more dominantly influenced by the dependent variable, while 42.30% of the independent variables are influenced by other factors not included in this study. There are two requirements for verification of the linear regression model, namely linearity test and normality test so that the model can be said to be valid.

Table 12. Linearity test and multiple linear regression normality test

Level Roads					
No	Measuring Distance	Model	Linearity Test Deviation from Linearity	Normalitas Test Kolmogorov - Smirnov	Shaphiro-Wilk
1	18 m	Y1 = 76.251 + 0.0002 X1 + 0.034 X2 - 0.045 X3	X1 = 0.612, X2 = 0.091, X3 = 0.152	0.200	0.433
2	23 m	Y2 = 72.869 + 0.0001 X1 + 0.041 X2 - 0.032 X3	X1 = 0.0111, X2 = 0.091, X3 = 0.118	0.200	0.577
Uphill Roads					
No	Measuring Distance	Model	Linearity Test Deviation from Linearity	Normalitas Test Kolmogorov - Smirnov	Shaphiro-Wilk
1	18 m	Y1 = 79.960 + 0.0002 X1 + 0.038 X2 - 0.066 X3	X1 = 0.095, X2 = 0.777, X3 = 0.082	0.200	0.572
2	23 m	Y2 = 76.662 + 0.0001 X1 + 0.044 X2 - 0.079 X3	X1 = 0.078, X2 = 0.976, X3 = 0.090	0.200	0.324

Table 12 shows that all variables meet the requirements of significance >0.05 on both the linearity test and the normality test, so it can be concluded that all variables in the model can be used. Besides the model verification test, another test that must be fulfilled is the model validity test.

Table 13. Multiple linear regression model error test

Level Roads			
No.	Measuring Distance	Model	Average Error
1	18 m	Y1 = 76.251 + 0.0002 X1 + 0.034 X2 - 0.045 X3	0.002
2	23 m	Y2 = 72.869 + 0.0001 X1 + 0.041 X2 - 0.032 X3	0.000
Uphill Roads			
No.	Measuring Distance	Model	Average Error
1	18 m	Y1 = 79.960 + 0.0002 X1 + 0.038 X2 - 0.066 X3	0.002
2	23 m	Y2 = 76.662 + 0.0001 X1 + 0.044 X2 - 0.079 X3	0.001

From Table 13, it is found that the average error value is close to 0, so that the four models are valid for use and in accordance with the noise value that occurs in reality.

4.3 Discussion of Regression Models

The purpose of this regression analysis is to predict the magnitude of the influence of vehicle flow, percentage of heavy vehicles is more than two axles, and also the average speed of heavy vehicle over two axles on highway noise. From the four models, it can be seen that the regression coefficient X1 and X2 are positive, which means that an increase in vehicle flow and percentage of heavy vehicle over two axles can increase noise. While the value of the regression coefficient X3 is negative, which means that a decrease speed of heavy vehicle over two axles can increase noise.

In the resulting model at an uphill roads location, the regression coefficient of variable X2 (percentage of heavy vehicles is more than two axles) and variable X3 (the average speed of heavy vehicles is more than two axles) has a greater value than on a level roads location, this can happen because on an uphill roads the vehicle engine position is required at low gear with high engine speed, resulting in higher noise.

4.4 Noise Evaluation and Mitigation

The highest noise level when measuring at a level roads location of 74 dB (A) and at an uphill roads of 77 dB (A) has exceeded the threshold set by Kep-48 / MENLH / 11/1996 for residential and residential areas, which is not more of 55 dBA. Figure 1 shows the condition of residents close to the toll road when conducting noise measurements, so mitigation is needed to reduce the noise that occurs.

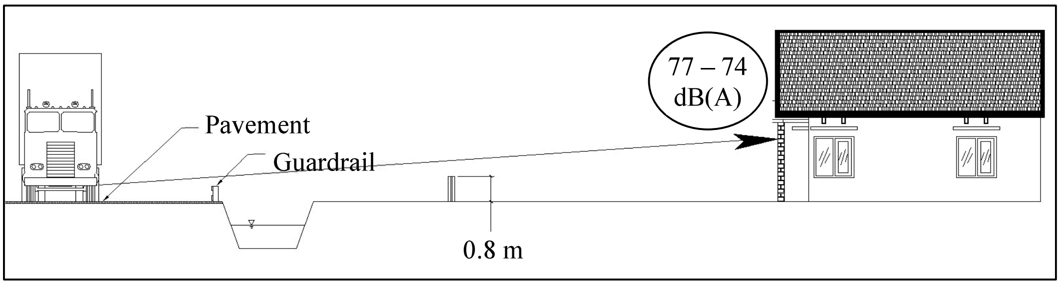

Figure 1. Conditions Before Granting Noise Absorbing Buildings

According to Pt-T-16-2005-B in Table 2 and Table 3, an example of mitigation that can be done is to increase the existing space of the road fence wall to 4 m as shown in Figure 2. The wall is made of precast concrete panels and is capable of reducing noise by 19 dB (A). To maximize noise reduction, a plant barrier in the form of Pringgodani bamboo is added which can reduce noise by 4.9 dB (A). So that the noise on the Padaleunyi toll road adjacent to the settlement can be reduced to 50.1 dB (A) on flat road locations and 53.1 dB (A) on uphill road locations. Both of these values have met the predetermined noise threshold.

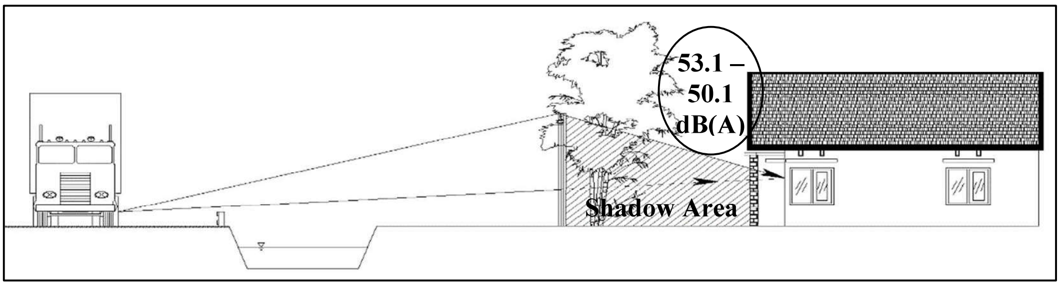

Figure 2. Conditions with Noise-Absorbing Building and Plants

5. CONCLUSIONS AND RECOMMENDATION

5.1 Conclusion

- The noise measurement shows the noise level in the uphill roads locations is higher than the noise level in the level roads locations.
- From the four models produced, it can be concluded that it is true that the noise on the uphill roads has an influence on the vehicle speed factor.
- The highest noise level has exceeded the threshold set by Kep-48 / MENLH / 11/1996 for residential areas.

- The recommended Noise Absorbing Buildings (NAB) based on PtT-16-2005-B is to increase the height of the reinforced concrete walls located in the space belongs to the road and add a barrier in the form of Pringgodani bamboo.

5.2 Recommendation

There are several suggestions that can be considered in evaluating traffic-induced noise, namely it is hoped that in future studies it can measure noise in the form of basic noise, so that the noise value can be analyzed into majority noise and background noise. Also, it is necessary to conduct research on other types of noise mitigation that are effective and environmentally friendly, for example by using Photovoltaic Noise Barriers.

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